Session 1: Effective Utilization of Natural Energy

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Ishitani: Speaking earlier about realizing a low-carbon society, the National Institute for Environmental Studies (NIES) suggested an ambitious carbon reduction of 70–75 percent. Because nuclear power and natural energy are Japan's only energy sources, this is where our attention must be directed, but nuclear power is not an amenable issue for discussion in this kind of setting. Turning to natural energy, then, solar looks like the most feasible option given the right innovation policies. Biofuels too are comparatively straightforward in a technological sense, but it will be critically important to address the fundamental issue of potential, which is currently lacking. Today, therefore, I'd like to focus discussion on these two areas.

Overview of Renewable Energy Programme in Europe

Thomas B. Johansson
Energy is a major source of concern in Europe, and is much discussed from the perspective of energy security. Climate change too is obviously a key issue, and particularly with many manufacturing jobs shifting east, innovation is being foregrounded as a way of maintaining the competitiveness of the European economy and promoting employment.

Renewable energy is seen as one means of reaching targets in this area. Population growth, economic growth, and rising energy demand are driving the world forward, but these same factors have also made prospects more complex. There is also the possibility of oil production peaking out, and this needs to be addressed in tandem with the increase in oil demand.

Turning to climate change, the Intergovernmental Panel on Climate Change (IPCC) reports indicate the extent to which carbon dioxide (CO_2) emissions would need to be reduced on a global scale in order to keep the rise in global temperature at less than two degrees. This two-degree target has been set by the European Union (EU), and is not the subject of international consensus. However, much of Europe has taken to heart the serious impact predicted in numerous areas, including ecosystems, water supply, health, and food production, even at a rise of two degrees.

CO_2 emissions will need to be slashed to below zero on a global scale by the end of this century, which will mean accelerating the reduction of emissions levels in Europe, Japan, and other parts of the developed world to zero or below by 2040–2050. This will be an even greater challenge than is generally recognized either internationally or among the developed countries.

In March 2007, the EU reached agreement on an approach to the above, and around two months ago produced a more detailed plan as to how to reduce greenhouse gas emissions by at least 20 percent by 2020. If other countries too adopt these ambitious reduction goals and strategies, we intend elevating that reduction to 30 percent. Europe also needs to improve its renewable energy consumption from the current 8 percent to 20 percent.

These broad goals were presented as a legislative package in January this year by the European Commission for consideration by the European Parliament and the European Council. The package addresses emissions trading, and also proposes quotas to be shouldered as part of the agreed initiatives. It contains detailed provisions on renewable energy, as well as proposals on carbon capture and storage.

In implementing the renewable energy program, we have set the goal of raising renewable energy consumption to 20 percent of final energy consumption. This will require all EU members to exploit their own potential, as well as all renewable energy-related technologies. There is also a new directive on using renewable energy for heating and cooling. Solar and wind power generation are currently the two major sources of renewable energy in Europe, recording impressive double-figure growth.

To get to this stage, the EU has focused primarily on deploying policy instruments rather than developing technology on the grounds that the purpose of policy is to support powerful action and promotion efforts. Support systems include tax incentives, national trade quota systems, and feed-in tariff systems. Of these, feed-in tariff systems have been the most effective in maximizing renewable energy penetration.

What are the economic aspects of the issue? Some people have observed that feed-in tariff systems become extremely expensive, but the European Commission data suggests that certification systems are in fact more expensive. More renewable electricity can be purchased per euro via feed-in tariff systems than through certification systems. The money paid out under feed-in tariff systems is recovered by selling electricity, with these funds used to cover costs associated with power generation facilities. This is certainly a point worth noting, but it doesn't mean that overall costs become particularly high.

Another major area is progress with energy research. The European Commission has adopted a proposal for a European Strategic Energy Technology Plan, which is designed to boost production capacity through technology development, providing the necessary new technologies. Currently, Europe is not putting much money into this area. The Commission wants to increase research and get more funds into technology development.

The European Strategic Energy Technology Plan envisages European industry working with the public sector to promote energy research partnerships, engineering a transition to systems that provide greater support for sustainable development, including energy infrastructure, networks, and systems. Boosting energy efficiency is of course the highest priority, and this is an area where major progress can be made toward improving energy systems.

Europe's energy supply network is still under development, and our ultimate goal is to create a single market for not only electricity but also gas. In terms of operating such a large-scale grid, energy storage will become a key issue as more and more small-scale local wind and solar power generation facilities pop up around Europe in the years ahead. The plan also incorporates targets for second-generation biofuels, with the 20 percent target by 2020 for renewable energy including a 10 percent biofuel obligation.

