Clayteam

2nd International Symposium on Advanced Composite Materials Salon Talk

Material Inovation for Sustainable Social Activities Approaches to Environment-Conscious Products

AIST
NATIONAL INSTITUTE OF
ADVANCED INDUSTRIAL SCIENCE
AND TECHNOLOGY (AIST)

2nd International Symposium on Advanced
Composite Materials Salon Talk

Material Inovation for Sustainable Social Activities Approaches to Environment-Conscious Products

The Salon Talk was held as an opening event in the 7th Clayteam Seminar

＜Date：Nov. 7 (Mon) - 8 (Tue), 2011 Venue：AIST Waterfront＞

〈Coordinator〉

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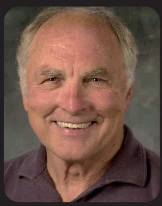
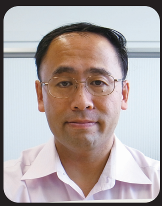


Prof. Galen Stucky
(University of California, Santa Barbara.)

Dr. Francis Clegg
(Sheffield Hallam University.)



Dr. Takeo Ebina
(AIST.)

Date：Nov. 7 (Mon) - 8 (Tue), 2011 Venue：AIST Waterfront
Organizer：AIST Consortium Clayteam
Corporations：JST, NIMS, The Clay Science Society of Japan, Japan Association of Zeolite
The Chemical Society of Japan, Japan Association of Mineralogical Sciences, NEDO

Clayteam

Introduction | Sustainable Sociaty pioneered by Composite Materials.(Dr. Yoshiaki Fukushima)


Dr. Yoshiaki Fukushima

F I am most interested in clay and clay is a mixture of water and clay minerals. I first used clay minerals to make composite materials but then I moved to the Pulsed Neutron Facility where I became interested in water mixed with clay minerals. Just the complex is very important.

The topic of this salon talk is sustainable society. In a sustainable society, energy security, and environmental persistence are very important. Two other important issues are the development of our economy and the enhancement of our quality of life. So, how do we obtain a sustainable society? We should increase our quality of life while preserving our environment.

At this point, I would like to discuss how to design for function and how automobile manufacturing by the Toyota Motor Corporation influences the environment. From the time an automobile is manufactured to the time it is scrapped, a lot of carbon dioxide is produced and so are a number of other toxic substances such as mononitrogen oxides. We need automobiles but we also need to reduce the amount of carbon dioxide that is produced when an automobile is running. From a viewpoint of energy, we calculate how to reduce carbon dioxide. For gasoline vehicles, gasoline-electric vehicles, fuel cell vehicles, and fuel cell hybrid vehicles, fuel efficiency from well to tank is very high in the petroleum industry. However, vehicle efficiency from tank to wheel for gasoline vehicles and gasoline-electric vehicles is very low. For fuel cell vehicles and fuel cell hybrid vehicles, vehicle efficiency is high but fuel efficiency is low. In summary, it is very important we increase our efficiency in producing engines or fuel cells and oil.

To achieve this, we need the necessary materials. My next slide is very old. In 1997, a Toyota conference was held where the main theme was the study of nanostructures in biological systems and the search for artificial ways to realize them. The conclusion of this conference was “search for hierarchical organization of nano parts; abilities to manipulate and carry each molecular units.” In the twentieth century, we had many natural and man-made nano parts but assembling them is essential. This was the result of the conference. In fact, we realized in automobile research that we already have assembled technology such as NO_x reduction in exhaust gas catalysts for automobiles. In this case, we have a nanoparticle of platinum and a nanoparticle of sulfur nitrate combined on an aluminum surface. This is a beautiful assembly of nano parts and although it is only artificial, we could not completely control this reaction. This is only the know-how to make such a beautiful system.

In Toyota, we assemble individual parts into an automobile. In nature, many nano parts are assembled into things such as leaves. So, nature can control nano parts while we can control larger parts. In other words, we can’t completely control nano parts function. So, how do we reach this technology or science? That is the important question for this salon talk.

