The JST-Mirai Program Lecture Notes Series:

Introducing Innovative R&D for the future

Japan Science and Technology Agency

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JST-Mirai Program

Preface

Due to the COVID-19 pandemic it is harder for us to meet face-to-face and stay in contact. JST Connect was launched in 2020 as a webinar series to keep the communication channel open between JST (Japan Science and Technology Agency) and representatives of the global STI community. By sharing information about JST's various activities we can create new connections and stimulate cooperation.

This booklet is a collection of presentations given at JST Connect in January 2021 regarding the JST-Mirai Program and three of its research projects. The three projects are "small-start type" in the "full-scale" research phase after passing stage-gate evaluation.

Stage-gate evaluation is one of the unique features of the JST-Mirai Program. It is not an easy gate to pass, and many of the projects in the feasibility study phase unfortunately end at this point. The projects introduced in this booklet are the best of the best. At the stage-gate evaluation, a project leader must convince the board that the project can produce social and economic value by overcoming clear and challenging scientific and technological hurdles. The chances of success may not be high but if the project leader can show confidence then the gate will open. In other words we encourage high-risk, high-return challenges.

Of course, Japan is not alone in its aim to invest in basic research and generate new social and economic values, and we are actively welcoming overseas partners to make international collaborations happen. We hope this booklet will be a good starting point for such collaborations.

Contents

Acknowledgement

We would like to thank the Department of International Affairs of JST for providing us the opportunity to introduce these research projects in the JST Connect webinar series.

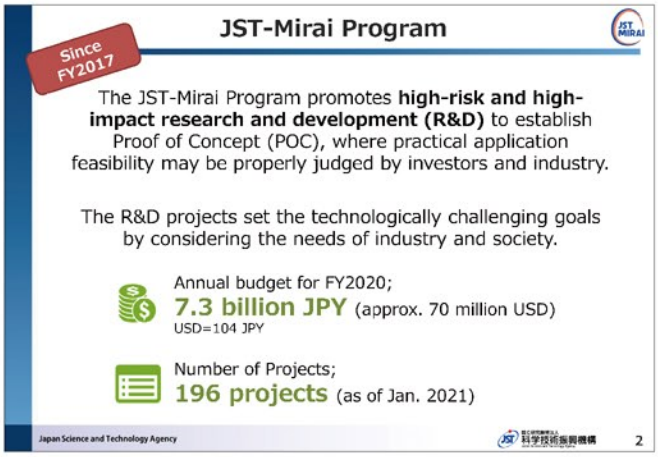
Introduction

Overview of the JST-Mirai Program

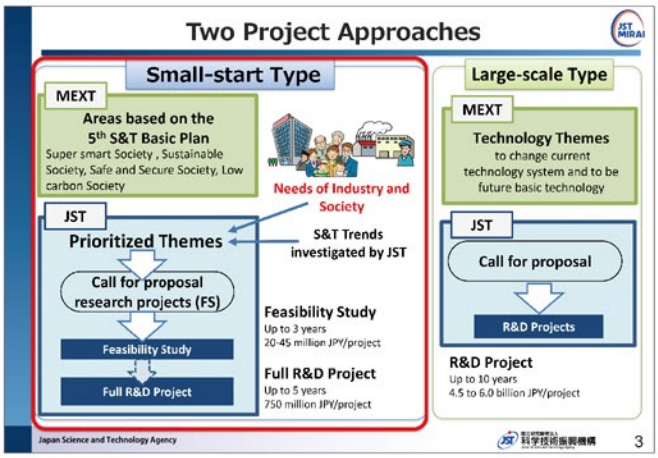
IMABAYASHI Fumie
Manager, Department of R&D for Future Creation,
Japan Science and Technology Agency

Today, I would like to introduce our funding program called JST-Mirai Program. My presentation covers a schematic overview and the future of the program followed by the three Project Leaders to present their projects.

Let me start with an overview of the program.

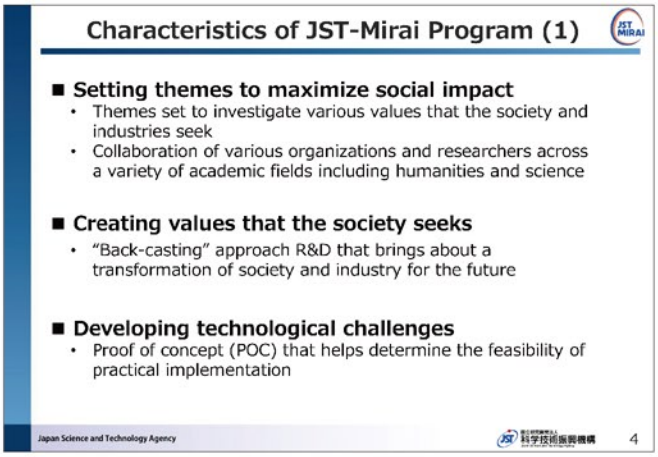


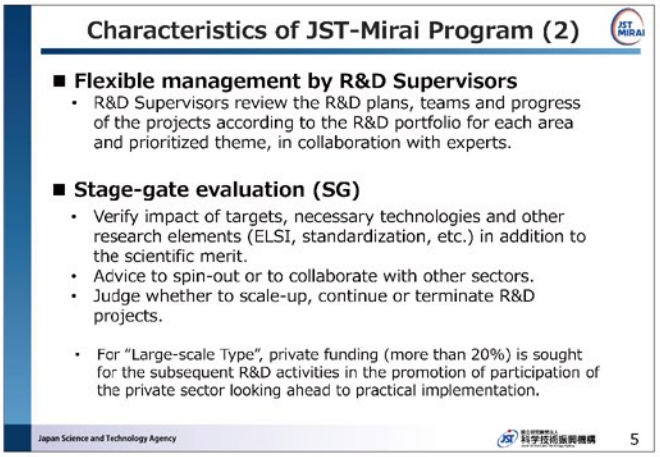
The JST-Mirai Program is relatively new and launched in 2017. It aims to promote high-risk and high-return R&D that leads to social and economic impact. For that purpose, this program helped develop proof-of-concept, POC, so that investors and industry may judge practical applications feasibility. In this program, the project requires to set technologically challenging goals by considering the need of industry and society. In this fiscal year (FY2020), our program budget is about ¥7.3 billion, approximately US $70 million. We have implemented 196 projects so far.



There are two types of projects in this program: One is the small-start type to launch a feasibility study with a relatively small budget and then scale them up through stage-gate evaluation. There are five strategic areas stipulated by the MEXT (Ministry of Education, Culture, Sports, Science and Technology of Japan). JST sets the prioritized themes accordingly and calls for proposal. So far, 95% of the projects belong to feasibility studies for this type. Among which six full R&D projects have been implemented.

The other approach is called the large-scale type. In this type, a relatively large-sized project is selected according to technological themes identified by the Government of Japan. There are only eight projects implemented so far.





From now on, I would like to focus on the small-start type.

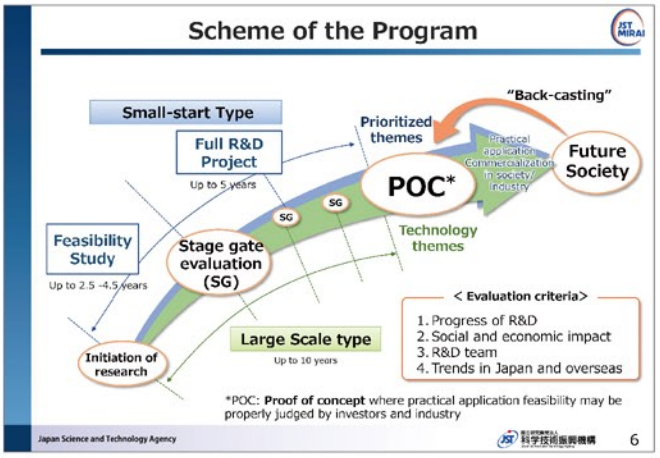
Why did JST launch this program?

To make a long story short, I would like to share five unique characteristics of the program to maximize the social impact of the research we fund.

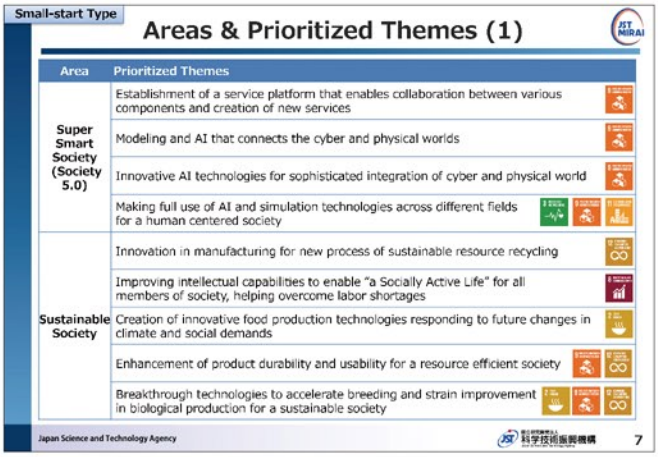
The first, JST set prioritized themes to investigate various values that the society and industry seek. With a committee of experts from various fields, the themes are determined to induce collaboration across a variety of organizations and research fields, not only the natural scientists and engineers but also humanity and social sciences for tackling social issues.

For driving such a collaboration, it is important to have clear missions to call for proposals. Considering themes as missions, we think about the society we want and then the value which could make it come true. We call this approach back-casting. Applying this back-casting approach, this program promotes R&D to prove the feasibility of the concept for creating new values to transform the society. In this program, therefore, each project must set technological challenges and attain a proof-of-concept so that the industry makes it ready for practical implementation.