I am currently involved in the Global Energy Assessment (GEA) project launched by the International Institute for Applied Systems Analysis (IIASA), which is located in the suburbs of Vienna. Japan too is a member of this project. The goal of the project is to find a way forward that addresses simultaneously all the problems currently confronting us as a result of the huge changes occurring in world energy systems. A paradigm shift is needed to realize a major improvement in the efficiency of final energy consumption and further increases in renewable energy.

The serious energy problems we face require a comprehensive and integrated approach. The first step in this regard is assessment, with the project aiming to develop a scientifically-based, comprehensive, integrated, and policy-relevant analysis that addresses all the above concerns and issues related to technology assessment. However, as the project develops, it is likely to move into strategic policy and investment analysis that draws on both global and local perspectives. It is also the only study that we know of that provides a timely, simultaneous, and comprehensive analysis of recent and emerging global challenges.

The GEA will produce four "knowledge clusters," comprising an initial assessment of the issues and determination of the key features; studies on technological options and resources; systems-level analysis; and the creation of scenarios toward the identification of energy systems that can meet energy challenges. This work will be grounded in the experience that the IIASA has developed in creating energy scenarios, which includes the realistic scenario it developed with the World Energy Council about 10 years ago. Policy issues too will of course be addressed. In other words, the aim will be to consider policies at the national, regional, and international levels toward realizing various types of energy systems that are optimal from a global perspective.

We will probably also follow the IPCC in producing major reports. However, we will additionally create shorter reports on intergovernmental processes and interesting fora where broad-ranging discussion is being conducted at the local level and among concerned parties. As this work proceeds, we should become able to boost the relevance and appropriateness of that information so as to meet the needs of policy- and decision-makers in both the public and private sectors. We hope to continue with these programs and widen the scope of the project still further. The aim is to conclude the project by fall 2010 and release the results by spring 2011.

Present Status and Future Prospects of Photovoltaics—Toward 2050

Makoto Konagai

A look at solar cell production by country reveals that production has soared in Japan and Europe, but it should be remembered that the range of materials used in solar cells is extremely broad. Currently, production is dominated by bulk silicon, namely single crystal silicon and cast silicon solar cells. Some ribbon silicon solar cells are being produced, but the most likely prospects for the years ahead will be thin-film silicon and other thin-film solar cells such as copper indium gallium selenide (CIGS) and cadmium telluride (CdTe) cells. In 2006, solar cell production stood at 2.5 GW, but this will have to be boosted by 10 to 100 times in the years ahead.

In Japan, a subsidy program launched in 1994 prompted steady growth in the number of residential photovoltaic (PV) system applicants, with more than 50,000 applications received in 2004 before the project closed in 2005. A glance at cumulative PV volume by country, however, shows Germany achieving an exponential rise to top Japan in 2006. At an international workshop last week, Dr. Arnulf Jäger-Waldau from the European Commission presented a chart that he'd created, which forecast PV production volume for the next three or four years. According to his chart, where world production was around 5 GW in 2006, a production capacity of 30 GW will have been developed by 2011. Japan will have a 4 GW capacity by that stage, but Europe's will be around double that, with countries like China and Taiwan also expected to boost their production capacity significantly. Where bulk silicon currently accounts for more than 90 percent of PV material, thin-film PV production will have shot up by 2011. Silicon research is the most advanced in the thin-film PV field, but the CdTe PVs developed by U.S. firms are currently displaying tremendous growth. Other types include CIGS, dye-sensitized, and organic PVs.

The official target put out by the Japanese government is to achieve a 4.82 GW installed capacity by 2010 with a generation cost of 23 yen/kWh. Given current installed capacity, we can probably achieve that target by 2011. Looking further ahead, Japan wants to boost that capacity to 100 GW by 2030, but this will mean bringing the kWh cost down to around seven yen.

Conversion efficiency is the critical parameter in reducing the kWh cost, but other important factors are cost-cutting and durability. In discussion of the PV Roadmap toward 2030 (PV 2030), the aim was a product life of around 30 years, but Dr. Yukinori Kuwano was very insistent that this be increased to 50 years. For those of us in academia, that level of conversion efficiency would seem extremely difficult to achieve, and we're looking ahead to some major challenges. A number of breakthroughs will be vital in the years ahead, or, in other words, that magic "innovation."

There is also the Cool Earth 50 initiative, which aims to halve CO2 levels by 2050. An energy conversion efficiency of 20–25 percent would still leave solar cells as a poor energy source, so Cool Earth 50 aims to lift that efficiency to 40 percent.

In terms of current energy conversion efficiency, the highest level we've achieved with silicon is 24.7 percent. Multicrystalline silicon cells have reached 20 percent, gallium arsenide (GaAs) 25 percent, copper indium gallium selenide (CIGS) 18 percent, thin-film silicon around 10 percent, organic dye-sensitized 10 percent, and dual- and triple-junction compound semiconductor cells of the III-V groups more than 30 percent.