Systematic Approaches in Research and Development processes. (Prof. Galen Stucky)


Prof. Galen Stucky

S The presentation I will give today closely follows what you have just heard in the preceding talk, which is basically how do we solve our problems when the world is becoming increasingly complex. I will also talk about the many opportunities that I think exist. One issue has to do with sustainable energy, and how we can achieve that in an efficient way.

In the United States, we have put a great deal of effort into trying to create more energy such as substitutes to replace oil and gas. If you look at this slide from the Department of Energy Lawrence Livermore National Laboratory, you can see that approximately 57% of the energy generated in 2008 for use in the United States was wasted. This energy is wasted in numerous ways. A notable example is that at best only 20 percent of the total energy available in a gallon of gasoline is actually required for moving the car. Roughly 80 percent is through energy dissipation that does not contribute to the energy required to mechanically move the car.

Looking at the ~57% of the total energy generated that is not used in the United States for applications, instead of working on ways to increase the ~43% that generates what is hopefully useful energy, a bigger impact on the global energy picture can be made by more efficiently using the energy that is now wasted. Gaining better access and making efficient use of sustainable energy sources such as solar, wind, and hydrodynamic energy is highly desirable, this is also a way to make better use of the energy that is, through the gift of nature, available to us. If used wisely and in a manner that does not degrade the ecosystem of the earth, it can contribute in a positive way, and eliminate the inefficient generation and use of energy from other sources. There is an interesting project going on in Northwestern United States being developed by one of the bigger companies that produces electricity for the area. This company produces a large amount of their electricity through a natural “wind tunnel”, which is a river gorge that runs from the coast inland along the Columbia River. The main problem is that the wind is variable, so sometimes it is windy and sometimes there is little wind. When a storm comes through, windmill electric generators produce an excess of energy that goes into the power lines. One thing that the company is doing is to pass some of the excess directly through to the individual end-users who can store a small portion of energy by heating up more water in their water heater for the family. These devices are in effect batteries, and therefore another way to store energy. Collectively this can make a significant contribution to the more efficient use of the available energy. Variations on this small scale are possible, and collectively of great importance.

I also want to say something about another huge waste of energy that is a very old problem. We have been working on this for a relatively short time, 12 years. I was approached in the late 1990s by a small company, which had natural gas holdings in the Gulf of Mexico and off the coast of Africa among other places. The issue was that they were generating large amounts of natural gas by pressure cooling but not all ports want tankers that have compressed natural gas in them to dock. Another option is to pump it back into the strata containing the crude oil, but there are problems in doing this effectively and efficiently.

On the left side of the second slide is a photograph of the Santa Barbara Channel. Everyday, 3.5 million cubic feet of gas gurgles out of its seeps. This is primarily a natural phenomena, although there are a number of oil platforms close by with some leakage as well. In the United States, some corporations are “fracking”. This typically involves the high-pressure introduction of agents into oil-bearing shale to release natural gas and oil, a man-made approach to release crude oil and natural gas in large quantities. There are many people who think that this is not a good idea in terms of the ecosystem, including contamination of the very important underground water aquifers. The amount of natural gas flaring is $10^{11}m^3$ per year. Although this satellite image is from several years ago and you can’t see all of the flares, the red that you can see on the image is due to large amounts of natural gas being flared. This is being done all over the world.

The problem is with what is called stranded natural gas, which can consist of methane, ethane, propane, carbon dioxide, sulfur-containing species such as hydrogen sulfide, water vapor and volatile organics in general. Attempts to solve this problem go back many years (1920s) and the Syngas and Fischer-Tropsch processes, and more recently to Mobil who developed an elegant gas to liquids (GTL) process for converting methanol to gasoline. The Fischer-Tropsch and Syngas processes are major technological achievements, and have been substantially improved and refined over the years. However, it still takes a large amount of energy; for example steam reforming of methane to give carbon monoxide and hydrogen at temperatures of ~ 800 ºC and high pressure. Cracking the methane C-H bond and converting the product into a liquid fuel or commodity is still quite inefficient and expensive. It requires large capital costs and processing plants so that flaring the natural gas is used in by far the majority of cases, including oil platforms and even for the recently developed oil shale fracking production sites. The challenge for both industry and for the young people the audience is to come up with a better solution for natural gas conversion. As noted above, a group at UCSB has being working on this for the last 12 years and have made considerable progress, to the point of a large demonstration plant being built and put into operation. Nevertheless until an efficient low pressure, low temperature process of large volume natural gas conversion is brought on line commercially, the conversion of stranded or remote natural gas remains as an opportunity for a high impact contribution for the more efficient use of our energy resources.