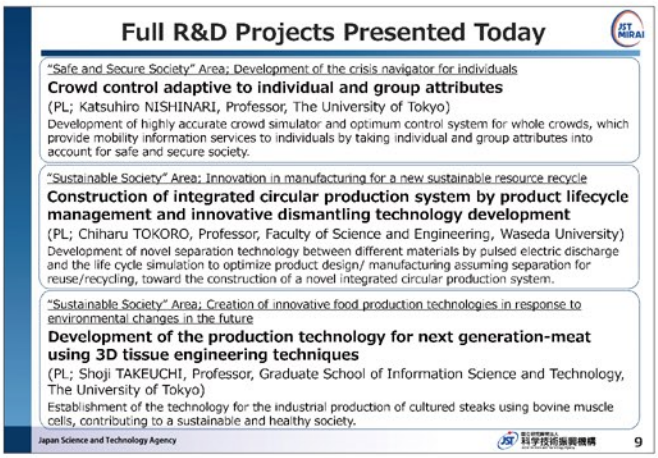
Another feature of the program is flexible management by R&D supervisors. The R&D supervisors review the plans and the progress of the project according to the portfolio for each area and theme. In collaboration with the experts, they also provide advice to the organized themes for scaling up. For promoting high-risk and high-return R&D, this program implements stage-gate evaluation that aims to verify the viability of the feasibility studies into full projects based on not only the technological progress but also the impact of the concept to be proven. The project is judged for its continuity.



The next slide shows the schematic life cycle of the project summarizing these five features I mentioned. For small-start type, feasibility studies are conducted for up to 3 years under each of the prioritized theme. Then, the full R&D project will be determined through the stage-gate evaluation, and that will be invested more for a maximum of 5 years.



The five areas and the themes are listed on the next two slides. These are Super Smart Society (Society 5.0), Sustainable Society area, Safe and Secure Society, Low Carbon Society and Common Platform Technology, Facility and Equipment Area. For the details of the themes and projects, please visit our brand new English website.



Today, as mentioned, we invite three project leaders: Professor Nishinari, Professor Tokoro, and Professor Takeuchi, who lead the full R&D project after the stage-gate evaluation.

Last but not least, I would like to share the three pillars of international activities of the program.

By the nature of the program, it is important to explore international partners as well as industry partners when necessary.

The first activity is to exchange researchers between Japan and overseas for sharing knowhow and research data, etcetera.

Second, this program also encourages the projects to co-organize international symposia or workshops. Such international activities, hopefully, become our opportunity to discuss global standardization of new technology developed for practical implementations.

The third one is the overseas researchers could participate in the project directly if his or her research institute signed the research agreement with JST.

These three activities are expected in this program as an international collaboration.

Through this webinar, I hope that the JST-Mirai Program and this project will get more international attention and develop new international networking and collaboration for the future.

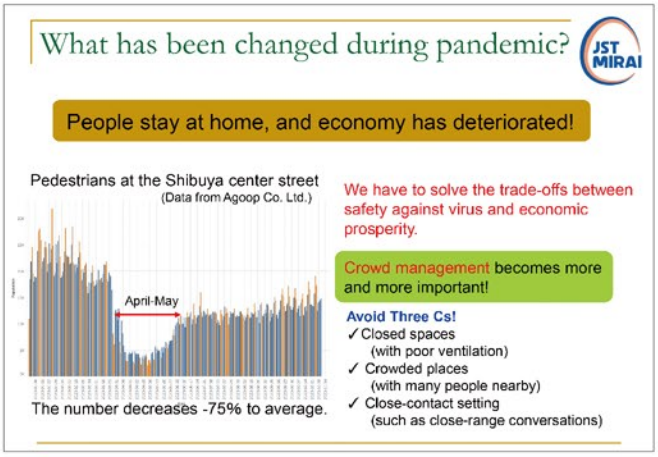
Thank you for your attention.

Presentation 1

Crowd control adaptive to individual and group attributes

NISHINARI Katsuhiro
Professor, The University of Tokyo

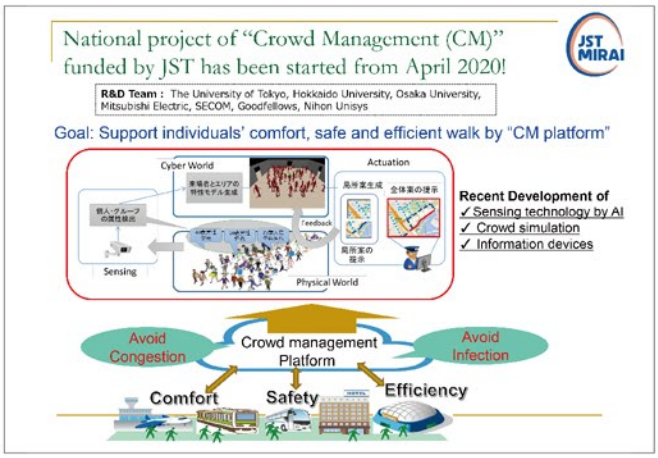
My research is crowd control and crowd management. This is very closely related to the pandemic situation, so I would like to start my talk by this slide.



We are all suffering from the pandemic situation, COVID-19, for about 1 year, and I do not know when it will stop. People are staying at home. Unfortunately, economic has deteriorated. This is a data taken from smartphones.

You can see that last year, after the pandemic occurred, from April to May, this is the sudden decrease in the number of people in Shibuya, which is central part of Tokyo. 95% is decreasing. But now, it is recovering. Again, we have a third wave right now.

I think that we have to solve the tradeoffs between the safety against the virus and the economic prosperity. In order to do that, crowd management becomes more and more important in the recent years. The government talked about avoiding three Cs. Maybe you have already heard about that. The three Cs stand for these three components: Close spaces we have to avoid, and crowded spaces and close-contact settings. In order to support that, I am now proposing the platform that will help the people in living with safety, comfort, and efficiently.



I would like to study or make a research by my project to develop the supporting system for walking individuals for comfort, safety, and efficiency, by constructing the crowd management platform, as you see. Of course, much, much before the pandemic I had started this study, more than about 30 years ago. At that time, I would like to avoid the congestion of the crowd, which I do not like, maybe many people do not like that. Recently, we had to also avoid infection of the virus. In order to achieve the goal, I proposed the system which is described below.

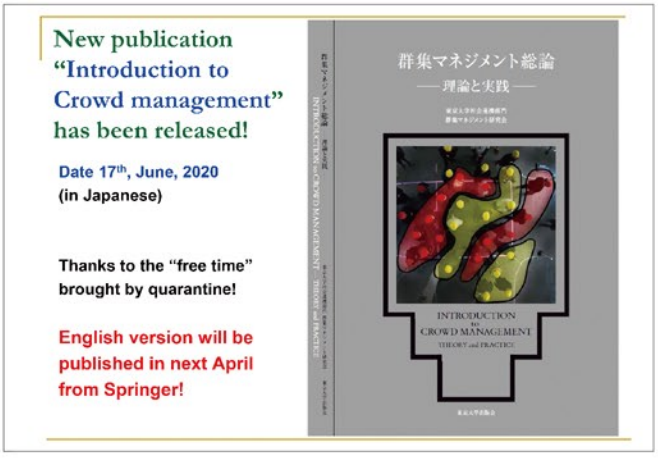
The system consists of three parts: One is

sensing, which measured the current status of the crowd by using camera, Lidar or AI system and so on, or smartphone which I have shown in the previous slide.

The next part is crowd simulation. The example is here. Maybe you can see the movie. This is the simulation of the Shinjuku Station. There are a lot of people close to each other. By using this kind of simulations, we can predict where it is dense or where it is not dense. After that, we can assess the risk of the crowd.

Then, the next part is here, the information devices we use for crowd. We give the information to the crowd which way is the best for you and so on, by using the smartphone everybody has already. Also for the guard man, we recommend the system for controlling the crowd. Both for the guard man and for the crowd, our system works in order to achieve the comfort, safety, and efficient motion of the crowd. This is what we are tackling.

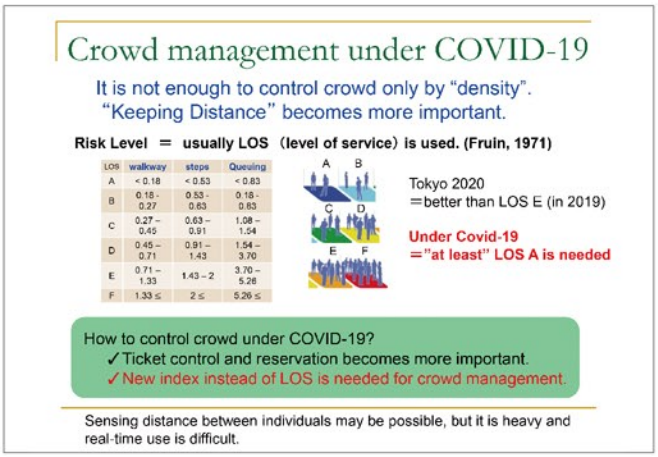
My partners are not only the universities but also, many, many companies like security company, the biggest security company in Japan, SECOM, and Mitsubishi Electric and so on.



Last year, I published the introduction to the crowd management. I think this is the first book ever published on crowd management. This is thanks to the quarantine. I have a lot of free time for writing books. This book is written in Japanese. But in April, this will be published from the Springer, my translation of this book. If you are interested in crowd management, then please refer to this book.

