



Energeia

Light Years Ahead

David J. Baker, *Baylux Business Strategies*

Ask the average person where electricity comes from, and he or she is likely to reply, "Out of a wall socket." Pressed further, they may suggest a thermal or hydroelectric plant as the source, depending on where they live in the country. In response to further probing, some may guess either nuclear power or fossil fuel as the origin. But it would be only a guess. Most people haven't a clue where their electricity comes from. And why should they, as long as it's available when they need it? Plug something in, switch it on, and the power is there. No one thinks too much about how the kilowatts are made.

How are they made? Some come from hydroelectric sources, but most come from thermal plants using nuclear power or fossil fuels to produce gas and steam to run turbines which, in turn, drive generators. What most people don't know is that more than half the electricity used in America comes from coal.

The fuel of the 19th century is the fuel of the late 20th century, and it looks like it will be the best bet for the 21st century as well. How is this possible? Wasn't coal the cause of pollution that blackened buildings, created killer smog and caused emphysema (not to mention miners' health problems like black lung disease)?

All true once, but true no longer. Coal has changed. Not only do environmental regulations require that coal mining leaves the land in at least as good condition as before mining began, but also working conditions for miners have improved beyond all measure. Our forebears would not recognize the mechanized and automated mines of today - or the green fields and hillsides that were once surface mines. Nor would they believe that the

power we take for granted comes from plants that give no visible evidence of the sooty fuel that fouled their cities, thickened their air and ruined their health.

Coal is clean - The Rise and Fall of Nuclear Power

Modern technology has found ways to use coal more efficiently without undesirable side effects. A ton of coal today yields up to 10 times as much energy as could have been recovered from it 40 years ago.

In the 1950s and '60s, coal-fired thermal generating plants were inefficient and dirty and environmental concerns made their future precarious. Biomass plants, oil-fired plants, natural gas-fired plants and nuclear plants were thought to be the way of the future. Relatively pollution-free and more efficient, they were expected to replace coal-fired plants, and huge investments were made in these new plants to meet America's growing energy demand. But, with the exception of natural gas, the promise of

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Selective Surface Flow Carbon Membrane for Gas Separation

Shivaji Sircar, *Air Products and Chemicals, Inc.*

A new class of nanoporous carbon membrane for gas separation called Selective Surface Flow (SSF™) has been developed by Air Products and Chemicals, Inc. It consists of a thin layer (2-3 mm) of a nanoporous carbon matrix (5-7 Å pore diameter) supported on the bore side of a macroporous alumina tube. The membrane is produced by carbonizing a thin layer of poly-vinylidene chloride (PVDC) polymer. The resulting membrane has a very narrow pore-size distribution which is characteristic of PVDC carbons.

The mechanism of gas transport through the membrane is described as follows (Figure 1, page 4): the feed-gas mixture is passed over one side of the membrane at relatively higher pressure (P_H) and the other side of the membrane is maintained at a relatively lower pressure (P_L). The larger and the more polar molecules of the feed-gas mixture are selectively adsorbed on the membrane walls at the high-pressure side and diffuse along the pore surface to the low-pressure side where they desorb into the gas phase. Under certain conditions, the adsorbed molecules hinder or completely block the flow of non-adsorbed components of the feed-gas mixture through the void space between the pore walls. This unique mechanism of gas provides the following practical advantages: 1) the high pressure effluent from the membrane consists of a gas stream enriched in the less selectively adsorbed component of the feed stream which is

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these fuels has not been kept. Nuclear power has proved to be both costly and unpopular. The last US nuclear plant to enter service started up in 1966.

What happened to nuclear power? What became of the pollution-free technology that was to produce electricity as if by magic? Like most lavish promises, it came with hidden costs. Those nuclear plants that were built and put into operation demand a larger work force than do fossil fuel plants of comparable size. They attract strong opposition because of perceived safety concerns. They are efficient, have low fuel costs and are pollution free, but disposal of nuclear waste is always a potential problem. The likelihood of anyone building a new nuclear plant is remote simply because it probably would prove impossible to gain the necessary approvals.