Another thing I want to talk about is something that the Greeks thought about thousands of years go. We really need to keep our focus on the fact that we are dealing with systems in every aspect of our lives. Not only the component systems of electronic devices or the multiplex reactions of commercial and bio chemical processes, e.g., catalysis, but also for all systems, small and large, that are interfaced to the environment, the society and the world. We have a global ecosystem and understanding it and working within it will determine whether or not there is a future for this planet and all its living inhabitants. Global warming is one of the more commonly discussed ecosystem problems, which involve our troposphere, which is from 4 to about 11 miles thick. It contains 80% of the atmosphere's mass and 99% of its water vapor and aerosols. If we continue to abuse or misuse it, we will have potentially catastrophic consequences as a result of the chaotic responses that will be generated.

As another example the Genome Project in the United States was formally founded in 1990 by the United States Department of Energy and the United States National Institutes of Health. It was expected to take 15 years to complete. When presented to our congress for funding, it was presented as an opportunity to make major advances in predicting and resolving human health problems. By doing a gene analysis for each individual, we were supposed to be able to diagnose and predict what illness each individual would have and what was needed so that person could live better and be healthier. The definition of a genome is the sum total of an organism’s hereditary information. Thus, genomics is the study of all the genes of a cell, or tissue, at the NDA (genotype), mRNA (transcriptase), or protein (proteome) levels. The most recent conclusion from the most distinguished group of human body scientists in the United States, who also were involved in the initiation and evolution of the project, is that the old-fashioned method of taking a family history remains a better guide for predicting the probability of a given physical ailment, such as heart disease for the individual than does a complete genome analysis as it is presently formulated.

Jamey Marth, the head of the Nanomedicine Institute at the University of California at Santa Barbara stated in *Natural Cell Biology* that “The pathophysiology of disease remains poorly understood. The genome has not been linked to many disease origins.” New approaches are needed to develop a better way to anticipate potential body system failure mechanisms and proactively generate a healthier human individual. What are these new approaches? One hypothesis right now is to think first in the context of the basic components of a cell (i.e., 8 nucleosides, glycans (32 saccharides), proteins (20 natural amino acids), and lipids (8 categories)). If, as in the genome project, one leaves out a basic component of the system (e.g., the glycans), you are leaving out important part of the cell system. Not looking at the entire system is perhaps the biggest failure in the Genome Project. Internal interfaces among the basic components and interactions of the glycans that are usually part of the external part of the cell with other cells and extra cell species are not properly considered. The important point that should be made, as in the case of oil and energy, is that it is always necessary to consider the total system.

For the human system, the four basic components are not the whole story: it is much more complicated than this because we have microbiomes. We have over 10 times more microbes than human cells in our bodies. They and we make up our total system. The human body is thus a complex system with bacteria, fungi, viruses, etc., most benign, many absolutely essential for life. Giving large amounts of antibiotics to an individual that will wipe out all the biotics and all the microbes is not thinking of the body in terms of a system. It is now generally accepted that pages of our genome library as a species are transcribed from the microbiomes. Another very important challenge that remains, but for which progress is being made, is in our ability to study and simultaneously follow the dynamics of the competing processes that make up a living system. More than a trillion cellular interactions happen in our body every second every day. We have complex systems where there are many things happening, and we need to be able to understand how these things occur in real time by multiplex , on all length and time scales, analysis.

As I mentioned previously, system thinking was recognized and realized by the Greeks several thousand of years ago so that it is nothing new. Itwas supplanted over the course of time by the idea that if we could just magnify things in greater and greater detail to the atomic/molecular level, the knowledge gained would rapidly lead to an overarching understanding of nature. However, this approach intrinsically tends to exclude the whole system. It is in general not possible to focus on a very small part of a system (e.g. as we do with TEM) and try to extrapolate those partial observations to interpret the whole system and its dynamics. It is necessary to study and characterize all the components of a system and their interactions in order to properly define the system. From a practical point of view, we need the ability to simultaneously combine multiple length scales (structure and properties) with component interface interactions (multiple time scales) and -surrounding media interactions with the system, which include mechanical, optical, electromagnetic, and chemical interactions among others.