What are the challenges?

Most difficult challenges in this research is that we have to avoid infection and also avoid crowded situation. So far, the history is very, very long. About half a century ago, Professor Fruin proposed that risk level of the crowd, which is classified into 6 from A to F; A is good and vacant, F is really jammed, like jampacked trains. We have to avoid E or F at the Tokyo Olympics. I am an Advisor of the Tokyo Olympic Committee right now in order to avoid the crowded situations, about 2 years ago. But from the last year, we had to also consider the distance between people.

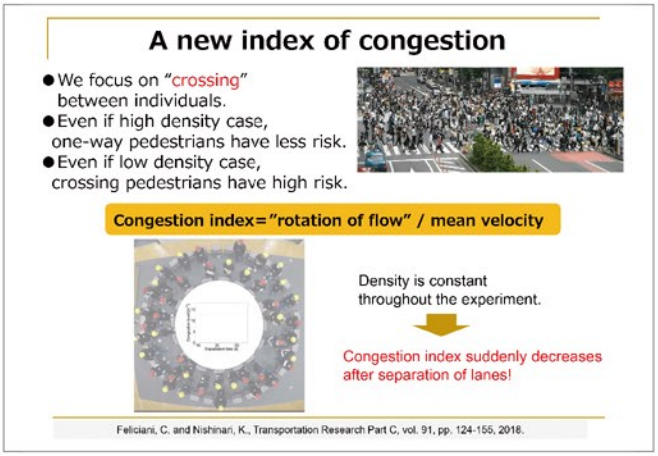


So far, we are only focusing on the density of the crowd. But from last year, we had to also consider the distance between the people, because social distance becomes more important than density in order to avoid infection. Nobody thinks about the distance. We only focus on the density. Up to now, there is a clear risk level which is classified by density, as given in this table. This is the density, the number of persons per square meter. In the COVID era, we have to consider not only the density but also the distance. There are no researches up to now about the distance. But measuring the distance between the people is very, very difficult and becomes very, very hard in a real-time way.

What we should do then?

First, I think that we should avoid the congested situation before the event. I mean that we have to introduce the ticket control and reservation system in order to avoid too many audience. Next, we have to introduce the New Index instead of the level of

service, which is proposed by Fruin about 50 years ago, for the crowd management.



One of the ideas of our group is that we use a congestion index. We introduce a new congestion index by considering the crossing between the people. As you see that this is a video taken at the Shibuya Central Street where a lot of people are walking but they are in a sense walking smoothly. Why? Even though it is the high-density case, if the people walk on one way or have a lane separation, there is no risk. But if the density becomes low, that the people are crossing each other, walking in random directions, then the risk becomes high. We think that we have to focus on the rotation of the body or rotation of the flow. This is a new index we proposed in order to avoid the risk of infection and also the risk of the stampede or some other things.

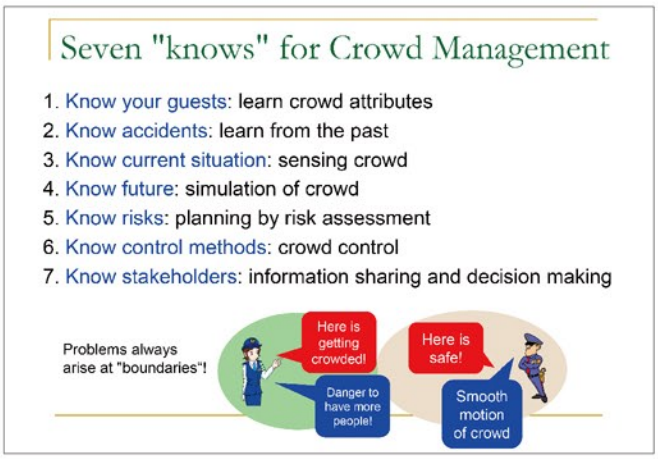
The Congestion Index is what we are proposing, and this is the recent experiment that shows priority of the Congestion Index. We can see that the number of people is not changing through the experiment, so the density is constant. But you see that after some time, there is a lane separation between the people going in the inner circle and outer circle, then for the people it becomes easy to walk.

In the first place, there is no lane separation, so there is a high congestion index. But after the lane separation, you see the drop in the congestion index, which means the safety situation. This is the first index that can separate from non-lane formation and lane formation case. We think that this is very important, to focus on the separation, rotation of the flow.

Please imagine that if you are in a congested place, you have to avoid the other person in order to make a detour. In such a case, your body rotates. We think that the rotation is very important considering such a situation. The rotation can be easily sensed by using a camera.

I also contribute to the safety boarding under collaboration with ANA (All Nippon Airways). My advice to the ANA is to stop priority boarding. Why? Because the priority passengers want to have an aisle seat which is very convenient to get off the airplane. But after sitting in the aisle seat, the normal passenger come too close to you and say "My seat is window, so could you stand up" or something. There is a conversation between such passengers which may become a risk. I advised to stop the priority boarding. Also, we should divide six groups boarding from rear to front.

From last June, ANA adopted my advice and now the operation starts. This conclusion can be derived from this kind of simulation which I made. This is a boarding simulation. You see that passengers are getting in from this entrance. We made a lot of simulations to see which strategy is the best. We now have a conclusion that dividing six groups and to stop priority boarding can minimize risk of the infection. This is my contribution to this situation.



Time is limited, so I would like to summarize what we are focusing on by the seven 'knows'. These are the most important things we have to consider when we use a crowd control or crowd management.

Know Your Guests: Crowds have different attributes, like countries or fans of sports or many, many things. We have to consider the attributes of the crowd.

Know Accidents: Learn from the past, of course.

The sensing is very important, so know current situation.

Prediction by the simulation is also important. This is 'Know Future'.

Know Risks: We have to do risk assessment by using the Congestion Index.

Know how we should control crowd.

I skipped all the method which I have done. But I am now considering the Nudge Theory, which can softly move the crowd by using, for example, sound or light, because people try to stay in the light place than dark place. We can use the light to control the people.

Know the Stakeholders. From the accidents, which occurred first, always problem arose at the boundaries between the stakeholders, because the stakeholders only focus on their only domains. The domain boundaries always become a trouble. This is what we are studying right now.

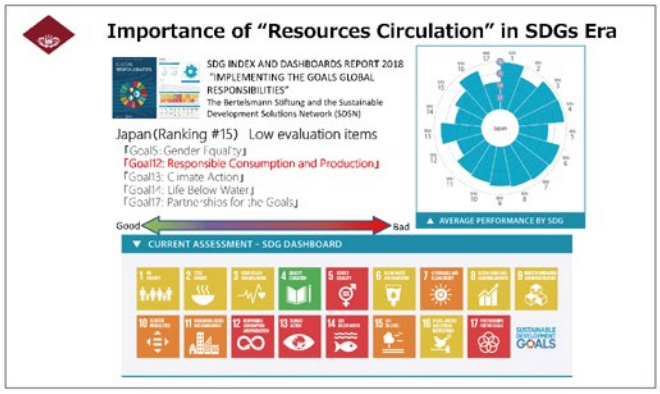
Okay, that is all. We hope that we can meet together at the Tokyo Olympics this year. At least, as a scientist and an advisor, we guarantee your safety. Thank you for your attention.

Presentation 2

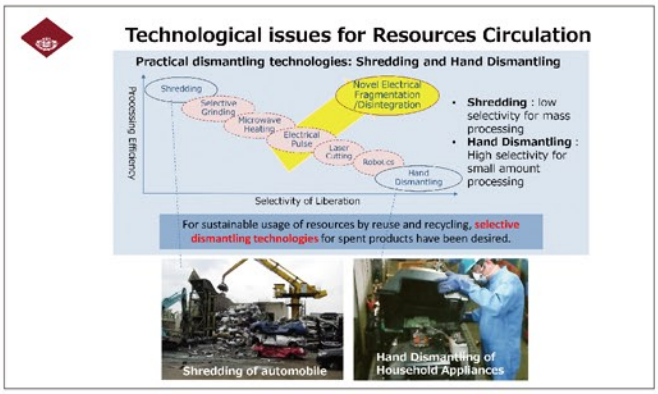
Construction of an integrated circular production system by product lifecycle management and innovative dismantling technology development

TOKORO Chiharu
Professor, Faculty of Science and Engineering, Waseda University

I am Tokoro from Waseda University. I am very honored to be here during this JST Connect to present our project. Our project is about the construction of sustainable recycling, reuse and recycling, sound material-cycle society, especially by some innovative dismantling technologies. Actually, my major is Chemical Engineering, Mineral Processing and Recycling. I would like to introduce today about some novel innovative separation technology for resource recycling.



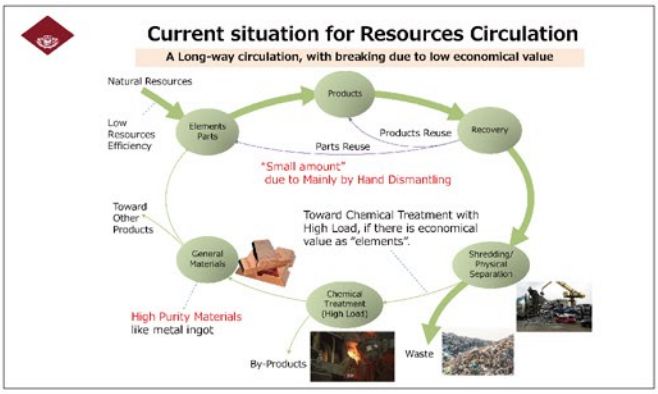
As you know, the SDGs are a very important issue in the current situation and in Goal 12, the importance of resources circulation is clearly mentioned there. This is one of the rankings for the whole of Japan. The red color is a not-so-good situation. The green color is a good situation for each target end goal. As you know, Goal 12 is a very difficult target. Now, creating a sound material-cycle society is an urgent issue not only in Japan but also in developed countries around the world.



