A Feasibility Study of an Algae Façade System

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ABSTRACT

In contemporary high-rise buildings in urban settings, the popularity of glass façades is on the rise due to innovative aesthetics. However, the environmental impact from glass facades is of increasing concern because of their high heat loss and unwanted heat gain. As a sustainable alternative, we propose an algae façade system that integrates an algae bioreactor within a glazing façade. Algae facades provide good daylight transmission and shading capability, perform efficiently as a load-bearing façade system, and can replace current glazing systems with adequate thermal and structural performance. An algae facade is designed to improve indoor air quality through O_2 production and CO_2 absorption as a result of photosynthesis of algae. In addition, algae grown from bio-facades have the potential to be converted into renewable fuel stocks such as biomass or biofuel. The primary objective of this project is to identify possible algae species for algae façade application and to measure O_2 generation and CO_2 absorption rates in relation to climate and façade orientations. The primary objective of this paper is to carry out a feasibility study of an algae façade system in the areas of fabrication, structural and environmental performances. Research methods used in this research include simulation and experimentation. The preliminary analysis includes that algae facades can significantly advance a building's sustainability through improved energy performance of building envelopes including carbon capture and renewable energy generation.

KEYWORDS: Algae Façade, CO_2 Absorption, Biofuel, Building Sustainability

1. INTRODUCTION

The negative impacts of peak oil use and global warming are already being felt in both the developed and developing world. Buildings worldwide, more so than rapid transit and other urban infrastructure, are responsible for about 40% of CO_2 emissions, with the United States being the largest culprit by far (DOE 2010). CO_2 emissions in the US in 2008 were 14% higher than in 1990. As construction expands in countries such as China and India, absolute emissions figures will rise. Reducing building energy consumption is a design imperative, and innovative design strategies to reduce energy consumption are essential for tackling future climate change and non-renewable energy depletion. To this end, we address sustainability concerns related to building façade systems through an integrative research approach in which we collectively influence system design, materials, fabrication, energy consumption and end-of-product-life.

As a sustainable alternative to glass facades, an algae façade system was developed, which integrates an algae bioreactor within a glazing facade system. This innovative algae facade is configured to replace current glazing systems while providing adequate thermal and structural performance, good daylight transmission and shading capability. The algae facade system is also designed to improve indoor air quality through O_2 production and CO_2 absorption as a result of the photosynthesis of algae. As another benefit, the algae grown in the algae façade can be converted into renewable fuel stocks, such as biomass or biofuel.

The algae facade system is made of an algae bioreactor system integrated between two glazing systems. The bioreactor system is contained between two sheets of acrylic where the algae grow in a nutrient-rich liquid. A "vision zone" and an "algae-growing zone" are configured to offer good energy and structure performance. An unobstructed vision zone allows viewing, daylighting and ventilation where necessary. The algae-growing zone is a water cavity containing algae cultures. The algae-growing apparatus is made up of distribution pipes and mechanical systems including an air pump, a water pump and an algae filtration system. Figure 1 shows an overview of an algae facade system.