For 2-D layered materials, a great deal of research has been accomplished. These materials can be assembled very precisely using molecular beam epitaxy, and by computer microchip fabrication processes, where complex hierarchical structures are created by heterostructure layer by layer- assembly in order to create a macroscale structure or device. Again, the properties for these systems are determined on all length and time scales—nanoscale to the macroscale, with the interfaces among the components generally providing the major challenges. Another example is the creation of multilayer radiation-tolerant nanocomposites. Individual layers are made that are nanometers thick. When radiation causes defects, the interfaces trap or remove the defects. This prevents the defects from propagating on the longer length scale and causing macroscale cracks. For example, copper/niobium interfaces are being used that are stable at temperatures as high as 800 °C.

It is essential to remember that when we design and synthesize materials or devices for applications, there is a structural length scale but most importantly there is a physical property length scale as well. When making a composite structure, we try to utilize the minimal assembly free energy/optimum efficiency to optimize these competing variables. Therefore, the different property scales, from electronic to photonic to mechanical to thermal, must be considered.

In conclusion, we need to not forget that we live in a multivariable, multidimensional universe that in itself is an infinite system, which is made up from the astro-scale to the atomic and subatomic scales of subsystems that are collectively interacting. Whether we design or study things from the bottom up or from a more macroscale perspective, we have to try to understand these collective interactions to the best of our ability.

A point that I learned very quickly when, back in 1985, I first joined the faculty at the University of California at Santa Barbara is that nature does not divide itself up into disciplines such as chemistry, engineering, biology and physics. Nature is comprehensive; all of these schools of thought are implicit and integrated into the whole of Nature. We have created these divisions, and in the process of doing that we have built up isolated silos of what we call expertise, separated from each other and without the necessary interfaces to truly understand the whole. This is a historical fault of the academic world. John Ross and Alan Arkin have recently edited an issue of the Procedings of the National Academy of Sciences, and in their prefaces aptly state,

"…The complexity (of systems) comes from the fact that in many systems there are a large number of variables, many connections among the variables including feedback loops, and many, usually nonlinear, equations of motion, or kinetic and transport equations."

And another quote, this time from Albert Einstein, who wrote this many years ago:

"A human being is part of a whole, called by us the 'Universe,' a part limited in time and space. He experiences himself, his thoughts and feelings, as something separated from the rest _a kind of optical delusion of his consciousness."

And if you think about this perspective, it helps to understand why we cannot reconcile the theory of relativity with quantum theory. We have black holes. Our astrophysicists came to the conclusion that the best way to resolve this is via string theory, which hypothesizes that we have a 10- to 11-dimensional, reality instead of the four that we commonly use in our engineering and scientific studies. It is humbling to realize that we are looking at, and live in, only a projection of total reality as far as astrophysicists are concerned. Continuing the above quote from Einstein,

"This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest us. Our task must be to free ourselves from this prison by widening our circles of compassion to embrace all living creatures and the whole of nature in its beauty."

This is what I will leave with you. There are many challenges, but at the same time I believe that there are unlimited opportunities if one follows a unity of knowledge or consilience (E. O. Wilson), systems approach.

F Thank you. I'll remember I'm dealing with systems like the Greeks and that systems can be defined organically. I'll also be sure to take a complex systems approach to problems.

Next, we will hear from Dr. Clegg.

Multilayered Packaging Sheets fabricated with Biogenic Materials.(Dr. Francis Clegg)

Dr. Francis Clegg

C Thank you for inviting me here, it has been a great experience so far and I hope that it continues to be. My presentation is about a more focused idea, the European perspective on sustainable packaging, which covers my research at the moment.

Our group title at Sheffield, PCAS, basically explains what we do, we research polymers, we make composites and we use spectroscopy amongst other techniques to characterise our products. The composites are usually based on clay science.