We think we have two kinds of bottlenecks that mean we cannot create a good sound material-cycle society. One is our social system and the other is a technological issue. For the technological issue for resources circulation, actually, we have no good separation technology. In the current situation, practical dismantling technology is like this. We have two kinds of technologies. One is shredding. Shredding is like this automobile one. Shredding is very good for mass processing but has low selectivity. We have no accuracy for the separation.

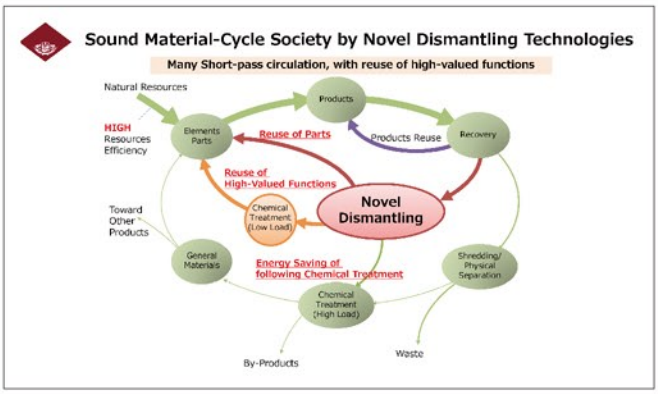
Meanwhile, dismantling by hand is very, very accurate. For example, in Japan, all or most household appliances recycling factories use many kinds of hand dismantling to separate plastics, metals or other materials. It is very accurate, but it is not so good for mass processing. We need several other kinds of dismantling technologies using, for example, more innovative mechanical mechanisms or using robotics, lasers, microwaves, partial heating, or something else. I guess that one

key point is a fusion of the physical and the chemical ones for separation. In this project, we are now trying to develop a novel electrical fragmentation or disintegration for this kind of separation.

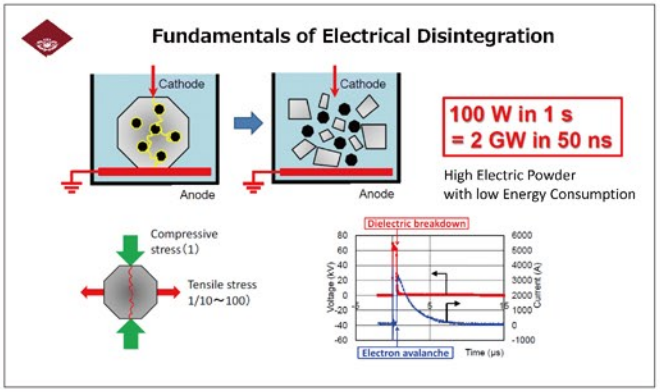


This is our target, our image for the new recycling loop. This slide shows the current situation for a recycling loop, especially for metal. This is like a long way circulation, a very big loop. But this loop tends to break due to a low economic value.

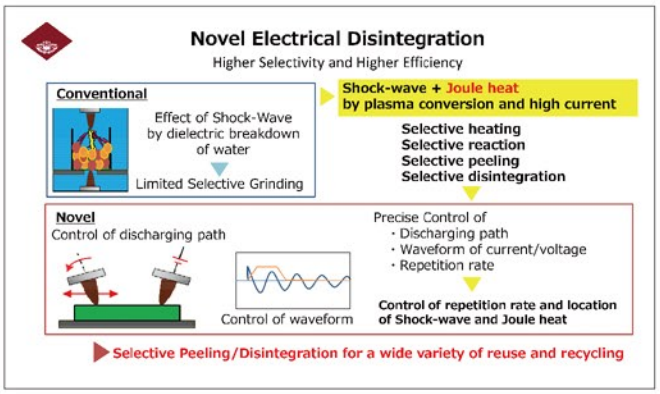
For example, natural resources used for elements or parts. After they are used and spent, recovery is necessary and followed by the shredding or physical separation. Most of it has no economic value to make it worth proceeding to high-load chemical treatment. Therefore most of it is disposed of, unfortunately. A part of higher-economic value metals can go to the high-load chemical treatment, and they are going to the general materials, and they are recycled to high purity metals, like this. But most of them, for example plastic, glass or other low economic value metals cannot go to this kind of high-load chemical treatment.



We need a much shorter route inside like this. At first, we need product reuse. We should promote a shorter reuse loop like this. Also, we need some novel technology for dismantling. We need a shorter circuit to use elements or parts. Of course, this novel dismantling is very useful for energy-saving following chemical treatment.

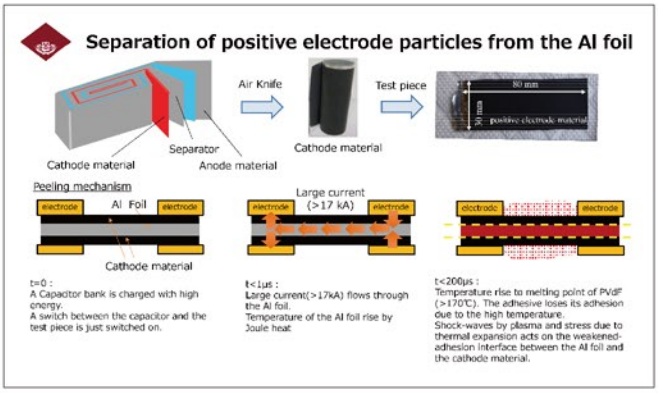


In this project, to create this novel technology, our target is electrical disintegration. Actually, electrical disintegration is not so novel. We already have some commercialized instruments for mass processing, grinding, or comminution. With this electrical disintegration, we can get a very high big electric power with low energy consumption because we use electric power in very, very short time, nanoseconds or microseconds. We can create very high electric power with low energy consumption.

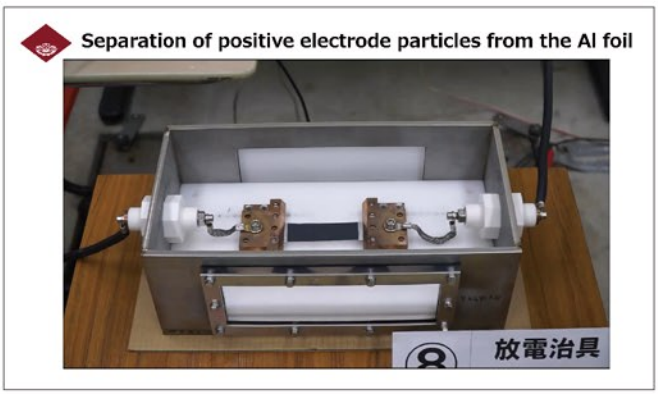


We modified this conventional electrical disintegration to a novel one. Our concept is to control the discharging path or waveform of current, voltage, or repetition rate, so we can control the discharging path and we can conduct more selective heating, selective reaction, selective peeling, or selective disintegration.

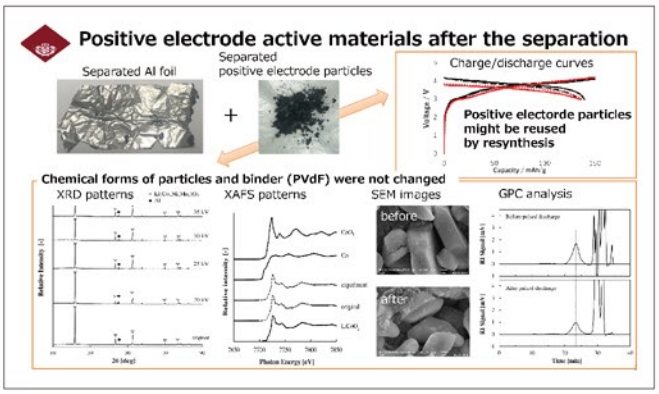
One of the examples of this technology is LiB (lithium-ion battery). We adapt this kind of novel electrical disintegration to the separation of positive electrode particles from the aluminum foil in LiB. As you know, we need more high-efficiency recycling technology for LiB because the spent LiB generation will be increased in the near future. This is positive electrode material, and positive electrode particles stick on the surface of aluminum foil.



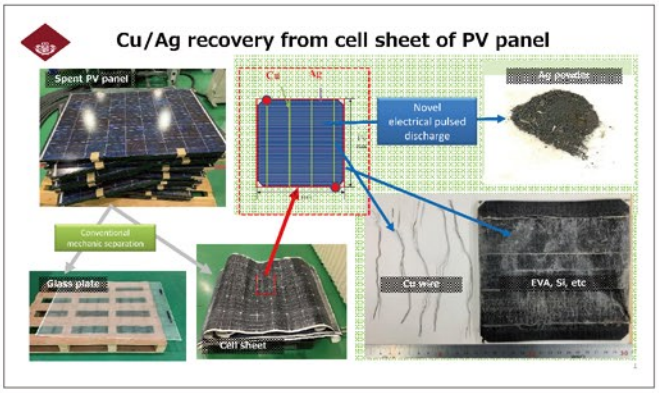
Our objective is to separate this aluminum foil and positive electrode particles like this. If we put the electrical disintegration, electrical pulse on the positive electrode material, a large current will flow through the aluminum foil and the temperature of the aluminum foil will rise by Joule heat. Then, this temperature rises to the melting point of PVdF. PVdF is an adhesive between the aluminum foil and the positive electrode material. This adhesive loses its adhesion due to the high temperature. Also, we can get some shockwaves by plasma generation of aluminum. These positive electrode particles will be separated, liberated from this aluminum foil.