However, silicon presents a clear theoretical efficiency limit of 29 percent, even when the various factors that constrain initial rates are excluded. There are only two ways to get around this efficiency limit for single-junction solar cells. One that has long been known is to make them multi-junction, but problems with production methods, materials development, and manufacturing costs have meant that this method is not now universally used. However, it is widely used for crystalline PVs, and in the case of triple-junction solar cells (consisting of gallium indium phosphide, gallium indium arsenide, and germanium semiconductors), can demonstrate a conversion efficiency of 40.7 percent for 240 suns. However, PVs like these will not be a feasible option in achieving a 10 TW installed capacity by 2050, in which case a key direction in technology development will be to raise efficiency by using thin-film technology that allows for large-area cells and mass production. In other words, one approach would be to make even thin-film silicon triple-junction, or even four- or five-junction, to raise conversion efficiency still further.

As for the second method, PV theory to date has been based on the concept that each absorbed photon creates one electron-hole pair. A paradigm breakthrough in this regard could well see a huge lift in efficiency. For example, if the absorption of a photon into a semiconductor's conduction band and valence band generated not one but two electron-hole pairs, the theoretical efficiency would rocket. Another approach might be to create an intermediate band within the band gap. Where a photon with a lower energy level than the band gap normally travels through that gap, an intermediate band would enable a low-energy photon to be used to generate an electron-hole pair. Usually, when impurities are inserted into these bands, it prompts recombination rather than the desired effect. However, the quantum dots of recent years, for example, raise the likelihood of photon excitation rather than recombination, something that could be used to good effect.

Extremely important data on this phenomenon emerged last year from America's National Renewable Energy Laboratory (NREL), focusing on photons with three times the energy of the band gap. We already knew that even in the case of ordinary bulk silicon, impact ionization would produce more than one electron-hole pair where energy was high, but this phenomenon is more likely to manifest when silicon quantum dots are used. In other words, it may be that using quantum dots will allow the generation of multiple electron-hole pairs from one photon.

I'd like to make one final point. What has become apparent from the work that my department has conducted with the National Institute of Advanced Industrial Science and Technology (AIST) and Dr. Porponth Sichanugrist's organization is that when we think about solar power generation on a global basis in the years ahead, we can't necessarily assume application of those technologies developed to date under standard conditions. If Japan develops a solar power generation system with a 100 GW capacity by 2030, this would be the equivalent of one kW per capita generation. Factor in one kW for each of the world's 10 billion people and you have a 10 TW generation capacity. Top of the list in terms of locating such facilities would be heavily populated areas such as India and south China, Indonesia, and deserts and other low-latitude regions. Because the solar spectrum is completely different and the temperature too is different, the amount of power generated by solar cells per annum will vary by around 20 percent where PVs are used in low-latitude regions.

PV Activity in Thailand

Porponth Sichanugrist
Peak power usage in Thailand in 10–15 years will be 20,000 MW. The cost at this point will be 16.67 baht/unit. As one baht is currently worth three yen, please multiply that figure by three. The load difference between peak and off-peak periods will grow at a pace of around 300 MW. In other words, to develop the necessary capacity to cope with peak conditions, we will need to build one 300 MW power plant every year. Solar power costs around 10 baht/unit in Thailand, or 30 yen/unit. The fact that this is cheaper than the peak cost means that

solar cells are currently appropriate for Thailand for meeting peak demand. An unofficial government plan aims to use solar cells to supply 10 percent of that peak in 2010–2020.

To this end, in 2006, we developed a tariff adder system that utilizes the feed-in tariff concept mentioned earlier. In Thailand's case, the government pays an additional eight baht per unit for a maximum of 10 years to parties generating power with solar cells. This applies not to what is generated, but rather the net surplus—in other words, net metering. However, because households tend to have almost no power left over, this system is currently only applied to power plants. Since this system was instituted, three solar power plants have been built in Thailand. Certain privileges are also provided to investors, with PVs positioned as a focal industry. Investors receive an eight-year tax break, while no tariffs are levied on machinery and material imports. As a result of these moves, First Solar, Inc. is planning to build a 100 MW solar power plant in Thailand.

We also intend taking a more proactive approach to carbon credits in the future, but for that a little more collaboration will be needed in Asia. For example, we intend injecting our technology into Cambodia and India in the coming years, but I think that slightly more emphasis needs to be placed on working together with places like India and Burma.

From a slightly different perspective, we're also thinking about how solar cells could be applied to biodiesel. Making biodiesel has traditionally required power and heat, and I think that if we use the photovoltaic/thermal (PV/T) system developed in Thailand, we can create a completely independent system that can be installed in rural areas in India, etc. for supplying that power and heat. In that sense too, I'd like to work with India and other parts of South Asia in the years ahead.