When we talk about sustainability, there are three main factors involved: economy, society, and environment. These three are all interconnected, they all come together. Food and water are two critical issues which support this sustainability loop.

We do research into the packaging of food, to try to overcome the problems that we may be faced with in the future. But, is packaging part of the answer? What does packing do? It is very functional: it contains the food, protects the food and also gives us information about the food. However, many people see lots of disadvantages with packaging: it is seen as a waste of raw materials and energy, it is difficult to reuse and recycle, often large volumes of waste is associated with packaging, and consumers often also see it as expensive or even useless.

The packaging industry is huge, as you can see the EU market is worth US$ 127 Billion, another big scary number. It just goes to show that there is a lot of packaging out there. But packing has got an overly negative viewpoint. If we look at the energy consumption for the food cycle, packaging takes up only about 7 percent of the energy that is used throughout the cycle. The majority of the energy is consumed during the food production itself but also in storage and in transport. I think the most important thing to note is that packaging affects the other factors; for example, it can reduce the energy consumption by allowing food to last longer. There is general agreement now that packaging does prevent food waste, and it is seen as part of the solution rather than part of the problem.

There is a lot of interest in Europe towards sustainable and renewable packaging. In the next couple of days, there is a meeting organized by the European Commission, to debate how to prevent and reduce food waste in Europe. At the heart of this discussion is packaging. How can packaging help?

The European Commission is also sponsoring research projects. This particular one (COST FP 1003) is looking at renewable materials from the forest industry, and is aimed at producing a product that only contains renewable materials (often paper packaging will have a polymeric barrier, based on a petroleum oil, in order to give it a better barrier property). So, this project is aimed at trying to produce better packaging with renewable materials.

FlexPakRenew is project that I have been working on for the past three years and is just coming to an end. The focus of the project was to create a multilayered packaging system. At the bottom we have the base paper, which provides the mechanical strength. We then have a choice of two or three layers on top of this base in order to gain specific types of barrier properties, for example, either gas, or grease, or water vapor. We may choose to add some additional functionality as well, for example, for it to be antimicrobial, so that when it is in contact with food, the food can last a little longer. My research focus was on one of the core layers and was based on starch, a swelling clay and a plasticizer. The starch acts as the matrix, the swelling clay was the barrier for the water vapor, and the plasticizer was used to reduce the natural brittleness of the starch since we needed to make it more flexible. The plasticizer also controls the way in which the clay is dispersed, and in fact can have a positive effect on the barrier properties. We were particularly interested in the water vapor transmission rates of these films. Other parts of the project were looking at xylan-based films, wherein the xylan is derived from birch trees. In addition, we were also developing a solvent-free, chemical grafting process onto the polymers in order to render the polymer surface more hydrophobic.

The SEM image shows an example of the starch-clay-plasticizer coating on paper board but the same principles would apply if it were paper. In the absence of the coating the cellulose fibers of the paper are clearly evident, but with the biocoat it is very smooth, there are no pinholes and we gain a good barrier.

The untreated paper has a poor water vapour barrier (800 g/m^2.day) and when we add a starch and clay coating we improve the barrier. With the right combination of starch, clay and plasticizer we get very good water vapor barrier properties, ~20 g/m^2 day.

Our objective was to try to make a multi-layered material that would match PET's water vapor barrier and oxygen permeability, this we achieved on the laboratory scale.

For the future, when we talk about sustainability in terms of packaging, we should focus on using only truly sustainable materials, for example, materials derived from wood (paper), crops (starch) etc.

To summarize, the aim of this salon is to discuss sustainability - but are we able to produce something that is truly sustainable? Does a major commodity material exist that can be produced that is truly sustainable? Can a packaging material for food with the appropriate properties be achieved without applying an additional barrier coating that isn't renewable? We don't know the answer.

Finally, we and others perform a lot of research with nanomaterials, clay being an example, and there are many issues about the safety of using these materials. These materials that we are making in order to produce a sustainable life, are they safe? Is it counterintuitive? And are they going to create more problems in the future?

Those are my thoughts. Thank you.

