招待論文 「Engineering Scheme to Expedite Effective Use of Resources」

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ABSTRACT: Utilization of wastes and recyclable resources should be encouraged in order to prevent the ecological demolition of global environments and also to ensure comfortable regional environments. A new criterion to choose most appropriate resources is proposed in this paper to cope with bottleneck posed by capitalistic cost criterion and to expedite effective use of those materials. For that purpose application of "value engineering" is investigated. In our proposal, a new concept of "eco-cost" is introduced to evaluate "true value" or "eco-value" in which environmental costs are also taken into account in addition to the traditional cost.

KEYWORDS: cost, eco-cost, eco-value, eco-value engineering, function, global environment, recycling, regional environment, resorce, value, value engineering

1. INTRODUCTION

1.1 EFFECTIVE USE RESOURCES

Recently effective use of resources is mentioned as one of the most urgent problems of our society. Basically two main aspects are involved with this subjects. One is exhaustion of resources and the other is preservation of environments. Worldwide growth of population is still lasting. Under the situation utilization of natural resources has to increase. While deposits of natural resources are limited. So, deliberate scheme is required to maintain a sustainable human society. Environmental aspect is more serious to human society since there is no substitution for environment. In this paper engineering scheme how to promote the effective use of unused resources is discussed based on quantitative evaluation of environmental load.

1.2 BACKGROUND OF RESOURCE PROBLEM

Needless to mention, conservation of resources and saving of energy are essential in order to mitigate environmental load and to realize sustainable human society. This is a basic stance why effective use of resources has to be encouraged. But there are two different stand points to confront environmental problems either of which cannot be ignored. One is global environment and the other is regional environment. Depending upon these two view points, the main objects of countermeasures becomes quite different. For the former view point accumulation of carbon dioxide and ozone layer destructing gases in a global scale are the main targets and, for the latter shortage of dumping space of wastes, illegal dumping or outflow of hazardous substances are main concerns in Japan, for example. Of course regional problems and their countermeasures are different depending upon local conditions. At first thought, effective use of resources attained by recycling or by intentional use of unused materials are apt to be assumed useful for both global and regional environment. But sometimes it cannot be always useful for global environment if excess energy is required in actual practice of utilization of these materials. Because in actual practice of recycling, for example, sometimes more energy is spent for processing than that required for manufacturing virgin material. At present energy and discharge of carbon dioxide is synonymous, so to speak, since about 90% of primary energy is based on combustion of fossil fuel. (Fig-1)

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From the foregoing discussion, it maybe understood that there are different aspects between regional environment and global environment and their countermeasures are not always same. So, it is important for us to be conscious of our stand point regarding on which basis the problem should be treated. Feelings on global environment might be different from individual to individual, because it looks that variation of environment proceeds in a show pace.

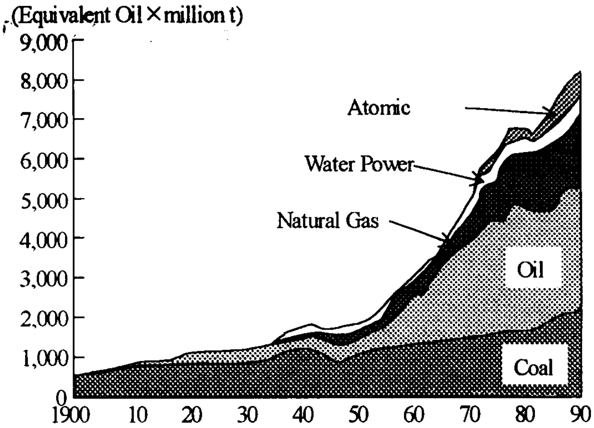

Fig.1 Transition of Worldwide Consumption of Energy

1.4 TRANSITION OF CO_2 CONCENTRATION

Well known data is shown in Fig-2, average concentration of carbon dioxide is apparently increasing. Cyclic fluctuation is caused by seasonal change of climate and can be regarded as regional effect. Estimation of concentration is traced back to the age of Industrial Revolution suggesting 260ppm of CO_2 concentration at that age. From this observation it is clear that concentration of carbon dioxide is steadily increasing. While average speed of atmospheric temperature rise is observed as 0.005 degree in centigrade per year for these hundred years. It is generally agreed that this rise can be attributed to the effect of increase in carbon dioxide concentration. The rising speed is 50 times greater than the speed calculated from atmospheric temperature variation estimated from geological record for 100,000 year cycle.