Coal currently supplies about 55 % of America's electricity; nuclear power provides 23 %. Natural gas generation amounts to 10 %; hydroelectric and other renewable sources 11 %; and oil 2 %. Some of the nation's nuclear capacity is getting old. When it shuts down, it will not be replaced with new nuclear plants unless there are major changes both in regulation and in public

attitudes. Natural gas or coal are the most viable sources of electricity now and, most likely, in the years to come.

Natural gas-fired generation is expected to grow seven times as fast as coal-fired generation in the next 15 years. Even so, nuclear sources will decline, renewable sources cannot grow much, and that leaves coal to fill the gap. According to James Markowsky, executive vice president power-generation for American Electric Power (AEP), this will mean a 20 % increase in the amount of electricity currently generated from coal. "The use of coal to fuel our nation's electric infrastructure is an absolute necessity," he says. "Our economy and lifestyles depend on coal now and will continue to depend on coal well into the future."

Alternate fossil fuels are more expensive than coal. Currently natural gas is the fuel of choice for new electric generation. Seventy-five percent of new plants chose it because initial costs per installed kilowatt are less than half as much as a coal plant. This is because of pollution control measures in coal plants that are not required in natural gas plants. But if expansion continues at the current rate, the demand for natural gas, and so its price, will probably rise faster than the price of coal. Clean coal will help moderate the price of natural

gas if it is available as an option. Coal is the most economical source of energy we have. Moreover, it is available in abundance. America has proven coal reserves to last at least 250 years at current rates of consumption.

The World View

The situation is similar in the rest of the world. Coal is the world's most abundant fossil fuel. It is found the globe over, and distributed quite evenly. It is the most economical and most widely available fuel in developing and developed countries. Is it any wonder that the use of coal to generate electricity is expected to grow rapidly? The World Energy Council and the International Energy Agency predict that coal consumption for electrical generation will double in the next 15 years. Sixty percent of this growth will take place in Asia-Pacific countries. It is clean-coal technology that will make this growth not only possible but acceptable. Even if natural gas continues to be an economical choice, many other countries do not have this option and instead will pay to import American clean-coal technology. AEP's Markowsky says that while the choice of natural gas makes sense, it is equally sensible to have an alternative. "We need coal as a viable option," he said, going on to describe the Clean Coal

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Light Years, continued

Technology Program — a joint government and industry effort to develop clean coal technology. “The CCTP is driven by industry. DOE and industry have shared the cost, and currently there are 42 projects in 19 states, either underway or completed, that demonstrate the potential of clean coal.”

While not a CCTP project, the Zimmer plant, owned in part by Cincinnati Gas & Electric, is a coal-fired plant in New Richmond, Ohio that was converted from nuclear power. The plant was 90 % completed in 1984 when it became evident that it would never be licensed. At that time the owners decided to convert the plant to coal. This took another seven years, and the 1300-megawatt plant went into operation in 1991, burning high-sulfur local coal.

High Sulfur: No Problem

What about pollution abatement? Can you burn high-sulfur coal and meet pollution requirements? Yes, you can. Scrubber technology at the Zimmer plant traps the three main pollutants that result from burning coal: sulfur dioxide (SO₂), nitrogen oxide (NO_x) and fly ash. Zimmer plant emissions meet not only current Clean Air Act requirements but also the new standards that go into effect in 2004.

Modern scrubbers, a “post-combustion” approach to clean coal, are capable of removing up to 98 % of SO₂ and up to 99 % of particulate matter from burnt coal. Scrubbers are just one solution. There are four ways to clean coal. These are: Pre-combustion, Combustion, Post-combustion, and Conversion.

The pre-combustion method consists of cleaning sulfur from coal. This can be done by physically washing the crushed coal with water. In this way, up to 90 % of pyritic sulfur can be removed. Organic sulfur cannot be washed away because it is chemically bonded to the coal molecule. Experimental chemical and biological techniques may improve on this rate in the future. The second process removes pollutants during combustion. This involves circulating fluidized bed combustion or CFB, in which coal is burned in the presence of limestone on a cushion of air. The limestone captures the SO₂ as the coal burns, and the temperature remains below the level required for NO_x to form. This process was known as far back as the 1920s, but in its latest form, combustion takes place under pressure. The combined-cycle turbine operation

boosts overall efficiency to as high as 50 %, compared to 36 % for the conventional process.