Sustainable Biomass Utilization Scenario and Asian Biomass Strategy

Kinya Sakanishi

Looking at the biomass energy potential for each continent in terms of volume, Asia comes in at 87 EJ, which is the equivalent of 2.3 billion kl petroleum and represents around 40 percent of total world biomass energy. This high figure is due to Asia's many tropical areas—like Thailand—the high speed of growth, the agricultural waste expected to be produced by palm and other types of plantations that could be used for biomass, and the availability of forest resources. Japan's total biomass potential is around 17 million kl, comprising the equivalent of around 6 million kl from the woody biomass deriving from forestry and 6.4 million kl from the pulp industry, as well as agricultural waste, sewage sludge, and food waste. Given that Japan uses 60 million kl petroleum per annum and 40 million kl diesel, that means a biomass potential of around 17 percent. Deriving around 10 percent of our total energy from biomass would therefore seem a reasonable numerical goal for Japan.

Here I've created a table showing biomass types, technologies, and products. Mitsubishi Research Institute, the Ministry of Agriculture, Forestry and Fisheries, and the AIST have launched collaborative research on marine biomass, but as we have yet to calculate the exact quantity of biomass energy potential, I won't be talking about marine biomass today. Instead, I'd like to focus on a technology for making ethanol from lignocellulose substances that are not foodstuffs, and a technology for gasifying substances not amenable to ethanol fermentation to create dimethyl ethylene and synthetic petroleum and fuel.

This first generation is already in application using Brazilian sugar cane and American corn, but problems have arisen in the form of competition between fuel and food. With the second generation, R&D is turning to waste products from food and paper production, forest resources, and agricultural waste. We're currently developing a system for low-energy ethanol recovery through saccharification and fermentation in a single reactor. It is extremely difficult to convert these kinds of woody substances to glucose, with the key challenge being to activate them without resorting to reagents like sulphuric acid. For enzymatic saccharification, we are using a bacterium called acremonium, manufacturing enzymes ourselves on site. Hemicellulase yields xylose, and because natural microorganisms can't usually break down xylitol, genetic modification technology is necessary. Our technology uses ethanol fermentation for the C5 portion.

In terms of pre-treatment, the first step is to pulverize wood waste into micron-size particles. X-ray and other analyses show that our method is achieving nano-level cleavage. Then, if we use the enzyme cellulase, the nano-level fibers can be saccharified and converted to glucose. Accordingly, we're currently engaged in technology development toward cleaving the cellulose down to nanometer size.

We've experimented with different types of wood such as eucalyptus, oak, and beech, but there is a lot of xylose in broad-leaved trees and agricultural waste, so if we can use these as raw material for ethanol and put them through a xylose fermentation process, we should lift the yield rate by up to 1.5 times. Research on genetically-modified bacteria should open the way for more production of ethanol from broad-leaved trees and agricultural waste. Most trees in Japan are conifers like cedar and Japanese cypress, which don't have much xylose. However, conventional glucose fermentation uses the same technology as employed in making alcohol for drinking, so the aim is to produce a lot of ethanol from conifers without xylose fermentation. The Biomass Nippon Strategy accordingly focuses on using un-harvested cedar and wood that has been cut and left in the mountains.

The second technology employs biomass-to-liquid (BTL), using gasification to create synthetic gas to produce biodiesel and other fuels. This will be a new premium diesel that is aromatic-free, does not produce soot, and because it is sulfur-free, enables the use of nitrogen oxide decomposition catalyst devices. In addition, it will be superior to fossil fuel resources in that the use of biomass fuels contributes to CO_2 reduction, while in the future it could also become a raw material for hydrogen. In terms of making dimethyl ethylene, methanol, and other oxygenated fuels too, biomass is extremely advantageous because it already contains oxygen. In Europe, BTL plants are already being developed, with efforts spearheaded by German firms Lurgi GmbH and Choren Industries.

At the AIST, we are taking wood and agricultural waste and inducing hydrocracking using a gasification method that can control the hydrogen/carbon monoxide ratio at two, as well as a method for developing an extremely active Fischer-Tropsch catalyst, so that the wax and other heavy substances distilled from the process are of a sufficient quality to be used in kerosene, light oil, and jet fuel. Typical products are heavy oil fractions and wax with a carbon number of 20 or more, and these can be used as pure heavy oils, or broken down further to raise the yield rate of kerosene, light oil, and jet fuel residue.

Thirdly, for systems assessment, we have created a database on biomass caloric values, moisture, and other information, and this is being used in conjunction with Pro2 software to run simulations in order to evaluate the carbon balance, energy balance, efficiency, CO_2 reduction effect, impact (life cycle assessment; LCA) and economic efficiency. As forests and agricultural products absorb CO_2, sustained planting and production is obviously essential. Because CO_2 is emitted in the process of harvesting and transporting these products, we also assess the amount of CO_2 emitted in the production of biofuels.