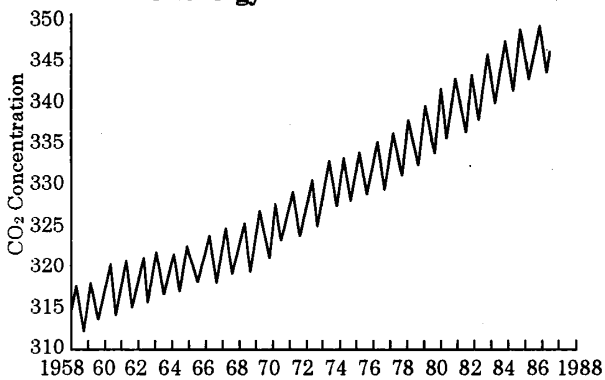

Fig.2 Variation of CO_2 Concentration of Atmosphere Observed in Hawaii

1.5 SIGNIFICANCE OF GLOBAL ENVIRONMENT

Unprejudiced and quantitative recognition of influence of global environment is indispensable. At first, global environment is a matter of concern for whole human being or even whole creatures living on earth. Secondly, countermeasures that are valid in a short term or only in a local region are of no use. And thirdly, its influence will last for a long time even to our posterity and will grow more and more serious if left as it is.

1.6 AFFORESTATION

It is believed that afforestation improves amenity of living environment a great deal and it is true that its effects on regional environment are distinct. But, afforestation has very little meaning for improvement of global environment. As is shown in Table-1 and 2, barren area 15 times bigger than the area of Japan islands has to be afforested every year in order to compensate the increase in carbon dioxide by afforestation.

Table-1 Calculation of Global Accumulation of Carbon Dioxide

Radius of Earth 6400km

Surface Area of Earth $4\times\pi\times(64\times10^5)^2$cm^2

Assumed Increase in CO^2 Concentration per year 1ppm

Increment of Carbon Dioxide

$$=4\times\pi\times6.4^2\times10^{16}\times10^3\times10^{-6}\times10^{-6}\text{ton}=51.4\times10^8\text{ton/year}$$

Since the present increasing speed is higher than 1ppm/year, if 1.2ppm/year is assumed, $51.4\times10^8\times1.2=61.4\times10^8$ton/year

1.7 SIGNIFICANCE OF ZERO EMISSION

Zero emission or perfect recycling seems to be ideal from regional environment point of view, because disposal of waste is not needed. But, if a great deal of energy consumption is required for recycling of materials, such practice of recycling is not helpful for the global environment. Therefore, processing method of used materials for recycling should be of low energy consumption. It is ideal that the processing itself could furnish a new function to the relevant material.

Table-2 Required Area of Forest to Supress CO_2 Discharge

Absorption of CO_2 per Acre : 10ton/ha
CO_2 Discharge per year 5×10^9ton/year
Area : 5×10^9ton/10 = 5×10^8ha = 5×10^6km^2
$5\times10^6 = 2.24\times10^3$km square (2240km)
Every year barren land area 1.5 times Indian territory should be afforested.

1.8 BOTTLENECK IN EFFECTIVE USE OF RESOURCES

There is another bottleneck in a recycling of used materials or utilization of unused wastes or industrial by-products. In many cases, attempts to utilize unused resources result in degradation of performances or cost-up of final products. These products are not accepted from the market even if it is anticipated that the utilization of the resources is quite effective from environmental point of view. In order to overcome this commercial principle of the market, an introduction of a new criterion is inevitable to promote effective use of resources. For this purpose quantitative evaluation environmental load is significant. For global environment, for example, life cycle CO_2 discharge will serve as an indication. If the quantitative value is known, the value can be converted to cost since costs for compensation for each environmental load are obtainable. It may be possible to establish a new criterion to evaluate an industrial material if these environmental costs are incorporated with the conventional cost concept.