With partial funding from the US Department of Energy (DoE), AEP has built the 70-megawatt Tidd pressurized fluidized bed combustion plant in Brilliant, Ohio, as a demonstration project. This was the country’s first large-scale demonstration of new environmentally clean coal combustion technology and the first to be funded by the CCTP. The result has been described as self-scrubbing coal. In Florida, the Jacksonville Electric Authority and DoE are sharing the cost of refurbishing an existing plant and installing what will be the largest CFB facility in the world — and one of the cleanest.

Post-combustion cleaning involves the use of scrubber systems like the one at Cincinnati Gas & Electric’s Zimmer plant. Another example is Georgia Power Company’s Newport, Georgia plant where the scrubber removes up to 98 % of the SO₂, captures 99 % of other particulate, and produces gypsum as a byproduct. Sulfur collected by scrubbing often is used for other commercial applications.

The fourth method of cleaning coal is conversion. Since all fossil fuels share the same chemical heritage, it is not particularly difficult to convert them one to another. The process of changing coal into oil or gas has been known since 1913, but the availability of inexpensive natural gas or oil makes higher-cost conversion unattractive. Generally it has been done only on a large scale when gas or oil was either unavailable or in short supply. For thermal generation, conversion is attractive because oil made from coal can be cleaned more easily before burning. Gas made from coal burns almost as cleanly as natural gas.

The Wabash River Coal Gasification Project in Indiana, a DoE joint venture demonstration project, has been in operation since 1995. It processes high-sulfur local coal into gas that is burned at PSI Energy’s Wabash River Generating Station in West Terre Haute, Indiana. At 262 megawatts, it is the largest single-train coal gasification combined-cycle power plant operating in the United States. The project reportedly exceeds the Phase II limits of the Clean Air Act. Tampa Electric has a 250-megawatt plant that is one of the cleanest coal-fired power stations in the world. It turns coal into gas and filters out impurities. The plant achieves emission levels closer to a natural gas plant than a coal-burning

facility, with more than 95 % of the sulfur pollutants removed. An integrated gasification combined-cycle system, the plant produces power at 42 to 50 % efficiency. Other CCTP projects that are complete include the pyropower circulating fluidized bed combustion process at Nucla, Colorado; the coal reburning project of Wisconsin Power & Light at Casville, Wisconsin; the natural gas reburning and sorbent injection project of Illinois Power at Hennepin, Illinois; and the Passamaquoddy recovery scrubber at Thomaston, Maine.

Down the Line

Representatives from 170 countries met recently in Kyoto, Japan, to agree to terms of an international treaty to limit production of so-called greenhouse gases. Carbon dioxide, the leading greenhouse gas, is produced by burning any fossil fuel. However, conversion brings increased efficiency to burning coal. Eventually, new gasification combined-cycle power systems may cut CO₂ emissions by nearly 40 % compared to a traditional coal plant. With the growth in coal consumption that forecasters predict, this efficiency, and reduction in CO₂, will be essential to the achievement of reduced greenhouse gas targets around the world.

Ninety percent of all the coal used in America is burned to generate electricity, according to the Energy Information Administration. Abundant coal reserves in the rest of the world enable this resource to be used all over the globe. The key to development everywhere is increased energy supplies, and coal can provide this. As America and other countries face the twin struggles of meeting demand for energy and reducing emissions, they likely will turn more and more to clean coal for the answer.

America already has invested more than \$7.5 billion in the development of clean-coal technology. The results are the coal-fired plants that are cleanly generating electricity today. Research and development investment is ongoing to ensure that not only will the wall socket deliver when we want it to, but that the power will be there *without* unacceptable environmental cost.