Finally, I'd like to explain the Biomass-Asia Strategy. This entails injecting Japanese technology into Southeast Asia, which has abundant biomass resources, to manufacture biofuels and reduce CO_2. In the future, we also want to create biochemicals and raw materials for materials from biomass. Thailand, Vietnam, Indonesia, Malaysia, and the Philippines have a lot of crude palm oil residue, unused lignocellulose-type substances, and residue (bagasse) from the sugar, which is the main product from sugar cane. They also have cassava residue and rice husks, as well as various wood by-products emerging from the production process, and we should be able to put these materials to good use.

Another issue with biomass is local production and local consumption. Because biomass requires energy to be supplied locally, small-scale diffusion is essential, and by around 2050, biomass will probably also need to be generating hydrogen for use in combination with fuel cells, etc. We will also need to be producing bioethanol and biodiesel as biofuels that can compete with the oil industry.

The Kyoto Protocol's clean development mechanism (CDM) currently only covers substances like chlorofluorocarbons and nitrous oxide, with biofuels yet to be included, but a CDM could also be used to supply energy in Southeast Asia and restore forests. The kind of mechanism I have in mind would entail sustainable biomass production while preventing desertification, with biomaterials and biochemicals developed and imported from surplus biomass resources.

We are currently considering a complex program for producing methanol and BTL diesel from the residue from palm oil production, as well as a sugar and rice energy complex, which would enable the simultaneous production of both food and biofuel from rice and sugarcane in countries like Thailand and Vietnam. A new wood refinery complex will also be needed that takes the residue from trees once they have been milled for timber and refined for paper and uses lignin as a chemical, for example, and also plants forests for ethanol use.

Hydrogen Production from Water with Solar Energy

Kazunari Domen

I will be discussing the production of hydrogen from water, a process that is still not particularly efficient compared to solar cells, nor even immediately feasible. So my presentation will essentially focus on future prospects. At present, the most practical means of splitting water into hydrogen and oxygen is to combine solar cells and electrolysis, but another method is to split water directly on the surface of an electrode using photoelectrochemical cells. We know that what would be called in solar-cell terms a multi-layered thin-film cell can be used to split water with a solar energy conversion efficiency of 12–18 percent, but this is difficult to transfer to large-scale applications. One method proposed by Dr. Michael Grätzel and his colleagues is to combine cheap photoelectrochemical cells with liquid-based solar cells, but this too only has a solar energy conversion efficiency of 3–4 percent at this point.

I want to look at a method of water splitting called artificial photosynthesis or photocatalysis. This method may be superior in the future when it comes to extremely large-scale applications. When light is used to split water, where one photon excites one electron, two photons are used to produce one hydrogen molecule. In this case, light up to a wavelength of 1000 nm, or close to near-infrared level, can generally be used. However, because of the reaction time, the longest practicable wavelength for splitting water is the longest wavelength in the visible light spectrum, or up to around 800 nm.

When splitting water using this method, given a quantum yield (equivalent to incident photon to current conversion efficiency; IPCE) of 100 percent, light of up to a 800 nm wavelength will theoretically produce a solar energy conversion efficiency of more than 30 percent. Given a more realistic quantum yield of around 60 percent, we're looking at an efficiency of around 20 percent, and the challenge ahead is to develop the materials for this.

Here is an example of photocatalysis using ultraviolet light to split water. This is a particle with sodium-tantalum-oxide of micron-order size loaded on the surface with a small amount of nickel oxide. Where light is shined on the surface, bubbles of hydrogen and oxygen emerge, and water can be split stably for more than 400 hours at a quantum efficiency of around 50 percent. However, this is using ultraviolet light; sunlight can't be used.

This is a solid-solution gallium nitride-zinc oxide material that we've recently developed—the yellow particles here, which are no more than one micron in size. Where rhodium and chrome are used to attach small nano-molecules to the surface to split water, applying visible light enables the generation of hydrogen and oxygen at a ratio of 2:1, effectively splitting water through artificial photosynthesis. This is currently the most active photocatalyst in the world within the visible light spectrum, but the solar energy conversion efficiency is still less than 1 percent because the wavelength of usable light is still less than 500 nm along the 400-800 nm visible light spectrum.

To enable the use of longer wavelengths, we came up with the idea of two-step water excitation. This was first tried by Dr. Sayama and his colleagues, who are also attending this conference. Our innovation was to use a material that could absorb a long wavelength of 670 nm. Currently, we've managed to use a 600 nm wavelength across two steps for oxygen evolution, and close to 670 nm for hydrogen evolution. This material should allow us to achieve a solar energy conversion efficiency of more than 10 percent, but because the quantum yield is currently extremely low, the conversion efficiency of this method too remains low. One possibility in terms of using longer wavelengths would be a niobium-based material. If such a material can be developed, we will be able to create a system that can use almost all the visible light spectrum in the near future.