2. CONCRETE AND GLOBAL ENVIRONMENT

2.1 DISCHARGE OF CO_2 AT CEMENT PRODUCTION

Carbon dioxide discharge from cement industry is not negligible. For example, in producing 1 ton of Portland cement, 0.87 ton of CO_2 gas is discharged. As shown in Table-3 more than 50% of the discharge is derived from decomposition of raw material when limestone is changed into calcia (CaO). Some additional discharge is (assumed pure $CaCO_3$ in the calculation) due to the energy consumption during burning process. This mechanism of discharge is essential for Portland cement production. The total amount for cement industry is calculated about 500 million ton a year which is equivalent to 2% of gross discharge for all industries.

Table-3 Raw Material of Cement

$CaCO3 \longrightarrow CaO + CO_2$ (Stoichiometry)
110 56 44 (Atmic Weight)

Lime stone requirement to produce 1kg of cement lime stone pure ($CaCO_3$ is assumed for chemical composition of lime stone)	$640\times100/56 = 1143$g
Carbon Dioxide Discharge from 1143g of lime stone	$1143\times44/100 = 503$g
Discharge of CO_2 for Energy Required for Burning	367g
Total Discharge : 503 + 367 = 870g/kg of Cement	

2.2 COUNTERMEASURES FOR CEMENT INDUSTRY TO REDUCE OF CO_2

Several countermeasures to reduce the discharge are listed in Table-4. One way is to reduce calcia content in chemical composition of cement. One example is to increase belite content in Portland cement, development of this type of cement is broadly carried out in Japan at present. As shown in Table-5, by increasing belite content calcia content and energy required for burning can be decreased. One of the other reasons is that this type of cement is also very effective to reduce cracking in concrete structures, which is still quite serious in large scale constructions. Replacement of pozzolanic materials up to their allowable limits is the another effective way. In many cases industrial by-products have been used in large quantity until now. Investigation of new technology to increase further the replacement ratio on each by-products are encouraged. Also applications of low-grade concrete is more definitely prescribed in specification because excess performances should be avoided as possible. Use of innert granular materials other than cements such as rock powder, burnt ashes of municipal wastes etc. is investigated at present.

Table-4 Mineral Composition of Normal Portland Cement

C : CaO, S : SiO_2, A : Al_2O_3, F : Fe_2O_3

$C_3S \longrightarrow 3CaOSiO_2$ (Alite)

$C_2S \longrightarrow 2CaOSiO_2$ (Blite)

$C_3A \longrightarrow 3CaO\ Al_2O_3$

$C_4AF \longrightarrow 4CaO\ Al_2O_3\ Fe_2O_3$

Present Composition Calcium Oxide (CaO)

CaO 63~65%

Alite about 60%

Blite about 20%

Table-5 Countermeasures for Cement Industry

1.To reduce CaO content in Cement

(a) Alite (40%) ⟶ Blite (20%)

	Molecular Weight
$3CaO \cdot SiO_2$	228 (Atomic Weight of Si : 28)
CaO ratio of Alite	168/228 = 0.74
$2CaO \cdot SiO_2$	172
CaO ratio of Blite	112/172 = 0.65

(b) To increase Replacement ratio of Pozzolanic Material

for example : upper limit of slag replacement : 60% (Japan)

2. Development of New Technology ------ Use of Invert Powder Material

2.3 ENERGY CONSUMPTION

According to the national statistics, industrial breakdown of energy consumption in Japan has been analyzed as follows. These figures are 8.7% for production of construction materials, 3.6% for transportation concerning with construction work, 1.3% for construction work, 11.4% for utilization of enterprise facilities and 11.8% for utilization of private house facilities, which are summed up 36.8% in total. Energy consumption for utilization of enterprise and house facilities are almost allotted to operation of machinery equipments, so they are excluded. Then energy consumed by production, transportation and engineering work of construction materials is 13.6% of the total energy consumption. At international conference COP3 held in Kyoto in 1997 for prevention of global warming, cut-down target of carbon dioxide discharge for each countries is agreed.

3. EVALUATION OF ENVIRONMENTAL LOAD FOR EFFECTIVE USE OF RESOURCES

3.1 LIFE CYCLE ASSESSMENT (LCA)

Various methods have been investigated and published with regard to the evaluation methods of environmental loads. Since almost all civil engineering structures are infrastructures for which very long service life is required, it is inevitable to evaluate its environmental load throughout all its life cycle, that is, from construction, maintenance in service period, dismantlement and until waste disposal. The following steps are recommended in ISO 14040 for life cycle assessment of environments.