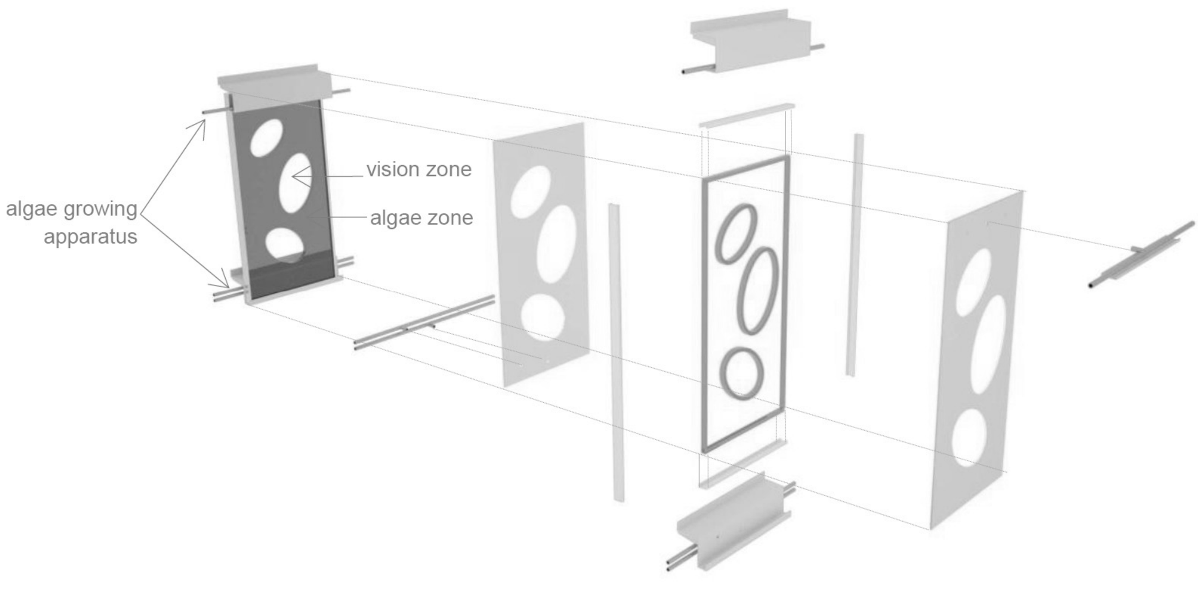
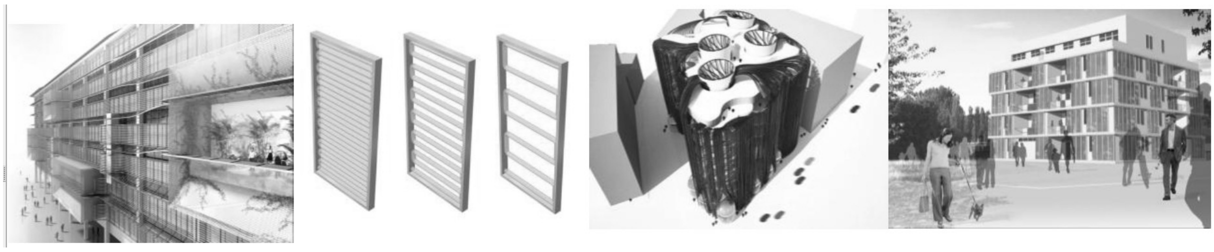


Figure 1. Algae façade system overview

2. DESIGN DEVELOPMENT

Precedent Study: There are several precedents that use algae façade systems in conceptual design or built examples. In the GSA retrofitted project in LA proposed by HOK, the algae façade was designed to filter wastewater and absorb CO2 emissions from the nearby freeway while serving as a shading device for the interior space. It also aims to produce lipids that can be turned into bio-fuel (Figure 2 (a)). Another conceptual project is Algae Urban Farm in Tehran, Iran proposed by ecoLogic Studio.

The project also utilized a photobioreactor tube similar to the one used in the GSA building above that provides innovative passive cooling stratigies through its shading effect. Not only does it provide sun shading but it also allows for the bottom floors to open up for natural ventilation. The algae façade of this building is also used as thermal storage and a heat regulator. The BIQ House is the world's first built example that uses an algae façade as a shading device. It is located in Hamburg, Germany, a five-story apartment building designed by Splitterwerk Architects in collaboration with Arup. The algae panels block the sun's excessive heat and light from entering the building and transform that energy with a bio reactor into usable biomass. This biomass then supplies the BIQ House with the energy it requires. The large algae panels also provide thermal heating for the building.



(a) (b) (c)

Figure 2. algae façade application on the GSA building in LA (a),
algae urban farm (b) and BIQ house (c)

Photobioreactor: Algae is grown using two different systems. The first is an open pond system, in which algae is grown in outdoor ponds and collected. It is a more economical approach, but can present many challenges with external contaminants. The second system is a closed system referred to as a photobioreactor. This system usually capsulates the algae in tubes to avoid cross contamination. The algae are much more regulated, and therefore it has a better outcome in unit growth rate.

In the past decade there has been much research on photobioreactor systems to produce algae efficiently for biofuels. As Singh and Sharma (2012) write, "a photobioreactor can be described as an enclosed, illuminated culture vessel designed for controlled biomass production" that is "closed to the environment having no direct exchange of gases and contaminants with the environment." Unlike open pond type algae farms, "closed photobioreactors are suitable for the production of strains rich in high value products" and allow for greater control over algae growth rate and output quality (Sierra, et al., 2008). There are many photobioreactor prototypes that have been developed. These include bubble column, airlift, flat panel, horizontal tubular, helical type, stirred tank, and hybrid type photobioreactors (Singh and Sharma, 2012).