We thought that we might be able to use these fine particles with the photoelectrochemical method mentioned earlier, and when we tried it, simply applying the powder produced a quantum efficiency, or IPCE, of 20–30 percent. However, it's not clear at this stage whether this approach will be viable for large-scale applications.

To ascertain the kind of speed at which hydrogen and oxygen would evolve where the solar energy conversion efficiency was around 5 to 10 percent, a group led by Dr. Kazuyuki Tohji at Tohoku University is conducting an experiment to generate hydrogen using only sulphide ions as the reagent. Our current aim is to split pure water at around that level of efficiency.

In America, the Lawrence Berkeley National Laboratory launched the Helios Project in this area last month (February 2008). A key point here is that their goal is to achieve a solar energy conversion efficiency of 1 percent in order to make solar fuel. If this method can be applied on a large scale, the idea is that all the fuel used in all transport—all cars—in the U.S. could be covered using solar fuel. In that sense, the photocatalyst that we're developing is already very close to that 1 percent target.

Discussion

H. Ishitani
I'd like to open the floor to your views on this morning's presentations, or anything you'd like to add to them. Looking first at solar cells, while there are obviously some issues with future PV technology, they are certainly a major option in terms of CO2 reduction and energy security. The big problem in realizing PVs is obviously cost. How should the world—Japan and the developing countries included—approach PV promotion? What do we have to do?

Dr. Kuwano, perhaps we could draw on your long experience?

Y. Kuwano
I think the EU has done a wonderful job in bringing the new term "climate change" to world attention. Because the Europeans live close to the Arctic, they have an extremely pragmatic approach, and they're currently creating new leading-edge business in the form of carbon emissions trading.

Second, on what tools do we draw to combat climate change? I think that the utilization of solar energy will be critical in resolving climate change and energy issues.

Third, it's been 50 years since solar cells were invented, but the sun will continue to exist for some three billion more years. We have to boost current production volume 10 to 100 times, and that will mean generating global innovation.

H. Ishitani
I entirely agree with your three points, but when CO2 emission costs are left out of the equation, PV cells are still extremely expensive compared to fossil fuel-based power. In addition, compared to European companies, Japanese companies need to be extremely sensitive to competition with China and Korea, and high electricity costs would translate directly into damage to our industrial competitiveness. Is this an issue that we can overcome?

Alternatively, could it be argued that we need to persist with PV cells even given the higher cost because it's the right thing to do? Further, given that solar cells would only have to become a fraction cheaper to win market favor, we will also need to determine whether there are signs that pushing that argument is no longer necessary.

Y. Kuwano
Under the emissions trading scheme, the trading price for CO2 in Europe is currently around 3,000 yen/ton. In other words, the idea that CO2 is no longer something you can just emit for free has been introduced as exactly the kind of global innovation I am talking about. Systems are also in place whereby companies that emit more than their allowance have to pay penalties of five times that size—around 15,000 yen. As a result, CO2 emission rights are now being taken extremely seriously even in the Japanese mass media. I think that Europe has led this trend.

I know that there is considerable opposition in Japan to the introduction of a carbon tax because of its potential impact on business, but we need to move beyond this level to devise measures to meet the global innovations that Europe is introducing.

K. Tanaka

The tentative proposal that we have put to the conference is that in reducing CO2 emissions, the focus needs to be on cutting-edge technology and linking this to innovation, identifying those areas that require medium- to long-term plans. These include photovoltaics, biomass, hydrogen production, solar hydrogen production, and marine biomass. I would like to see concrete proposals put forward on these directions from the perspective of how, within a global framework, Japan can win out in global competition, and also how Japan can collaborate with other countries.

Junichiro Fujino
I think Dr. Kuwano is addressing a key area. At the point when the Kyoto Protocol was created at the Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, we had already formulated rules that imposed restrictions on carbon dioxide emissions. Now too, the EU believes that a price for carbon has been created through the introduction of the Emissions Trading Scheme, but in fact companies have already developed a price amongst themselves. In that sense, the rule-making process could be said to be a social innovation.

H. Ishitani
It's argued that Japanese firms are already paying around 2,000 yen/ton, but this doesn't address the fact that no CO2 emissions costs at all are being paid for at the general final demand stage.

J. Fujino
My impression is that responsibility is currently too vaguely apportioned. Companies are developing programs at their own discretion, which has led to the introduction of such tools as environmental household account books. However, employees don't take that responsibility home with them. It's important that everyone shoulder the burden, as with Germany's feed-in tariff system.