3.2 GOAL DEFINITION

At this step target to carry out life cycle assessment is clarified. For effective use of resources the confirmation of environmental load and investigation of mitigation method corresponds to this step.

3.3 INVENTORY

Data on energy balances in every stages such as picking-up of resources, processing of materials, construction, service, dismantlement, abandonment, collecting, treatment for reuse and transportation, are accumulated. Based on these data, each items on environmental loads such as CO_2 or other air polluding materials, water polluding materials, energy, quantity of resources and quantity of wastes are analysed. This aspect is prescribed in ISO 14041.

3.4 IMPACT ANALYSIS

Based on the total amount of environmental loads, their influence on human body or ecological system is analyzed, and their environmental impact is evaluated. This aspect is prescribed in ISO 14042.

3.5 INTERPRETATION

Based on the analysis on environmental loads, countermeasures to reduce environmental loads are investigated (ISO 14043). In the operation of these steps, consumption of energy or resources listed up in the evaluation items can be converted to carbon dioxide discharge at burning process or at power generation. Therefore for evaluation of environmental load originated from civil engineering structures, the items may be concentrated to three main factors, namely carbon dioxide discharge, quantity of wastes and hazadous wastes. Particularly for global warming problem, carbon dioxide discharge is most important.

3.6 $LCCO_2$

As one of the factors evaluating environmental load, $LCCO_2$ is nominated in the inventory of ISO. At Kyoto conference COP3 cut-down target for carbon-dioxide discharge was fixed as binding regulation for advanced countries. This regulation is based on an assumption that global warming is one of the most important phenomena for which international co-operation is invitable.

Table-6 Merits and Demerits of Calculation methods of $LCCO_2$

Method	Analysis from Industrial Trade Record	Summing up Method
Outline	National industries are classified into about 400 groups. Yearly turnover between the industries is analyzed mathematically to estimate energy consumption and carbon dioxide discharge for each individual industry.	In case of manufacturing a product, energy required for raw materials, processing and transportation summed up to obtain energy consumption in terms of carbon dioxide discharge for a unit quantity of products.
Merits	Effects of all national industries are covered, and side effects to the other industries are included. So integrated evaluation is possible.	Detailed analysis is feasible and the latest informations can be reflected easily in the evaluation.
Demerits	Available data for Japan is rather old. Recent trend cannot be evaluated. Classification of industries is still too rough and detailed discussion on small scale industry is not possible	Relevant data on energy required for materials, proceeding and transportation are needed. It is usually difficult to get highly reliable data for the analysis.

$LCCO_2$ was calculated by JSCE committee using two different methods compared in Table-6. Obtained data are shown in Table-7. Using these figures, $LCCO_2$ can be determined for each project or for each type of structure. Quantitative evaluation of different countermeasures including utilization of unused materials or recycled materials is possible in terms of carbon dioxide discharge.

4. APPLICATION OF VALUE ENGINEERING TO RESOURCE PROBLEM

4.1 HISTORY OF VALUE ENGINEERING

The basic concept of "value engineering" (VE) has been founded in United States in 1947. At that time all kinds of resources were insufficient after the war, in most engineering processes conventional or prescribed materials could not be obtained. Therefore substituted materials had to be used. But in many cases better final products were born at cheaper costs than ever. From these experiences, it is broadly recognized that substitution is very effective way of improving plan or design. This originated the basic idea of "value engineering"[1]. There are, however, diversified definitions of VE at present. For example, in a certain definition the purpose of VE is defined as "systematic research for function of products or services in order to secure the required function at the minimum total cost"[2], or in the other case, the description such that "the lower Value can be adopted and the best choice is not necessarily the highest Value when the effects of environment are taken into account"[3], is found in the definition. All these definitions are rather conceptual and no unified monism has been attained yet using well-defined evaluation equations etc. for example.

4.2 PRESENT STATUS OF VALUE ENGINEERING IN JAPAN

In Japanese construction industry, Value Engineering concept is prevailing in connection with contract system of public works where Value Engineering is referred at design stage, contract stage and post-contract stage. But in these cases main purposes of Value Engineering are concentrated to reduction of construction cost or curtailment of construction period. Owing to the introduction of Value Engineering, various proposals extended by the owners or the contractors are reflected more easily and more frequently to the actual cost or period of the projects. Traditional tender system and contract system, however, remain still unchanged, since basic evaluation criterion being the cost as ever in Japanese contract system.