UNCC's biology department (Figure 3) has a bubble column photobioreactor. In this particular prototype, various species of algae are cultivated in separate, vertically-oriented plastic tubes, about three inches in diameter. The photobioreactor sits in one of the windows of the biology lab, so that the algae specimens grown in each tube receive ample daily sunlight. The algae are fed through separate air supply tubes connected at the base of each column. The speed of aeration can be individually controlled for each column by tightening or loosening clamps located on each air supply tube.

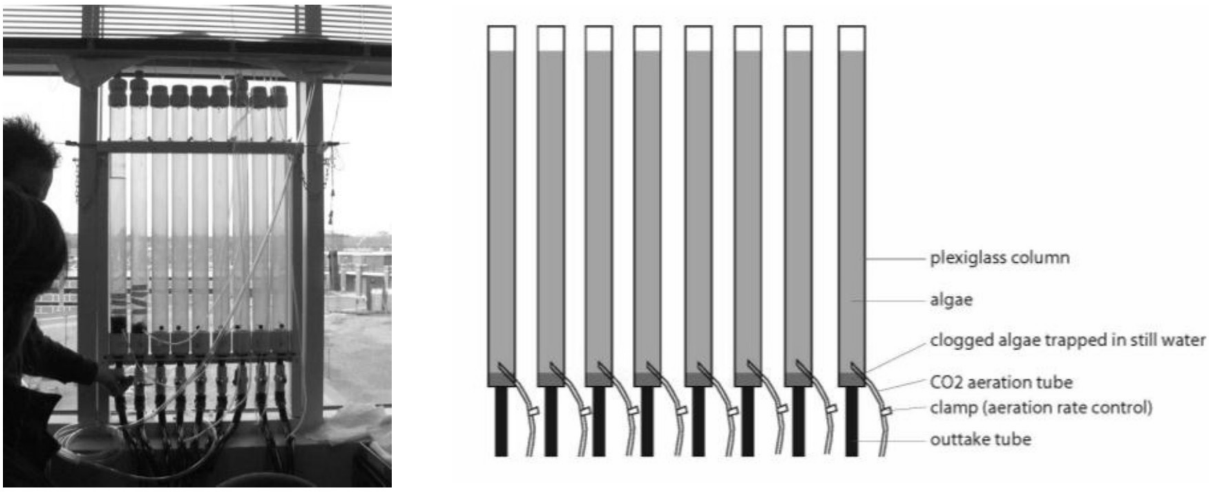


Figure 3. UNCC biology department bubble column photobioreactor

Of the photobioreactors that have been developed, the closest model to the proposed algae façade system is a flat plate photobioreactor. “Flat-plate reactors are characterized by a high surface-to-volume ratio, which leads to the best photosynthetic efficiencies observed for any [photobioreactor]” (Tamburic, et al., 2011). In the flat plate prototype, “agitation is provided either by bubbling air from its one side through perforated tube or by rotating it mechanically through motor” (Singh and Sharma, 2012). Key components of a flat plate bioreactor include: a medium inlet, water inlet, water outlet, gas (CO_2) inlet, and an algae culture harvesting outlet (Figure 4) (Sierra, et al., 2008).