F Thank you. So, to our sustainable message, it is necessary to add another word: food. This is very important. It is especially important to minimize environmental stress resulting from food packaging. Prof. Ebina will now conclude our talks for today.

Development of Films, and Thinking of Time Scales. (Dr. Takeo Ebina)


Dr. Takeo Ebina

E It will be tough work concluding all of the talks today. I work in the application and development of clay film. The first thing that I usually keep in mind is to review local resources, and the second is to be conscious of time—very usual things.
Here, we see the distribution of major clay deposits throughout Japan. Here is Tokyo, you are sitting here, and my institute's location is here in Sendai, Miyagi Prefecture. Place-by-place we see the different sources of clays. The first one is swelling clay bentonite. The major places for bentonite are all located in the Tohoku region, so it is very unique. On the 10th and 11th, we will visit western Kyushu to see the clay mines for pottery stones. Historically, we started our research by using swelling bentonite clay.
The Tohoku region is also famous for producing rice. But not only do we have the rice itself; the rice husk can be used as a source of clay, because 20 percent of the weight of rice husk is pure silica. And so, we have tried to synthesize clay using this rice husk.
And, surprisingly, we have successfully made a transparent clay film from the rice husk. Normally, when we talk about biomaterials, most of them are, of course, organic. But, this one is not organic; it is an inorganic biomaterial.
Here, you can see a picture that some of you will remember from the last international meeting held in Sendai. This is a cigarette set made at the Craft Training Center, the predecessor of AIST Tohoku, around 70 years ago. The structure of this is highly unique.
This bottom layer is wood, with a primer structure on its surface. On top we have a different layer with aluminum powder, which scatters light coming through the top layer, because the top layer is semi-transparent. The reflected light gains a bright red color by passing back through the top layer, and this gives a beautiful, glossy color. The method was patented in 1935, and so is a very old technique but we are still using it for packaging, covering a car's surface, and so on.
Thinking about time scales. Our clay mine—the closest bentonite mine to AIST—was formed about 15 million years ago (very, very old). Then, humans developed and starting creating items, like a clay board with web-shaped characters, a stamping on the clay board ([S]: we say cuneiform) in about B.C. 3000. I will show you a clay doll found in Aomori Prefecture, it is also very old but the shape is beautiful and highly surprising.
I have already shown to you the new lacquer method produced in Sendai in 1933. At MIT, Hauser presented a very flexible paper using bentonite obtained from Death Valley. Death Valley is located in California. Hauser said that bentonite paper can be used for wrapping things or for writing on, instead of using conventional paper. However, this is not an actual paper but something similar to a paper using clay. Although that was nearly 70 years ago, we are doing research related to bentonite paper nowadays. At the Toyota Research Institute, Prof. Fukushima's group actively researched on polymer/clay nanocomposites in the 1960s and 1970s. Gas barrier by clay based layer started to be studied from about 2000, and AIST showed the transparent clay film in 2004.
Thinking about corporate R&D timescales, these are very short. For example, after submission of our patent, it will be disclosed 1.5 years later. Also, every year we will extend our joint research. Every month we have a project meeting. We also have one week trial experiments. But, the shortest one is my case; I am always calling my coworkers and asking "Please do some experiments today."
I will show you another example: a very unique and beautiful clay doll. This is estimated to have been created in B.C. 1500. It was found in Hachinohe, my hometown, and I'm proud of this because it is the second oldest national treasure of Japan. It is surprising because, even though it is old, the shape expresses our body-shape well.
We are doing research very quickly, because the situation is competitive; creating a new material faster than other companies. It is tough work. We have to feel the drastic change of the industry time-to-time, moment-by-moment. But we feel another flow existing below this: more stable, more sustainable. Sometimes it is better to look downwards, or to dive down to the bottom of our life, and see what is more sustainable. Then, returning to the surface, we can think about the new material. So, this is basically a way of thinking about sustainability. Thank you.

Discussion | Suggestions towards realizing a Sustainable Society.