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Surface Flow, continued

often the desired product, 2) the membrane can be operated under relatively low pressure and at a near ambient value of P_L since the true driving force for transport of a component is dictated by the specific adsor-

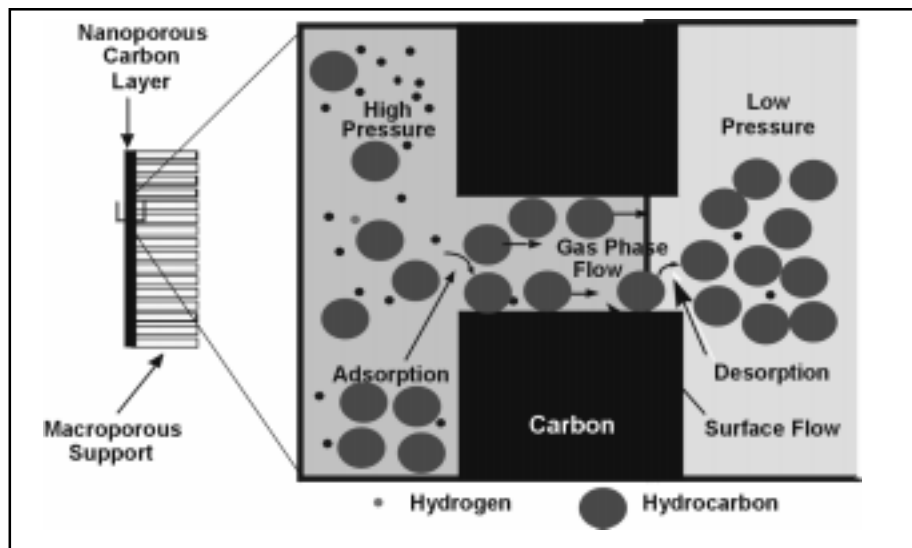


Figure 1. Gas transport through the membrane

bate loading across the membrane, 3) a large adsorbate loading of the selectively adsorbed component can be achieved at a relatively low P_H when it is strongly adsorbed, and 4) the fluxes of the selectively adsorbed components through the membrane can be very high because the energy barriers for surface diffusion of molecules on carbon are relatively low compared to those for transport of gases through a conventional polymeric matrix. The high flux eliminates the need for having ultra thin membranes. The selectivity of separation between the various components of the feed is governed by the equilibrium adsorption selectivity at the high pressure side, the selective surface diffusion in the carbon pores and the hindered diffusion of less selectively adsorbed components through the void space between the pore walls.

Since the components' partial pressure varies along the membrane tube, the specific adsorbate loading, the adsorption selectivity at the membrane pore mouth as well as the component diffusivity through the membrane pores also vary along the length of the membrane tube. Therefore, it is not possible to characterize the separation performance of the SSFTM membrane in terms of a single permeance of each component in the gas mixture. The SSFTM membrane is characterized by its

actual separation performance. The rejection, b , of the more strongly adsorbed species (fraction of that component in the feed gas which leaves the membrane in the low pressure effluent) is described as a function of the recovery, a , of the least strongly adsorbed species (fraction of that

component in the feed stream which leaves the membrane in the high pressure effluent). The flow rates and compositions of all gas streams can be described by specifying a , b , the feed gas flow rate and composition. Consequently, all separation performance data are expressed in terms of a rejection and recovery for a given set of P_H and P_L and feed gas composition.

SSFTM membranes can be used to recover H_2 from refinery water streams. Refinery waste gases typically contain a low concentration of H_2 (20-40 mole%) along with various concentrations of C_1 - C_4 hydrocarbons (saturated and unsaturated). They are available at a low to moderate pressure (15-200 psig). These gases are currently combusted to recover their heating values because there is no practical means to recover the hydrogen. Polymeric membranes selectively permeate c which would have to be recompressed to be further processed and pressure swing adsorption processes are inefficient when the H_2 concentration is below ~ 50% and the C_2 - concentrations are above a few percent. The SSFTM membrane can produce an H_2 enriched stream (50-70 mole%) at feed pressure from refinery waste gases by selectively permeating the hydrocarbons through the membrane. The H_2 enriched stream can then be processed in a conventional Pressure Swing Adsorption (PSA) unit to produce a pure H_2 product (99.99+ mole%).