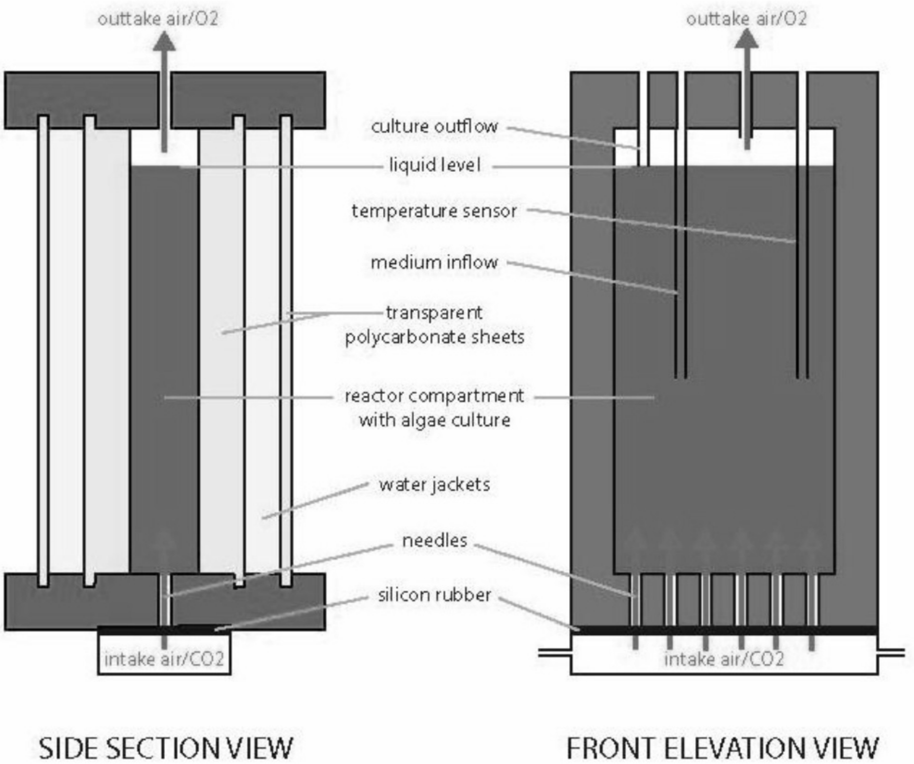


Figure 4. Flat plate photobioreactor components (based on diagram in Singh and Sharma, 2012)

The algae façade system uses thin acrylic panels, a system similar to the photobioreactor, functioning as a curtain wall and host the algae used in the system we create. The acrylic panels will be 12 feet tall by 5 feet wide with a 1 inch water gap for the algae to grow in. These panels will be fabricated with ½ inch thick acrylic sheets and will also have one to three viewing apertures for visibility in and out of the building.

Prototyping: A series of prototyping of algae facades was carried out at the fabrication lab in the School of Architecture at UNC Charlotte. Prior to the fabrication, material thickness of each system part was calculated to achieve material and fabrication efficiency. Further, bonding methods and adhesives were also determined to best assemble façade panels. Two fabrication methods were considered: 1. thermo forming and bonding and 2. cutting and bonding. Due to the cost associated with mold making, the cutting and bonding method was used to fabricate prototyping panels. In order to regulate green light transmission through the algae zone, the inner most surface of the algae panel was adhered with a film with different opacity.

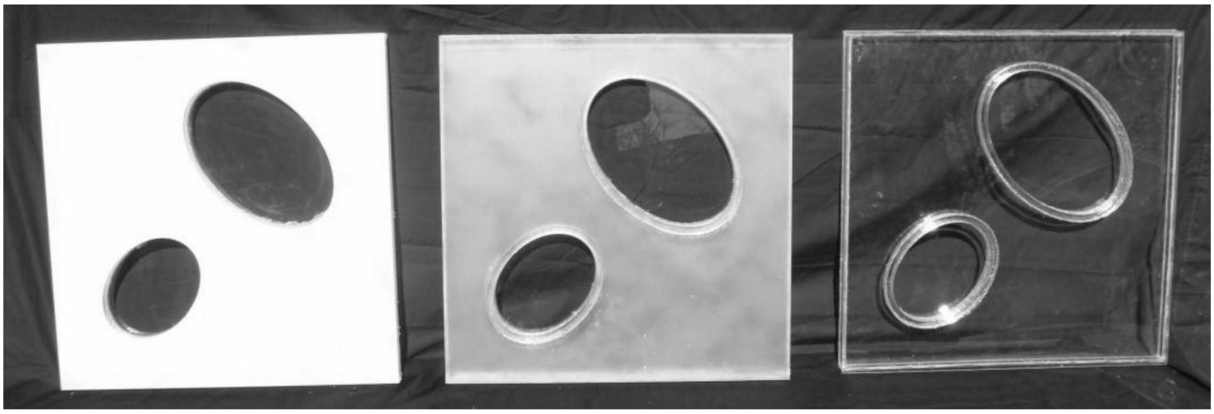
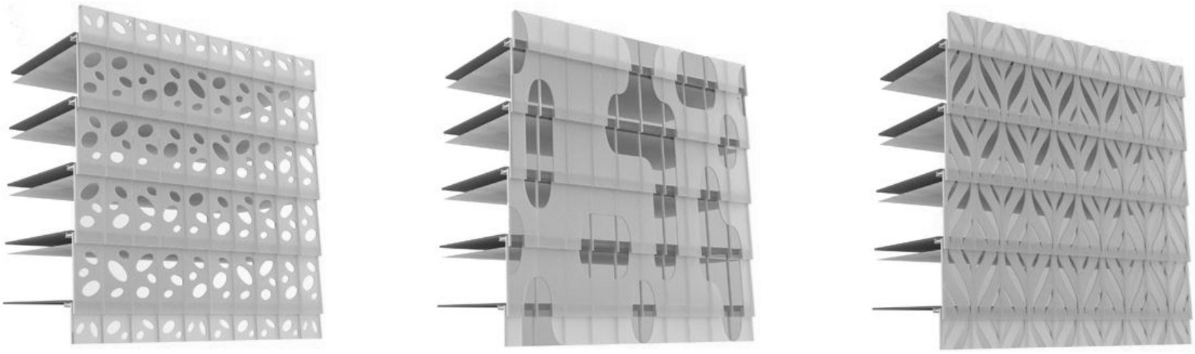