H. Ishitani
In Japan, companies create voluntary plans, reducing their carbon emissions based on caps that they have set themselves. However, you don't see this happening on an individual basis. I think Germany is very different in that regard, but is there a similar tendency across Europe as a whole?

T. Johansson
Public awareness has become extremely high in Germany, some parts of the United Kingdom, and a number of the Northern European countries, and people are beginning to look at their own carbon footprints. However, even if you put all these efforts together, their impact is still only minimal, and the general recognition in Europe is that voluntary action on the company level just isn't working.

Because issues like energy prices and competitiveness are focused in energy-intensive industries, they aren't that big an issue for most companies. However, in the case of energy-intensive industries, basically the developed countries need to negotiate within the WTO framework and ultimately levy tariffs on energy-intensive products from those countries that do not participate meaningfully in the carbon regime.

In Sweden at least, many firms are focusing on their own energy issues. A study undertaken by a colleague of mine revealed that small and medium-sized firms can reduce their power consumption by 30–50 percent and boost their income. I think that this sort of exercise should become an industry standard. Certainly, a number of issues do exist, but there are also a variety of solutions.

H. Ishitani
The situation is certainly very serious for energy-intensive industries, but in the case of Japan too, I think that in the end it comes down to the individual, and Japan's efforts are clearly insufficient in this regard.

J. Fujino
Japanese as individuals work very hard when it comes to, for example, separating out their garbage. But it seems as though they just separate out their garbage, with no further thought as to how that garbage is subsequently processed. In Finland, children begin studying public issues in elementary school, starting with how taxes are used. The renewable energy that Dr. Johansson discussed is certainly important, but it seems Finland also has a strategy about how energy efficiency and nuclear fusion too might be integrated into the whole energy picture.

K. Tanaka
The Japanese government has done very little in terms of education programs encouraging public acceptance of the new technologies, both risks and benefits included. As a result, whenever we try to do something new, it is extremely difficult to move forward while engaging simultaneously in a debate on the benefits and risks entailed, or to pursue both technology development and systemic considerations. The government's strategic arrangements in this regard are extremely weak. For example, solar cells obviously can't yet compete with existing power sources on cost, but the government could engage in strategic market creation. This approach was used successfully for a while in Japan, but as soon as subsidies were cut, the market also suddenly shrank. Japan is lagging when it comes to building comprehensive national strategies inclusive of such market-stimulating policies.

M. Konagai
Because industry is extremely active in this area, I think it would be very difficult to collaborate with our geographic neighbors. For example, a U.S. major manufacturing machinery maker is currently selling turnkey systems for production of the silicon thin-film solar cells that Dr. Kuwano and his team worked so hard to develop. Collaboration will therefore only be possible from a long-term perspective, and my presentation today was grounded in that distant future.

If I may make another point, Japan's target is to introduce around 100 GW by 2030, but according to Dr. Kuwano, we apparently have the land space to build facilities for around twice that capacity. However, the 100 million kW capacity that we need is half the 200 million kW capacity of our current power stations. Accordingly, I think we'll need to look at how to combine solar cell energy with other energy sources.

Ultimately, it would be ideal if we could run a superconducting cable around the world as in the GENESIS project proposed by Dr. Kuwano some years ago, but in terms of immediate possibilities, I think that the utilization of hydrogen as explained today by Dr. Domen would make a great theme for collaborative work.

H. Ishitani
"Competition" and "collaboration" sound so close in both English and Japanese that they often end up being used together as a complementary set. However, collaboration in the true sense of the world becomes impossible once the market enters the equation; you basically end up with competition. In terms of short-term technological progress, there's nothing wrong with healthy competition. However, when it comes to the long term, we should proceed on the basis that a free hand often generates ambitious targets that may not be instantly achievable but will always produce a return in the end.

M. Konagai
I think that's the key point for academia in considering the direction that it should take.

H. Ishitani
In any case, there are numerous technology development challenges to be dealt with before the entire energy supply can be shifted to solar cells. With fuel cells, everyone avoids saying that they have something that can be immediately commercialized. Premature promotion can be dangerous in that you can end up losing all credibility. That's where fuel cells currently are, and right now everyone's simply stressing their firm commitment to continuing research and development.

M. Konagai
Solar cell production too has continued to increase, and while this has been driven primarily by silicon PVs, eyes are now on the various new types of solar cells. Thin-film silicon is becoming a lot more reliable, but the relative cheapness of dye-sensitized and organic PVs is also attracting attention. However, if sufficient market credibility—in other words, sufficient confidence that the product will stand up to long-term use—isn't gained, a single wrong step could have a major impact on the whole industry, so new products need to be introduced very carefully. That's my main concern.

Ishitani: At the same time, it's not necessarily a good thing to push large quantities of old but safe batteries. Perhaps we should wait a little longer to see whether that would really get more batteries out there in the future given companies' current setups.