Table-7 $LCCO_2$

Classification Item	$LCCO_2$ Unit Discharge	Classification Items	Unit Discharge
(1)Aggregate Picked Rock	0.00154	(10)Asphalt	
(2)Crashed Rock	0.00189	(10.1)Asphalt	0.028
(3)Timber		(10.2)Asphalt Mixture for Pavement	0.0113
(3.1)Product	0.0297	(11)Rubber (Tire)	1.20
(3.2)Veneer	0.0519	(12)Paint	0.452
(4)Cement			
(4.1)Portland Cement	0.228	(21)Construction Equipments	1.52
(4.2)Blast Furnace Slag Cement (45% replaced)	0.135	(22)General Equipments	1.21
(4.3)Fresh Concrete*6	0.0369	(23)Materials for Temporary Installation	---*2
(5)Steel		(31)Gasoline	0.779*3
(5.1)Blast Furnace made Hot Rolled Steel	0.411		
(5.2)Electric Furnace made Bar Steel or Die Steel	0.128	(32)LNG	0.669*1
(6)Aluminum (Sache etc.)	2.03	(33)LPG	0.868*1
(7)Ceramics (for Building use)	0.188	(34)Electricity	0.129*4
(8)Glass (eq. Sheet Glass)	0.486		
(9)Plastics	0.492	(41)Transportation	0.930*5

Notes : unless otherwise described, the unit is kgC/kg, for *1 kgC/m^3, *3 kgC/l, *4 kgC/kwh, *5 kgC/t·km
*6 The figure is based on a mixture proportion, Portland cement 351kg/m^3, fine aggregate 849kg/m^3, coarse aggregate 945kg/m^3, water 147kg/m^3

4.3 ECO-VALUE ENGINEERING

In this article a new concept of Value Engineering, that is, "eco-value engineering" so to speak is groped in order to introduce environmental factors into the conventional Value Engineering in a quantitative manner. In the cement and concrete industry utilization of industrial wastes such as blast furnace slag, fly ash etc. or exploitation of municipal waste to cement manufacturing has been promoted until now. But no quantitative evaluation of ecological merits obtained by these materials that are so friendly to environments, or demerits caused by use of conventional materials has been done in planning or designing stage. Since ecological impact of concrete industry cannot be overlooked, in selecting every life cycle processes of concrete utilization such as manufacture, service, abolition or reuse, environmental load should have reasonable priority. For this purpose a social evaluation system under which environmentally friendly processes can have advantage over the present processes on cost basis has to be founded. In this paper a new evaluation equation, in which eco-cost derived from environmental load is added to the cost in the current VE concept is proposed.

5. ECO-VALUE ENGINEERING

5.1 DEFINITION OF VALUE IN VALUE ENGINEERING

In value engineering. Value referred as V here after is defined by the equation (1) quantitatively,

$$V = F/C \tag{1}$$

In this equation F and C denote function and cost respectively. Therefore the value is increased with increasing function and with decreasing cost for a given condition. Generally function expressed in terms of numerical value has positive correlation with cost although the proportionality is not always linear and sometimes the value might jump up discontinuously over a certain threshold value. But the concept of value is valid and useful for comparing applications that are similar in a qualitative sense. In these situation, the value is not necessarily variable. For example, if we assume three types of concrete as shown in Table-8, the value for concrete ③ is the highest and cost performance for concrete ③ is considered to be superior to the other types of concrete.

Table-8 Example of value calculation for concretes having different function and cost

Type of Concrete	Function (F)	Cost (C)	Value (V)
①	1	1	1
②	2	2	1
③	2	1.5	1.33

5.2 EVALUATION OF EXCESS PERFORMANCE

For a the particular application, if the required function is 1, concretes ② and ③ are marked to have excess performance respectively as shown in Table-9. After all, concrete ① is regarded as superior to the others because it has sufficient function for the requirement at the lowest cost. It is understood that function in the value engineering concept does not correspond to the actual function but to the minimum function to satisfy given requirements (F_0). Therefore, the equation (1) is rewritten as

$$V_0 = F_0/C \tag{2}$$

According to this equation the value (V_0) for three types of concrete are calculated as shown in Table-9. From this evaluation, concrete ① is nominated to have the most appropriate value. Clearly it is important to cut down excess performance for conservation of resources.