F Thank you Prof. Ebina. Now, I would like to ask the members of this room for questions or comments. To briefly review, Prof. Stucky discussed waste energy, a natural gas problem, and some human disease. Dr. Clegg discussed the food aspect while I discussed the water aspect. To solve these problems, Prof. Stucky suggested we should take complex system approach. Dr. Clegg described environmental stress from the European prospect, and Dr. Ebina suggested we are always looking on the surface but we also need to look at what is under the surface.
I am very interested in waste energy. Last year with the Toyota group, we just started to consider how to use waste energy. As Prof. Stucky said, over 80 percent of energy is wasted in the automobile industry. How to use waste energy is very important. Prof. Stucky, do you have any suggestions for this?

S One obvious way is to use good thermal-electric materials where you capture the heat that is generated. Currently, there are several projects directed along those lines. One of the most obvious cases is combustion. The other is using storage batteries, lithium electrical energy. I think electrical batteries are one of the problems that have been around for many years. Good progress has been made in the context of composite materials and being able to recycle much better. Furthermore, an issue I've been working on is to do with high energy density batteries to get a better capacity for less weight.

F Just electric energy? How about the other kinds of energy?

S There are many kinds. I think you have to very carefully look at the 80 percent, see what the biggest fraction of that is lost to, prioritize it, and try to tackle it. Some things are low-hanging fruit in that, some things are easier to do than others, and although they're not of the highest priority, we should try to go for those.

F There is much waste associated with food. What should we do Dr. Clegg?

C That is a very tough question. I mentioned packaging and how it is potentially a part of the solution. Some packaging is just not necessary. A number of expensive products have expensive packaging and that can be very wasteful. I think we must be clever with the whole food cycle in order to fix the problem. I don't think there is one solution that fits all problems. There are going to be lots of solutions working together to fix the problems.

S I would like to ask a question on packaging. I grew up on a farm for 20 years. What was essentially very important to us was recycling everything we used, so with packaging, I think we can do better. Dr. Clegg mentioned most packaging is oil based. In contrast to this type of packaging that usually goes into the garbage, do you think future packaging will be reusable for some purpose like creating more food if it is biodegradable, producing energy in some fashion or even storing energy?

C Yes, I think so. The packaging we have today does its job. The oil-based packaging is more efficient but we can't use plastics forever. Although only 4 percent of the petroleum industry goes towards packaging, it will become more of a problem when petroleum begins to run out in the future. To fix this problem, packaging needs to be four things. It needs to be bio-sourced, renewable, recyclable, and biodegradable. To get to one thing that fits all four criteria is quite difficult.
Some packaging today is quite recyclable. Low-density polyethylene and polypropylene can be recycled but at the moment, the process is not efficient. Even though city councils in the United Kingdom separately collect plastic from households and store it in a particular site, a lot of that plastic goes into landfill if no one purchases it to recycle. So, we need to build up these systems in order to cope with being able to recycle. Paper is a very good example since it has a very good recycling route.

S I just have one other question. Did you ever hear of EarthShell? It is a packaging that was developed by a start-up company in Santa Barbara. The idea was to make containers from the potato peelings/waste produced by McDonald's. From memory, it was about 40 to 50 percent calcium-carbonate. They made it so it could be easily molded and processed. They have distributed quite a few containers, and I think it is a good use of food waste and it is easily recycled.

C That reminds me of bio-based polyethylene which is very difficult to get now but in the future it may become more readily available. It is an ideal packaging but the trouble is the energy used to make the polyethylene. It is probably more than what is used for an oil-based system. You have to look at the chemistry of the materials but also the chemistry in making new materials because they work in parallel.

[F]: I understand that recycling is very important. When I reported a clay-nylon complex, someone said that is not suitable for recycling. Nylon itself is very easy to recycle but when it is mixed with clay, it is very difficult. Prof. Ebina, do you have any suggestions?

[E]: Reducing garbage by using bio-sourced, renewable, recyclable, and biodegradable packaging will gradually work.
Regarding the composite material which Prof. Fukushima mentioned, maybe it isn't good to mix clay and the plastic for recycling. This is a big problem but direct recycling is just mixing plastic garbage and maybe burning something. Just burning the plastic is a very simple way of using waste plastic. In this case, I think it is ok to mix clay and plastic because the total amount of the clay additive is limited.
More importantly, we should be aiming to create a high barrier film without using aluminum foil because it includes multiple layers of plastics that cannot be recycled. The aluminum is also important because the amount of aluminum in the world is limited. Many companies are trying to develop a high barrier film without using aluminum foil and I think this is one of our biggest targets.