Figure 5. Prototyping algae panels with different surface treatment

Architectural Application: Algae is often perceived in a negative light, and it is important to develop a number of façade typologies and building applications that lead to aesthetically pleasing and friendly design outcomes. Further, the algae façade should be able to execute the sustainable façade system characteristics (i.e., customizable for optimum energy performance; aesthetically innovative using geometric variations and color). As an example, the algae facade can be implemented in both high rise buildings and city service buildings to enhance sustainability in the built environment. When the algae facade is installed at a gas- or coal-fired power plant, it absorbs greenhouse gas emissions from a power plant for photosynthesis, and the grown algae can be converted into biomass for power production or biofuel. Similarly, the algae facade can be installed at incineration or manufacturing facilities that require oxygen to smelt wastes or raw materials while removing greenhouse gas emissions. Figure 6 illustrates a design exercise of different algae façade typologies.



(a) (b) (c)

Figure 6. Algae façade typologies: (a) geometric concept; (b) organic form of algae; (c) rationalized fractal pattern

3. PRELIMINARY PERFORMANCE ASSESSMENT

Daylighting Performance: Buildings consume 39% of the primary energy in the US, with about 18% used by artificial lighting (DOE, 2009). Heat produced by a lighting system can generate up to 24% of the total building cooling load (Leslie, 2003). In addition to these energy implications, daylighting has been shown to contribute significantly to human health and well-being, reducing absenteeism and increasing productivity in office environments. Algae facades admit a specific daylighting spectrum (e.g., green, blue or red) into interior spaces depending on what color algae retains with the daylight transmission through the algae zone. The preliminary assessment utilized HDR (high dynamic range) photogrammetric techniques to evaluate daylighting potential and space color created by the algae zone. The study showed that the vision zone of algae facades can daylight the perimeter zone of an interior space without artificial lighting. The algae zone, on the other hand, requires special attention to minimize color transmission. Currently, different films or materials are under investigation to block color penetration through the algae zone (see Figure 7). Algae facades admit specific daylighting spectrum such as green, blue or red light into interior spaces, depending on what colors the algae retains, which can be utilized for color therapy or supplementing building programs.

(a) (b) (c)

Figure 7: Preliminary daylighting assessment of BIBE a) luminance results; b) daylighting color transmission through algae zone with translucent film, and c) daylighting color transmission through algae zone with red film

Preliminary thermal performance assessment: The thermal performance of building envelopes affect the cooling and heating loads of a building, as well as the occupants' thermal comfort. A building envelope is responsible for 2%~20% of building energy consumption depending on the building programs and size (Kim, 2010). As the algae facade has evolved and developed, the thermography technique was used to assess the preliminary thermal performance because it offers a user-friendly assessment and facilitates design evolutions with fast performance feedback. Preliminary thermal testing indicated that the U-factor of the algae facade is comparable to a low-e coated IGU (insulated glass unit). It is expected that the algae facades outperform IGU in real application due to the thermal mass potential from algae and the addition of CO2 circulation in the water cavity of an algae facade. The IR image also indicated that the vision zone requires two layers of acrylic panel to provide good insulation value and thermal comfort. Figure 8 shows a thermal image testing output of the algae facade.