We have a movie. Unfortunately, this is in Japanese. This one is the positive electrode. This one is the electrode of the electric pulse. This is in the air. In the conventional method, we need water. But this experiment can be adapted for the air. In just one shot of electrical pulse, we can separate between aluminum foil and positive electrode particles. Positive electrode particles are black, so we call this black powder. It's very difficult by mechanical grinding to separate this kind of foil, that is, separate foil and particles. But this electrical pulse achieves a very sharp separation between the aluminum foil and the particles.

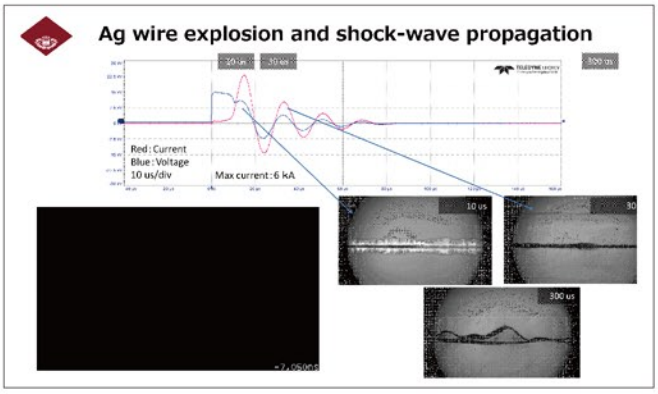


After that, we evaluate the chemical form of the separated black powder, positive electrode materials. Then, we confirm that it has not changed the chemical form or chemical composition. We hope we can create a new recycling loop by this dismantling of technologies. In concrete, we hope this can be used directly for LiB production.

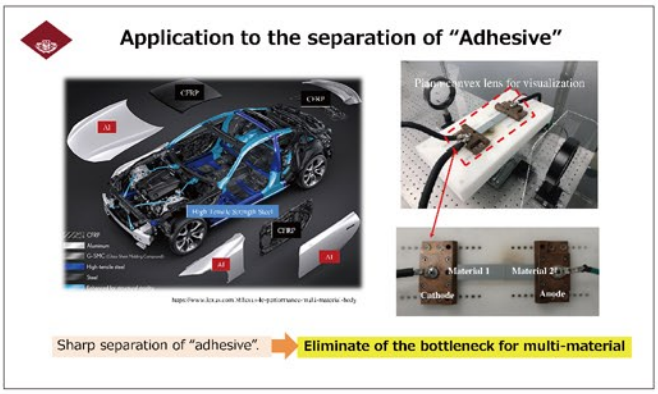


We also adapted this new technology to the recycling of PV (photovoltaic) panels. PV panels are also very important for smart energy and carbon neutrality. The PV panel has a large amount of glass, so firstly we separate the glass. Then, we reuse or recycle this material as a glass. But the cell sheet

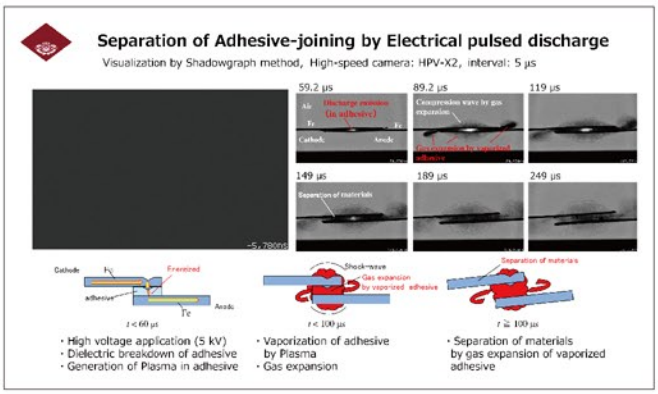
remains. The cell sheet contains lots of resins and copper wires and sliver wire. We need to separate them. We should separate copper and silver wires from the inside of the resins. Conventionally, this one is going through a heating system. After heating, this resin is changed to CO_2 and then we recover the metals from the remaining. But when we use electrical disintegration, we can separate just copper and silver wires like this. We also can recycle/reuse the resins.



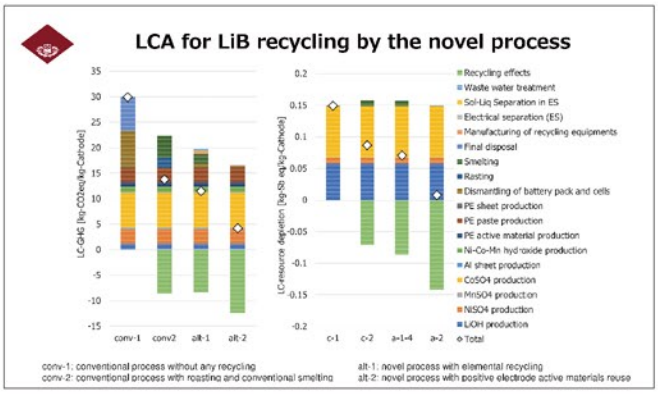
This one is a movie about the silver wire explosion and shockwave propagation by electrical disintegration. When we input the electrical pulse in the silver wire, the silver wire explosion and the shockwave propagation occurred like this. We can separate both the copper wire and the silver wire from the resin.



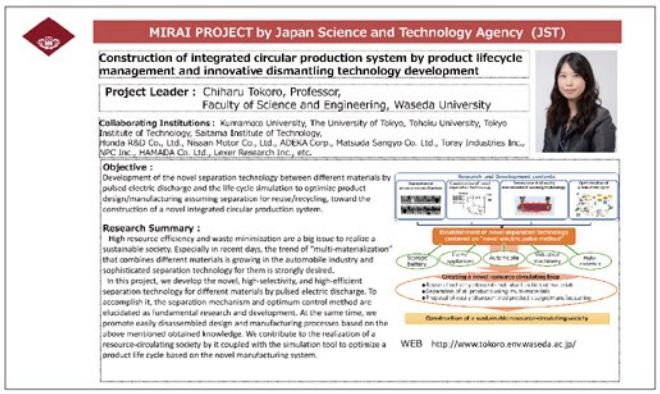
We also tried to apply this novel technology to separate adhesive joining. As you know, nowadays automobiles or other products have used more and more multi-materials using adhesive agents. We wanted to try to sharply separate themulti-materials with adhesive using this electrical disintegration.



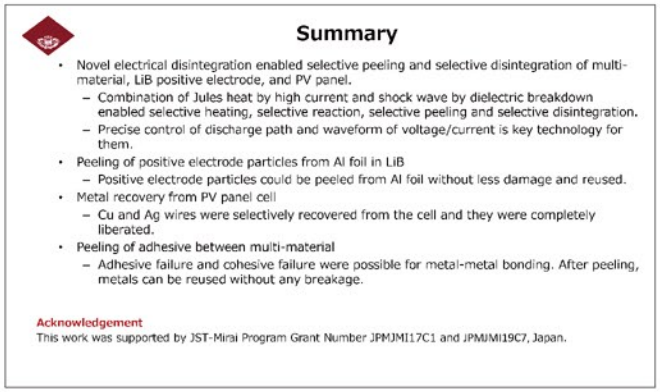
This is one of the examples. When we bring the electrical pulse discharge, in the adhesive, the dielectric breakdown occurred. Joule heating by large current also occurs. Vaporization of adhesive by Joule heating occurred and separated these two kinds of materials by the gas expansion of vaporized adhesive. This is a very, very sharp separation. We hope we can reuse these two materials after separation.



Then, as I explained at first, this is a very low energy technology. This is one of the examples of LCA (life-cycle assessment) for LiB recycling by the novel processes. Here, this graph is a conventional process without any recycling. This one is the conventional recycling system. These two are by novel processes. We can realize the low energy separation by these novel processes compared to the conventional one. Of course, we can realize the low environmental impact of resources depletion like this.



Now, we are conducting this kind of project with many other members. Not only from Waseda University but also Kumamoto University, the University of Tokyo, Tohoku University, Tokyo Institute of Technology and Saitama Institute of Technology joined to create this kind of novel separation technology. Also, many private companies joined in this: Honda, Nissan, ADEKA, Matsuda Sangyo, Toray, HAMADA, NPC and Lexer. I hope that we can create a new reuse and recycling loop by this kind of novel separation.



This is the summary. I introduced today the novel electrical disintegration technology using electrical pulse. This enabled the selective disintegration of multi-materials with adhesive in LiB positive electrodes and PV panels. The mechanism is a combination of Joule heat by high current and shockwave generation by dielectric breakdown. This has very high selectivity. Mechanical grinding and dismantling is not able to get this kind of higher selective separation but novel electric disintegration enabled it. From this technology, we hope more and more metals can be recovered and also glass or resin can be also recovered.

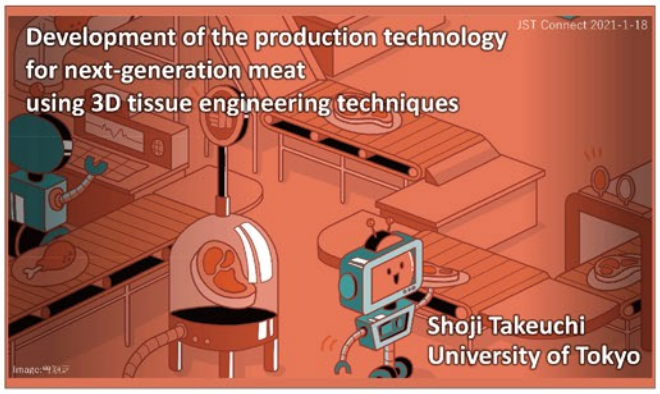
Thank you very much.