A typical fluid catalytic cracker off-gas contains 20% H_2 / 20% CH_4 / 8% C_2H_4 / 8% C_2H_6 / 29% C_3H_8 at a pressure of 30 psig. A very high rejection of C_2 + hydrocarbons ($C_2H_4 = 98.2\%$, $C_2H_6 = 98.8\%$, $C_2H_6 = 94.1\%$, $C_3H_4 = 93.3\%$) can be achieved by the SSFTM membrane at a H_2 recovery of 60%. The corresponding high-pressure effluent from the membrane contains 51.6% H_2 , 41.5% CH_4 , 2.0% C_2H_4 , 2.3% C_2H_6 , 1.5% C_3H_6 and 1.2% C_3H_8 which can be further compressed and purified in a PSA unit to produce a pure H_2 product. The overall H_2 product recovery from the feed gas by the hybrid process, for this case, is 50%.

An SSF membrane module containing 3.5 ft long tubes (1 ft² area) was field tested at a refinery site for separation of H_2 -Hydrocarbon mixtures. The feed gas to the membrane module was supplied at a constant pressure (60 psig) but its composition (14-30% H_2 , 35-50% CH_4 , 7-15% C_2H_6 , 5-7% C_2H_4 , 2-7% C_3H_8 , 2-7% C_3H_6) and temperature (76-112 °F) randomly varied during the field tests. The measured hydrocarbon rejections as function of H_2 recovery fluctuated in a consistent fashion and no degradation of the membrane performance was observed during nine months of continuous operation. The performance of the modular SSFTM membrane in the field was actually better than that exhibited by a single tube operated under laboratory conditions.

SSFTM membrane can be used to separate a wide variety of feed gas. They have been experimentally evaluated for several gas separation applications including (1) separation of H_2 from gas mixture containing C_1 - C_4 hydrocarbons, (2) separation of H_2 from gas mixtures containing CO_2 and CH_4 , (3) separation of binary H_2 - $S-H_2$ and H_2 - CH_4 mixtures and (4) separation of binary CO_2 - H_2 mixtures. The membranes can be operated at pressures as low as 30 psig and selectively permeate the more strongly adsorbing species, retaining the less strongly adsorbing component at the feed gas pressure. They can be used in multiple stages to achieve very high rejection and recovery (a dual stage process was devised which gives 98.3% rejection of H_2S with 77% recovery of H_2 from a 50/50 mixture). This is possible due to the unique separation mechanism in these membranes.

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Steps Toward (EPSCoR) Graduation

John Stencel

Director, Kentucky DoE EPSCoR Program



The US Congress established the EPSCoR (Experimental Program to Stimulate Competitive Research) Program in 1979 with funding initially through the National Science Foundation (NSF). This program is meant “to improve the quality of science and increase the ability of university scientists in eligible states to compete successfully for Federal funds.” Eligible states, those which historically have been less successful in competing for federal research and development (R&D) funding on a per capita basis, include: Alabama, Arkansas, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, North Dakota, Oklahoma, South Carolina, South Dakota, Vermont, West Virginia, Wyoming and the Commonwealth of Puerto Rico. Even though this initial effort was small, EPSCoR programs now embrace the Departments of Defense (DoD), Energy (DoE), and Agriculture (USDA), in addition to the National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), and the Environmental Protection Agency (EPA).

Besides the stimulation of competitive research, it is also believed that the overall national interests of the US are served by having a high-quality, geographically-dispersed science and engineering research and training capability. Students primarily attend colleges close to their home. The quality of life, job opportunities and infrastructure are all impacted by the presence of strong universities. These facts were recognized in a recent letter from most of the states’ governors to the US congress in which they stated that research at universities *creates jobs, increases productivity in the work force, and provides the training ground for our country’s next generation of highly skilled workers.* Kentucky’s governor Paul Patton endorsed this stance; he is a key leader in promoting a nationally competitive stance for Kentucky’s universities.

Each state has had the opportunity to design its response to the federal

EPSCoR initiatives. For Kentucky, this has been

through a quasi-independent State-wide EPSCoR Committee affiliated with the Kentucky Science and Technology Council, Inc., (KSTC). On a statewide basis, the Committee aims to: stimulate and enhance competitive research; effect systemic and sustainable improvement in the research and education capacities of all of the state’s universities and colleges; and, vitalize cooperative and quality education and human resource development efforts.