S Recently, I became aware of some numbers on cars in the United States which have to do with how far each person drove their car on the average. I think it was some like 100 kilometers or something small. If you think about the type of car this requires, we should be making smaller cars which take less energy and it would be another important way to save.

F Consumer trends have changed. Ten or twenty years ago, we only wanted a car. Now, many things are important. When Toyota tried to sell Prius as an environmentally friendly car, the campaign had no impact because although it is very energy efficient, the consumer only needs gas efficiency over short hauls. So, what is important and what is commercially valuable are different. If we include the cost of recycling into the production cost of cars, I'm sure consumer trends would change. Given this realty, it is very important to look at the total cycle and to look at the base like Prof. Ebina discussed.

S I think the changes will come. I also think there are some real opportunities in packaging and other things for small companies. Prof. Ebina said "anticipate the waves". Anticipate the changes which are going to take place. For example, in the United States, particularly Los Angeles, we have a huge highway network which in my mind is quite a bad infrastructure. From the history of that, I know it came about because of politics and money, and not for what was best for the people. Changing it again is very difficult but it will happen.

F As many people here come from commercial industry, consumer issues more than environmental or governmental issues take priority. In other words, we are concerned with what affects consumers. On the topics discussed today, do you have any suggestions for commercial industry?

S My background in industry is somewhat limited. I worked for DuPont Central Research and Development for 4 years in the middle of my career so I got to know DuPont quite well. I have also been involved with various kinds of start-up companies. The ultimate cost-benefit ratio of creating a product or doing a project certainly affects the topics we discussed today. One of the things that I learned is that if you can figure out a way to reduce multiple processes to one, it is a very valuable thing to do.
One more issue. The great thing about clays is that they are inexpensive. It is certainly a plus if you can cleverly utilize an inexpensive input, which is also abundant. In terms of compounds and materials synthesis, I feel we can make just about anything with the synthesis part but we can't make it cheaper. Not necessarily in a way that we can create large quantities.
The third thing is related to how Prof. Ebina thinks about using clay in the context of the environment. You use the resources at hand. The transportation cost of putting material together is very important. I also believe that in the future, the economy is going to become more focused that way.
Like the population curve shown earlier, things are changing very rapidly right now. Extremely rapidly! Whether the population understands that or not, what that means is that we are going to be more limited in resources including water, food, and the materials that we have to make things with. This is not totally unanticipated because I think the people here and most scientists, and certainly engineers, understand that change is taking place. The economics of those resources can change because when something becomes more valuable, cost will change. Timing is also important. You may have the right understanding about what is happening but the issue is can you anticipate the right time to act. So, I think it is really important to anticipate and look at what is happening as far as society is concerned. Unfortunately, I think a lot of what drives the decisions is not what the ultimate reality is going to be but money, and this leads to instability in the world economic system like we have now.

C I would just like to add to what Prof. Stucky said. When you listen to politicians they tend to be very reactionary to things that occur. They don't seem to be visionaries so we don't get people anticipating things. Actually, some politicians are visionaries but they have a very small voice and we don't hear what they say. So, I think we need more visionaries with bigger voices to foresee what is to come. I don't know if we should be scared of what is to come or whether technology will provide the answers.

F The time to end our salon talk is drawing near so please allow making some closing statements. Our conclusions regarding this problem are very large and we each have a different perspective. Finally, I would like to discuss my industry-based conclusions. First, we are currently wasting too much energy. From the viewpoint of efficiency, we must reuse this energy. My second point is related to composite materials. Prof. Ebina mentioned how traditional clay is important. I'm also interested in limestone consisting of calcium carbonate because it is an important composite material and biomaterial, and it is very abundant. Furthermore, it is important for energy restriction because of the conversion of calcium oxide to calcium hydroxide. In other words, I'm interested in water and energy. My last point is related to the importance of interface, which was mentioned previously. I think the keyword of "interface" is the conclusion of this salon talk. Thank you.