Presentation 3

Development of the production technology for next-generation meat using 3D tissue engineering techniques

TAKEUCHI Shoji

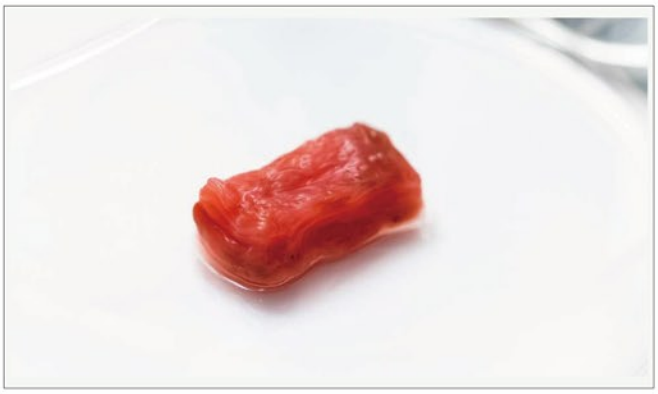
Professor, Graduate School of Information Science and Technology, The University of Tokyo



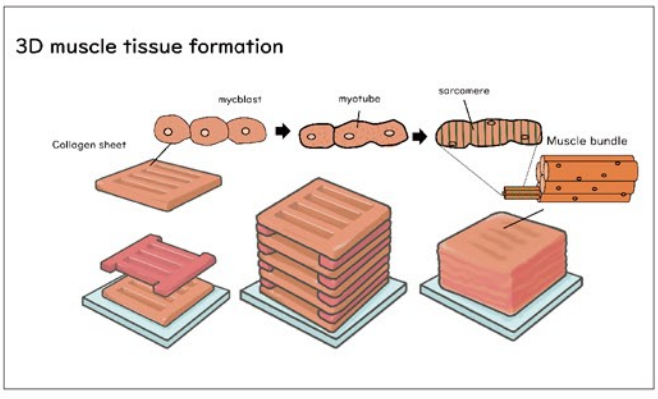
Good evening and good morning, everyone. I am Shoji Takeuchi from the University of Tokyo. Today, I would like to talk about what we are now doing under the JST-Mirai Project regarding next-generation meat.

This cartoon shows one goal of the research. We would like to make a factory or fabrication process to make meat without killing the animals, but with a very ecofriendly process.

What happens in this project?



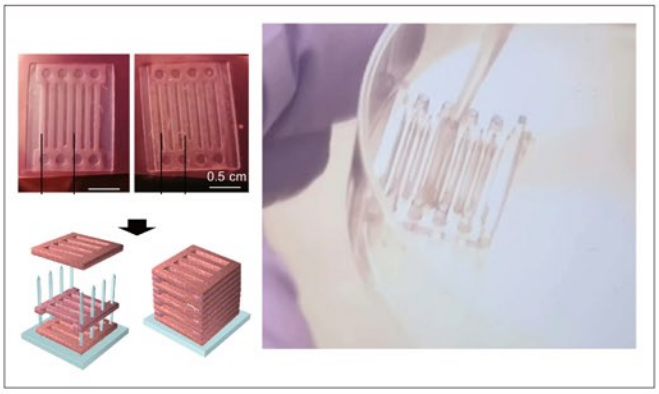
This is the world's first cultured steak, which is very small but made by bovine cells. We do not kill the animals, but can actually develop the meat by using the cells coming from the cow. The texture is very much like meat.



How do we make this?

We get cells from the cow, and then culture it in a special culture medium. On the first day, the number of cells is very small. But after 2 weeks, the cells grow and migrate. After that, we put the cells in a special template, like this with collagen

hydrogels, so that we can make sheet-type tissues by using the template.



In the template there are some slits so that the cells can align in a single direction. Aligning the muscle fibers in a single direction is very important to make a steak. After making the sheet of cells, we can actually stack the sheet into the Z direction so that we can make a very thick meat within a short time. I mean, it takes about 1 week after stacking the sheet. We can actually align most of the muscle fibers in a single direction.

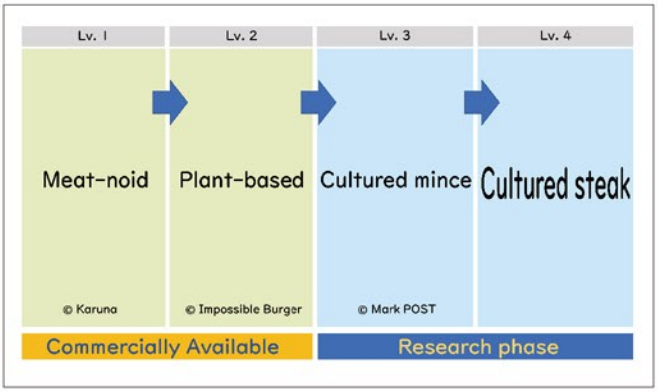
After taking the meat from the culture media and putting in red food dye, it looks like meat. This is what we are now doing.

Why are we doing this now?

As you may know, maybe after 30 years, the world population will increase and reach about 10 billion people. If most of the people eat meat, we cannot supply enough meat to everybody. Of course, increasing the number of livestock is one choice, but livestock create greenhouse gas emissions and environmental problems. Also, the production of meat in this way is not so efficient. For example, if you want to get 1kg of meat, you actually need 20,000L of water and 25kg of food to feed the cows. So the meat production process is not so efficient or ecofriendly.

There are lots of movements, especially in Europe and the United States, to eat alternative meat without killing the animals. For example, in New York, foie gras will be banned in the next 2 years, maybe next year. Also, the University of London has banned beef to help fight climate change.

Vegetarianism and veganism are now very popular worldwide.



Thinking about the alternative meats, there are several kinds of levels. I can actually categorize them into three.

The first level, level one, we call meat-noid. Meat-noid looks like a meat but it is not a meat. It is basically coming from soybeans or tofu. This kind of meat-noid is very familiar for Japanese, because in Kyoto there are Buddhist monks that have eaten it for hundreds of years. That means meat-noids are already commercially available.

Level two is also a plant-based meat but it looks like a real hamburger. If you are coming from the US or maybe Europe, it is already very familiar and very popular, the plant-based burger. But the taste is very, very similar to an actual burger because sometimes they actually use gene-manipulated soybeans to mimic the real taste. But if you like the natural taste or natural meat, the only other choice is to culture the cells and grow the cells into the meat which we call cultured meat, which is the current level, level three.

This concept has just started. It is still in the research phase, not in the commercially available stage, but is nowadays very popular worldwide.

Professor Mark Post is the first guy who first produced a cultured meat burger in 2013. They actually eat it. They say that it looks like beef. The texture looks like beef but the taste is not like beef, because they do not include any fat. At that time, the cost was very, very high. But recently Professor Mark Post actually made a startup company called Mosa Meat and said that in two years he will sell a cultured meat burger priced around $12. The cost issue might be solved very soon.

Now, how to make a burger?

They actually take a piece of meat from the beef, without killing the cow, and get 5-gram tissue of the muscles, by using a biopsy method. If you take a close look at the muscles, you can actually see the muscle fibers. The muscle fiber itself cannot proliferate, so you cannot expand the number of muscle fibers, but you can actually expand the satellite cells that exist around the muscle fibers.

We can actually take the satellite cells and grow and expand the number of cells, and then try to differentiate this kind of satellite cells into the muscle fibers and then make hamburgers.

This kind of technology is nowadays very popular, even if it is the research-phase. There are many universities in Europe and the US and also many startup companies have started to develop cultured meat as a future alternative meat.

What is next?

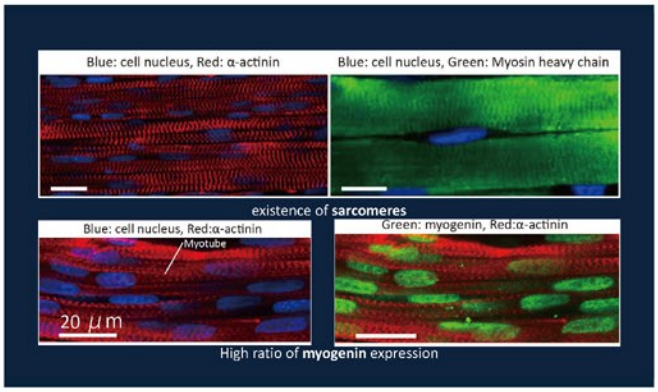
We need to think about next-generation meat, so we need to develop our research field much more. As you may know, cultured meat looks like a hamburger. Nowadays, most people are studying cultured mince. We believe the next generation should be cultured steak. Because once you make a steak, you can actually make a hamburger as well. The steak itself has really good cost performance.

In March 2019, we developed the world's first cultured steak. We actually collaborated with Nissin. It is a very big food company, known around the world for their Cup Noodles. We developed a method to form the 3D tissue by using our bottom-up tissue engineering method.