Table-9 Example of value calculation for concretes having different minimum requirement of function and cost

Type of Concrete	Function (F)	Minimum requirement of function (F_0)	Cost (C)	Value (V)
①	1	1	1	1
②	2	1	2	0.5
③	2	1	1.5	0.67

5.3 INTRODUCTION OF ENVIRONMENTAL COST

In equation (2), expenses to procure raw materials or to construct structures are counted as a part of cost. But the following expenses to eliminate environmental load are not counted for construction of concrete structures.

(a) expenses to eliminate environmental load deriving from procurement of raw materials or construction of structures
(b) expenses for environmental load originated from repairing or strengthening of structure to maintain function during its service life
(c) expenses for environmental load deriving from dismantling operation of structures
(d) expenses for environmental load deriving from abandonment of dismantled structures

From eco-value engineering point of view these expenses to suppress environmental load should be added to the conventional cost. From this consideration these additional expenses for environmental countermeasure is defined as eco-cost (EC), and also the true value, in which environmental load is taken into account, is defined as eco-value (EV). Then, the following equation is obtained

$$EV = F_0/(C+EC) \tag{3}$$

5.4 POSITIVE AND NEGATIVE ECO-COST

On calculating eco-cost (EC), positive cost that is equivalent to the cost to eliminate the environmental load should be adopted if the environmental load is increased. While, when waste materials or recycled materials are used in a project, expenses to eliminate environmental load if these materials are not utilized are not needed. In this case these expenses are counted as negative eco-cost since these costs are eliminated by the effective use of resources.

5.5 EVALUATION ITEM OF ECO-COST

With regard to the environmental loads (a) to (d) shown above, how to evaluate them as numerical costs is investigated.

For those factors which exert positive environmental load, the eco-cost is basically equal to the cost required to repress the load. For example, when carbon di-oxide is considered as the environmental load factor, the eco-cost corresponds to the expenses to fixate the discharged amount or to utilize in a process. With regard to the item (b), the service life of the structure becomes important. The eco-cost on this item is dependent upon cycling period of repairing or strengthening during its service life. In another words, highly durable concrete structures that are maintenance-free can reduce the eco-cost to a large extent. If the structure can be reused as it is as possible in dismantlement operation, the eco-cost on (c) item can be reduced. Further, if all the waste materials dismantled after service life can be recycled or reused, environmental load on item (d) can be reduced very much. Therefore, life cycle planning of structures at design stage becomes very important, responsibility of a party who is in charge of this stage will be deemed more and more grave in future.

5.6 EVALUATION OF NEGATIVE ECO-COST

As mentioned before, negative eco-cost can be used when wastes or unused resources are utilized. In this case, the absolute value of the eco-cost is equal to sum of expenses required for their abandonment and suppression of the environmental loads caused by abandonment. For example, when utilization of flyash is considered, the expenses correspond to the expense to secure temporary dumping apace within a territory of power plant, the expense needed for processing such as melting before disposal, and the expense to prevent soil contamination etc.

In the estimation of the eco-cost, the problem is what kind of factors should be listed up as the environmental loads. If only some of the factors are picked up, the system could not be fair to all the industry. Carbon dioxide discharge could be selected as a most general factor of the environmental load, but evaluation by other factors such as air pollution, (SO_x or NO_x etc.) or water contamination are more important particularly for some industries related to resources. At present it is difficult to establish a perfect system including all of the environmental loads, so the practical way is probably to pick up some of the main factors from these environmental loads.

6. CONCLUDING REMARKS

In this paper possibility of eco-value engineering is investigated. Environmental factors are taken into the current concept of "value engineering" in order to evaluate various ideas to mitigate environmental loads. Concept of eco-cost in connection with environmental load is added to the current cost concept. Through this procedure, it is shown positive efforts for environmental load can be positively evaluated.

At present quantitative informations regarding eco-costs are not sufficient enough to substantiate the engineering concept. Further endeavor is required to collect much more informations on eco-costs in detail.

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