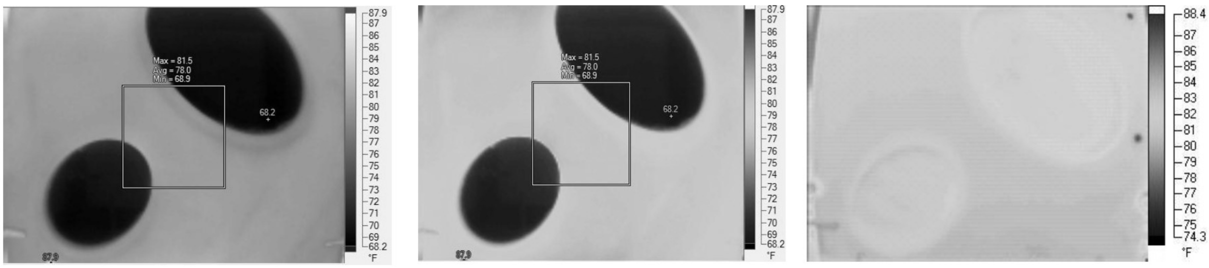


Figure 8. Preliminary thermal performance assessment of an algae facade

CO2 reduction and O2 generation: Since the rate of photosynthesis has yet to be determined per our project condition, we used an existing study to gain baseline data until measurements can be taken based on the actual algae facade. The Naval Research Lab in Washington, DC conducted a study to see how much oxygen is produced by 6.2 liters of algae solution. The research showed that the solution produced 4.5 liters/6.2liter algae solution/hr. Based on this published data, each algae facade panel with 5ft by 12ft can generate approximately 70liter of oxygen per hour. Applying this data to the scale of the study building for the life cycle analysis, a high-rise building that contains 5000 algae facade panels, for example, would produce a net production of 350 kiloliters of oxygen/hour from the entire facade. Since the amount of oxygen released is at a 1:1 ratio of CO_2 consumed, these figures imply that 350 kiloliters of CO_2/hour are absorbed by the entire facades. Based on the number of variables that determine the rate of photosynthesis in algae, this number cannot be assumed to be exact, however, it creates an initial value of what algae facades offer. Table 1 summarizes an estimated CO2 storage potential for a 42-story building per year.

Table 1: CO_2 reduction potential estimate based on published data

Daily kgCO_2 reduction from algae facade	Yearly kgCO_2 reduction from a study building
1kg	250 tons

Biofuel and biomass potential: Microalgae are also very efficient in the production of oil/lipid per dry weight and can "accumulate up to 50-70% of oil/lipid per dry weight." (Chen et al., 2013) Algae's composition and the presence of fatty acids allow it to be a promising contributor for biodiesel. The primary type of algae used in the algae facade system is *Chlorella vulgaris*, which produces 0.02-0.20 g/L/day of biomass and 11.2-40.0 mg/L/day of lipids, which is used in the production of biodiesel. In the production of biodiesel, approximately one kilogram of feedstock mass input yields approximately one kilogram of biodiesel output. Since each BIBE panel is approximately 106 liters, based on the published data, we estimated approximately 2.12-21.2 g/panel/day in biomass and 1.2-4.2 g/panel/day of lipids to be used in the production of biofuel. Table 2 summarizes an estimated biofuel potential for a 42-story building per year.

Table 2: Biofuel potential estimate based on published data

Daily yield of biofuel production from algae facade	Yearly yield of biofuel production from a study building
3g/facade	1100 gallons

4. CONCLUSIONS

The results of the research and design development show that an algae-integrated façade system concept has great potential for future development and use. The advantages of this façade system include good thermal performance, improved daylight transmission, structural integrity, and an algae cavity that modulates solar gains over the entire year. It reduces greenhouse gas emission and creates a sustainable energy system. An algae façade can be applied to a wide range of building programs and typologies that promote awareness of sustainability and reduce environmental impacts. The algae facade system is adaptable and can be reconfigured or customized to fulfil other primary responsibilities in different climate conditions and locations by varying different algae species.

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