Subcommittees of the Statewide EPSCoR Committee plan and carry out the details and day-by-day activities associated with each distinct, federal agency EPSCoR program. These subcommittees, with the assistance of project principal investigators and the Statewide Committee, cooperatively ally the universities at which the work is to be performed with the state and federal governments. Substantial financial participation by all parties involved in either the R&D or education initiatives is included in this alliance. The EPSCoR programs typically require cost sharing of almost 1:1, i.e. for every federal dollar a cost share of one dollar is required from state, university and industry partners. Since its inception, the total amount of federal EPSCoR funding to Kentucky is nearly \$28 M, with the Commonwealth providing a cost share of \$12.8 M and the Universities providing \$13.3 M. Therefore, substantial leveraging of each participant’s contribution is accomplished through EPSCoR.

Although not typically stated in this way, it is realized that an important goal for Kentucky is to graduate from the EPSCoR classification. This goal implies that standards of excellence in the overall education system and in employment opportunities must be fostered and then maintained. Without both, well-trained students may not have the quality-of-life

options they may have in other regions or states of the country. It is equally realized that employment opportunities are given birth by entrepreneurial activity.

Entrepreneurs are the dynamic force behind job creation.

EPSCoR is involved in helping to establish a more viable entrepreneurial base in Kentucky through the Kentucky DoE/EPSCoR Program. Through the KSTC, it created and sponsored the first-ever Commercialization & Entrepreneurship Institute in 1997 which was followed up in 1998 with an equally successful Institute. Here, the participants are immersed in an intensive learning experience focusing on the “how-to” of growing an innovation-driven company or commercializing an intellectual property. The training of students, business people, researchers and government employees in enterprise development; concept development; valuation and pricing; proprietary protection; capitalization strategies; creativity and entrepreneurship; and business strategies and planning is all part of this Institute.

Some other aspects of how the Kentucky DoE/EPSCoR Program is involved in Kentucky are outlined below. These few examples taken randomly from this Program also show the breadth of what EPSCoR is about.

1) Western Kentucky University in Bowling Green, KY has developed and tested, and is now going to help commercialize, a novel on-line measurement instrument for hydrocarbon fuels. Besides their equipment and software, partnering for commercialization with the John B. Long Company in Knoxville, TN and the SODERN Company in Paris, France is under negotiation. The success of this research has helped to secure over \$1.4 M in non-EPSCoR contracts and grants during the next year, including SBIR awards.

2) Murray State University in Murray, KY has established its first cooperative research program with

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Commentary, continued

Oak Ridge National Laboratory and has established a cooperative PhD degree with the University of Louisville as a consequence of DoE/EPSCoR funding. This cooperation extends the capabilities of Murray's faculty and complements their research, education and service goals. They recently successfully competed for a \$300K NSF, non-EPSCoR project in a topic area for which the KY DoE/EPSCoR Program had invested in equipment and research personnel.

3) The University of Kentucky has established new, long-term collaboration with scientists at the Thomas Jefferson Nuclear Accelerator Facility (TJNAF) in Virginia as a consequence of the DoE/EPSCoR investment. Faculty, staff and students at the university have

designed, constructed, and are installing a measurement device at the TJNAF which will be needed and used by experimenters from all over the world. The KY DoE/EPSCoR funding was also used to establish two new faculty positions at the university, the needed support for which will be taken over by the university subsequent to EPSCoR funding.

4) Education initiatives supported by KY DoE/EPSCoR have impacted more than 200 science and math teachers and 2000 students during the last three years, and have involved faculty and students at Morehead State University and Eastern Kentucky University. Part of this human resources development effort includes a new radionuclear chemistry training and education course in which new materials have been developed and were presented to

teaching faculty at four-year colleges in the Appalachian area and at historically black colleges and universities in the Southeastern US.

5) At Northern Kentucky University, the KY DoE/EPSCoR funded development of a new course for students who plan to become elementary and high school teachers. This course, called Chemistry for Preservice Teachers, was implemented originally within the Chemistry Department, and now is becoming part of the curriculum supported by the Education Department for all preservice teachers.

Collaborative working relationships are the lifeblood of EPSCoR. It has brought new possibilities to Kentucky, building bridges to competitiveness. We intend to graduate.

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