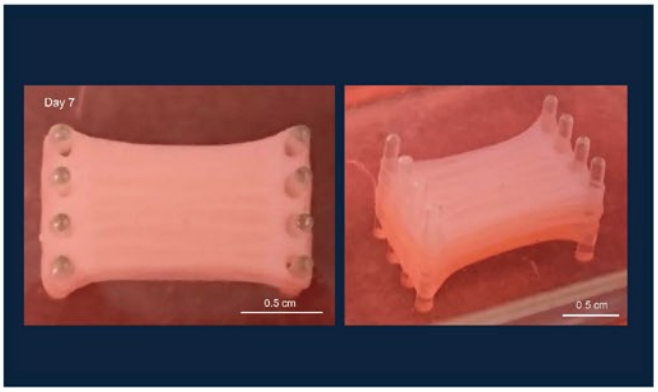
Nowadays, our cultured steak looks much more like steak, because we developed a steak like this and put red coloring in. But remember, most of the muscle fibers are aligned in a single direction. This is a very important technology we developed.

How did we make it?

We actually used a bottom-up tissue engineering method which is very state-of-the-art to form the 3D tissues. We made a sheet-type building block and put the muscle cells in the sheet. Since the sheet has a very small stripe, like this line, the cells can actually fuse to each other and make muscle fibers. But the muscle fibers automatically align in a single direction, which is a very important process.



To make thick tissues, we stuck the sheet into the Z direction and then cultured it for about maybe 1 or 2 weeks so that we can make a single unit of the meat. During the cultivation, the muscle fibers become mature, I mean they are differentiated, and make sarcomere patterns which is the strip morphology very unique for the muscle tissues. If you want to make muscles, you need to have sarcomere patterns.



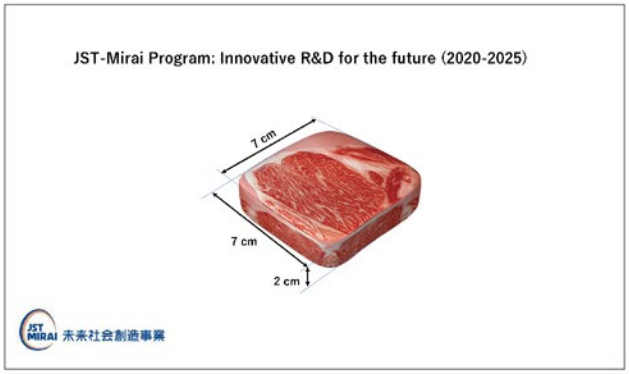
This is the actual photo, and this is the muscle sheet we developed. This is a single sheet. And after stacking the sheets one by one, we stacked over 30 sheets within two hours. This is still a handmade process but we want to apply 3D bioprinting in the near future.

Muscles have biological functions, like contractions. Our developed muscles must also have such biofunctions. When we apply voltage between the two edges of the muscles they contract automatically, like this, which is very important to say that we actually developed muscle tissues.

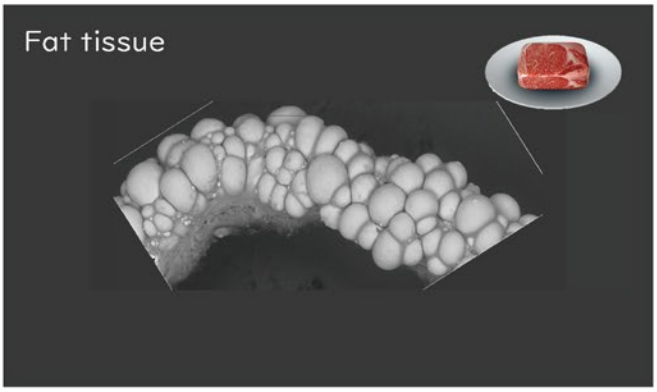
Morphological analysis is also very important. As I mentioned, muscle has to have sarcomere patterns. We can get a very beautiful sarcomere pattern in the 3D tissues. We can also get myogenin which is the representative protein coming from the muscles.

Using primary beef cells, we can actually get 1-centimeter cube steak. As I mentioned before, the muscle fibers are aligned in this direction which is very important for making a steak.

But again, the size of the meat is very small right now. It does not look like a normal steak. But we believe this technology can be scaled up within a short time, within this program.



In our JST-Mirai Program, which is a 5-year project from last year, within 5 years we developed 7cm x 7cm x 2cm which corresponds to 100 grams of the steak. This meat has single aligned muscle fibers and fat cells in the muscles. The fat cells are also very important to mimic the taste of steak.



That is why we also focused on making fat cells. These are the 3D fat cells we developed. All the oil droplets can be found in the fat cells. We tried to develop fat tissues and combine to the muscle tissues so that we can get a very tasty, cultured steak in the near future.

There are several issues that still remain with cultured meat. We actually categorized the issues into three groups.

One is the technology, of course. We need to develop three-dimensional tissues that taste like a steak and look like a steak.

The second issue is people's attitudes. Even if we develop very nice meat, if no one wants to eat it, it is worthless. Thus we need to improve the public acceptance of cultured meat, especially in Japan. To encourage people to eat cultured meat, we made a lot of booklets about cultured meats. Also, we

organized a symposium to make conversation with the general public.

The third issue is regulations. These are very important to ensure the safety of the meat for sale. That is why we have had a lot of conversations with the government so far.

Regarding social acceptance of cultured meat, knowing the level of public interest is also very important for our research. That is why in our team we have a professor from the University of Hirosaki with a social sciences background. Two years ago we surveyed 2,000 respondents regarding the public acceptance of cultured meat.

The good thing is that we can get a lot of the data and information about the negative ideas people have about cultured meat. Also, what they care about and so on. Such information is very important to develop actual meat that can be accepted by the general public. I think this kind of survey is very important not only for the advancement of science and technology, but also for the development of a new food culture.

To summarize my talk, we are now making cultured steak for the future society. Cultured meat production will have a huge impact on the environment; helping to solve issues like global warming, climate change and so on. We can help promote well-being and inclusiveness, just by eating cultured steak.

This is a team of the cultured steak. This is me, as a PI. We collaborated with a very famous tissue engineer, Shimizu Tatsuya-sensei at Tokyo Women's Medical University. Also, Ishikawa Hiroshi-sensei, he is from the Tsukuba University Medical School. There are other members famous as tissue engineers like Professor Sakaguchi and Professor Matsusaki, and the people coming from Nissin who want to sell the cultured meat in the near future. Lastly, I would like to show Professor Hibino. She is from the Social Sciences. I believe this team will improve the world by producing cultured meat.

With that, I would like to thank all the group members, and especially Ms. Mai Furuhashi. She comes from Nissin and is developing the cultured steak, the world's first cultured steak.

Thank you very much for your attention.

MC

Let me start from the top for Takeuchi-sensei. First off, what are the perceived disadvantages of cultured beef to human health?

Prof. Takeuchi

That is a good question. But we cannot say or we do not have an exact answer yet. We need to study the effect of the cultured meat to the human health. But we believe that all the materials we actually use are coming from the food, for example cells, growth media, proteins, amino acids and so on. All the materials are actually edible already just as it is. We believe that there is no such significant disadvantage for the human health.

MC

Okay. Thank you very much. Perhaps, if I can quickly follow up with that, it has been in the news already for quite some time this type of new meat. You mentioned Mark Post in your presentation. Are couple of them have already been commercialized and are already on the market?

Prof. Takeuchi

No, not yet.

All are still in research phase. Professor Mark Post said within 1 or 2 years, they want to sell the cultured beef, cultured burger, and it will cost about $12, I think so.

MC

$12, that sounds reasonable. I wonder though you have a lot of different technologies and you showed the videos about how to create the exact kind of muscle fibers. Is there a difference related to this health issue depending on how you exactly are going to create the fake meat.

Prof. Takeuchi

Our originality of the fabrication process against the other types of technologies, as I said, most of the cultured meat research in the world is focused on making the hamburger. You do not have to align the muscle fibers. Muscle fiber can be randomly aligned, but you can just make the muscle cells within the small packages. But if you think about making the steak, the steak looks like our muscles, and all our muscles have the aligned muscle fibers. To make such kind of aligned muscle fibers, it is very difficult to use the current technology. That is why we developed the new tissue engineering approach to align all the muscle fibers into the single direction.

MC

Thank you very much. To continue this topic, a lot of the resources go into beef production which is very attacking on the environment. There is a lot of downside to that. Another question we received was that it was mentioned earlier that raising beef is very costly and poses risk to the environment. Is it not that the production materials for cultured meat also poses risk to the environment in terms of waste disposal?

Prof. Takeuchi

That is a good question. No one can say the exact answer because we do not still yet. But we believe the current meat production using the livestock, they actually use the huge land and also the huge amount of water. But we can exactly decrease the size of the land and the amount of the water. That might be true. But if you say something about the cost, I cannot say the exact answer, because we do not know what kind of the material is actually needed for making the cultured meat. Of course, we are now selling the food, so we need to get very cheap materials, otherwise no one can eat it.

MC

Fair point! Thank you very much. I see we have a couple of more questions coming up. Perhaps, one quick one and then, we move to questions for the other professors as well. The kind of methodology that you thought for the muscle creation, can that

be repurposed for medical objectives as well?

Prof. Takeuchi

I actually wanted to start the cultured meat over 10 years ago maybe. No foundations existed at that time. That is why I tried to make muscle cells for the medical purpose. For example, if you make small muscle tissues, you can actually use such kind of muscle for the drug-testing materials. You can put the drugs and you can actually see how the muscles contract. You can understand how the drug affects the tissues and so on. Those kinds of the technology might be also used for the drug development and medical use and so on.

MC

Okay. Thank you very much. Let me now open the questions as well towards the other professors. I see we have some more questions for you. Do not worry, the other questions we receive, we will try to respond to them as well. But let me go back to the first presentation that we received from Nishinari-sensei. There is separately a question I received regarding how accurately, exactly you can simulate these crowds with the computer, and then, specifically the question goes towards, as it is important to know your crowd, does this kind of behavior change depend a lot on the country? Is actually culture a big factor in this simulation?

Prof. Nishinari

You are right that it is not easy to simulate the crowd like a Newton particle, because we are human beings and have a psychological effect, which we cannot simulate. But if the density becomes high, then our choice may be restricted just to stay aside and so on. Then, we can simulate the motion of the crowd.

The culture difference is very, very interesting. I have been collaborating with German researchers or India, China, or Italy for more than 20 years and comparing our results with the others and published papers together. At least, the critical density beyond which we have a jam is the same. It is very interesting. But, of course, the details are different, but critical density is almost the same.

That is why we have a regulation of level of service in a worldwide way.

MC

Okay. Thank you very much. Let me then look at the questions right now. Perhaps, let me go over to a question to Tokoro-sensei. First off, I would like to ask you this kind of technology sounds great, to be able to use this kind of electrical methodology. How exactly can you automate this on a large scale to recycle resources?

Prof. Tokoro

Okay. It is beyond my project, but of course, the automatic instrument is a very important thing. We need a collaboration with robotics because the electrodes will be just like a hand of robotics, so if we collaborate with the robotics, we can create some automation of this technology for each material.

MC

Okay. Thank you very much. I see we also have a follow-up question on your presentation. What is the rate of raw material recovery in recycling to novel dismantling as described today?

Prof. Tokoro

Actually, our separation is very sharp, so recovery is almost over 100%, over 90%. Of course, this separation is very novel and very sharp. We can recover completely. Over 90% of raw materials can be separated.

MC

Okay. That sounds very promising. Actually, perhaps opening it up and perhaps to all the professors here today. These are all extremely interesting technologies, methodologies. How do you see collaborative research with overseas researchers? To what extent are you doing that? And what kind of merits do you get from the international collaboration? Of course, how do you find your partners? Perhaps, we can go in order. First, I would like to ask Nishinari-sensei.

Prof. Nishinari

I have already partly answered, but we have been collaborating with many other researchers in different countries. We come to know together at many conferences that the issues they have and we have are almost the same. Because we have an aging society, and also, Germany and Italy are suffering from such problem. And what we should do next? We are discussing for more than 20 years, and we have a common fund for solving that. We keep collaborating with each other. We have many hints from each other, so it is a very, very interesting collaboration.

MC

Great! Nice to hear. Tokoro-sensei.

Prof. Tokoro

Actually, not yet. Actually for the conventional electrical disintegration, we collaborate with the European companies for the recovery of concrete or some recycling residue. But this time, this one is a very novel one. We have not yet collaborated with anyone from abroad. There is no limitation for the collaboration with abroad. If we can collaborate worldwide, we can get more and more information, because the current situation necessary for the raw material recycling is different in each country. We can get more information, if we can collaborate with any other abroad universities or companies.

MC

Great! In that case, are there any kinds of stumbling blocks that you see at the moment, why you are not yet doing this type of international collaboration?

Prof. Tokoro

Because it is novel, so there is no occasion to appeal for this kind of technologies, not yet.

MC

Okay. Thank you very much. Then, if I may move to Takeuchi-sensei.

Prof. Takeuchi

Regarding our international collaborations, if you say specifically about this project, I do not have an international collaboration yet, but I have a lot of friends regarding the cultured meat worldwide, like Mark Post who actually developed the first cultured meat burger. We often have the mutual communications discussing the progress of the cultured meat. These are the good things because when you think about the regulations, we tend to focus on the domestic regulations but if you watch the regulation worldwide, it is much better to make general regulations in the world.

If you think about the other topic, not only for the cultured meat, but also other research themes. I am coming from microengineering research, and I have a lot of collaborators, especially in France, the US, and many European countries. Those kinds of networks work very well when we have the human resource problems or the ideas to solve specific problems and so on. The global network is very important. That could be done before the COVID-19, but nowadays, it is very hard to physically communicate with each other. Zoom might work well, but it does not let us shake hands or drink together or do other things like that. Maybe after COVID-19, we will restart again.

MC

Definitely! Thank you very much for your answer. Takeuchi-san, actually I want to add one more question specifically for the cell sheets engineering methods, which is rather tedious and time-consuming, and according to this person, not really suitable for mass commodity. Are you evaluating other processing methods that may allow direct 3D cultures of the cells?

Prof. Takeuchi

Of course, for industrialization of the cultured meat, we need to think about the mass production of the cultured meat, of course. I still believe that our sheet stacking process is not so bad because we can apply the bioprinting method or other type of the robotic manipulation technologies. But at

the same time, we developed another type of technology as well. For example, we have more than 20 graduate students and undergraduates, they are always having a new idea to develop the cultured meat in their university. I hope that in the next few years, maybe we can develop another type of technology as well.

MC

Okay, thank you. I see actually one more question for you related to regulation. I guess consumers will know if they are already eating cultured meat, beef, especially that all ready-to-eat foods do not indicate if the beef patties comes from cultured beef or pure beef, from naturally-raised beef. To give consumers the choices, what can you do to ensure that consumers will be aware if they are about to buy and consume cultured beef?

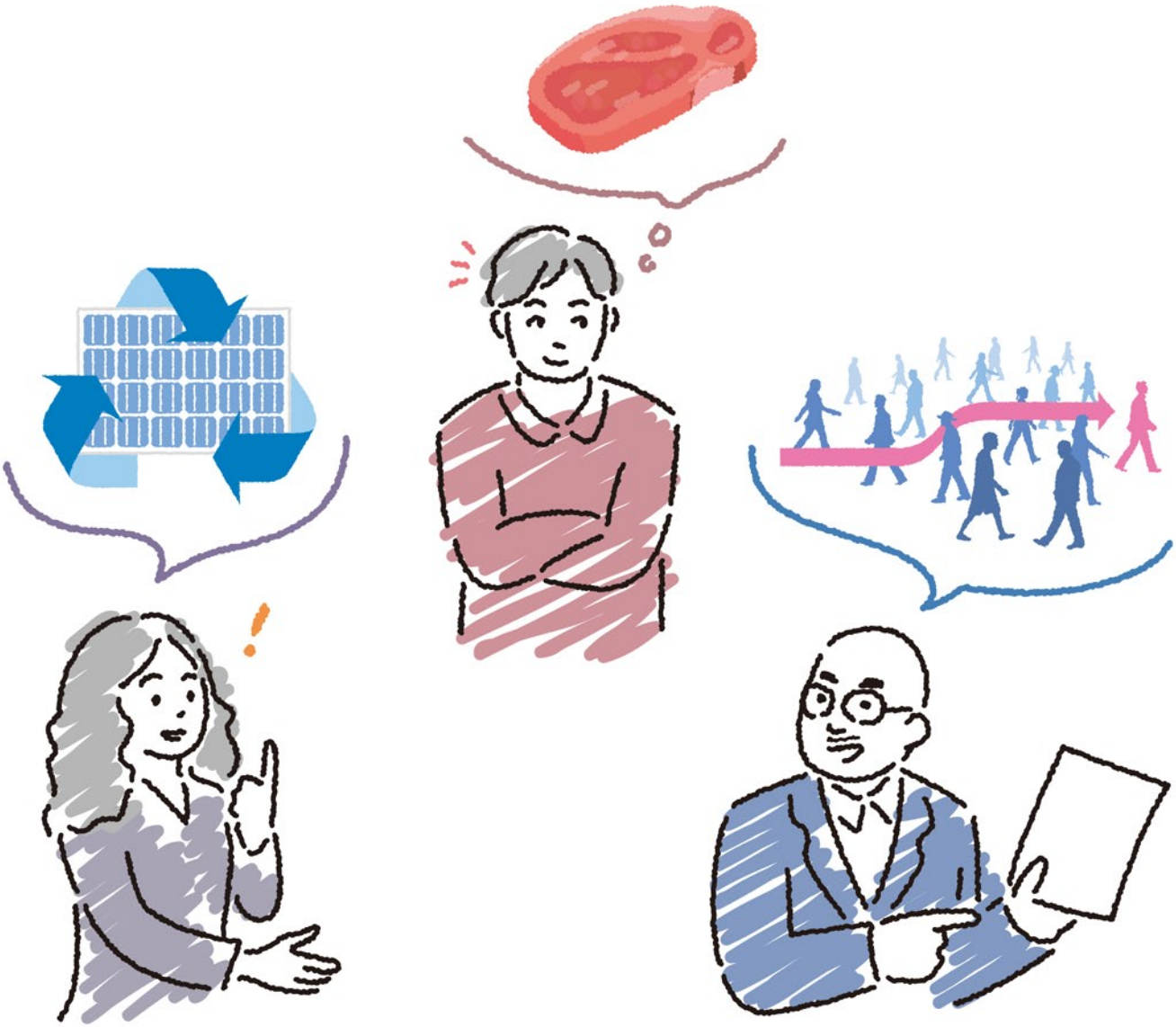
Prof. Takeuchi

That is an issue of the regulations. We are now thinking to put the cultured beef or cultured meat onto the exact beef packing. Of course, as he or she said, there is no regulation so far to put the real word to the cultured meat. That is why I think the regulation must be needed to organize such kind of issues.

MC

Thank you very much.

Let me thank all of you again for responding to the questions.



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