M. Konagai
It's difficult to predict how that ratio will change as time goes by, but what usually happens is that change occurs faster than predicted. If a really good, reliable product comes out, it will simply take off.

J. Fujino
If I may put my own interpretation on Dr. Ishitani's question, I think he's getting at whether later generations of solar cells would benefit more from, say, spending a trillion yen now to boost market penetration, or whether it would be better if that trillion yen was employed over 20, 30 years first for technology development before thinking about the market.

M. Konagai
Don't both aspects need to be advanced simultaneously?

Y. Kuwano
The markets that companies have developed are currently making at least some headway. I think it's the job of academia to work on new solar cell types until their reliability has been proven.

M. Konagai
I don't think it's the job of academia to prove reliability. Academia should identify means of proving reliability, but it should be firms that do the empirical testing.

Y. Kuwano
In reality it's very much case-by-case and there's no universal answer. We can use solar cells now. Everyone says they're more expensive than using electricity, but that's based on the assumption of a 20-year PV product life. If PV product life was calculated at 40 years, solar cells would be perfectly feasible right now. A 30-year life span costs out at 30 yen/kWh, but if that lifespan were doubled, the price would drop to the same level as industry-use electricity charges. The trade-off there, of course, is whether solar cells really do have the technological capacity to last 40 years. That's why everyone is working hard to launch PVs as a business. By contrast, the production of hydrogen using solar cells as discussed earlier has not reached that stage, and with biomass too, they're only just looking at using construction wood waste.

Dr. Tanaka was also talking about the purpose of this conference. In that context, Japanese solar cells are also being sold to EU countries, so they're still number one in terms of production volume. Where Europe has gone past Japan is the feed-in tariff system. Japan should adopt this system, a move that would comprise both international collaboration and international competition.

Fujii
I'm in electrical engineering, and my research is focused on systems engineering. From that perspective, it's obviously good if solar cells have a high level of efficiency, but given that the current level of efficiency is far greater than biomass, surely it's already quite adequate? The key issue is to bring down the cost. If we want to use solar cells to supply all Japan's primary energy, at a rough calculation we'll need to use about 5 percent of our land area. That's still not much when you consider that fields and paddies account for around 13 percent. Selling solar power at 20 yen/kWh would generate revenues of 3,000 yen/m2 per annum. As agriculture generates around 150 yen, where solar cells really do become economically feasible, I don't think the land issue will be insurmountable.

Dr. Ishitani was talking earlier about whether or not we should wait. Where the situation with solar cells is a little different from that of fuel cells is that solar cells have the potential to fit in quite comfortably at around 100 yen/kWh, between the 1,000 yen/kWh power cost in some places and the 20 yen/kWh cost for commercial-use power in other places. Even in the latter case, given the cost of transmitting power to remote mountain and rural areas, it would not be unreasonable to raise the price of electricity, but power is currently provided at a standard rate on the universal service principle. If power were to be sold at a price that reflected its real cost, I think that solar cells and wind power generation would be more widely introduced.

M. Konagai
As with other products, the sales price for solar cells will differ according to the level of penetration. If the current volume were to double, the price would drop to around 0.8. So if crystallized and thin-film PV production booms over the next several years, the price will drop significantly as well.

Toshiaki Ikoma
I'd like to lift the discussion to a more macro level. We're not supposed to be discussing costs here, we're supposed to be looking at how solar energy will be used to solve global environmental problems in 20 or 30 years' time.

H. Ishitani
To consider energy systems 40 or 50 years from now, we have to start with what we can do right now, because if we try to realize the kind of technologies that we think will be around in 50 years' time, it will take another 30 or 40 years from that point.

T. Ikoma
Well, that's certainly the backcasting approach, but with silicon solar batteries—solar cells—already so clearly defined, bringing down costs in future years will require targeting more than just silicon. What they want us to do here is to discuss policy with a view to scenarios 50 years from now, such as what we should do if, for example, making silicon PVs is using too much energy or if resources become scarce.

J. Fujino
What I liked about Dr. Sichanugrist's presentation was the idea of combining solar cell and biomass technologies to make both heat and power for the local supply of local energy needs.

Ookawa
At the National Institute for Environmental Studies (NIES), we have developed two scenarios for 2050: one based on nuclear power, and one based on natural energy. Solar cells are small and produce direct current, so if the issue of varying building height can be dealt with, they'll be an ideal urban energy source for final-demand users. Biomass, on the other hand, is better suited to rural areas. I think we therefore need to create dissemination scenarios for 2050 geared to the different types of energy.

Ishitani
A number of scenarios have already been created by the Agency of Natural Resources and Energy and NIES, and that's why we're looking here at solar energy. I don't have many concerns in that particular regard. However, I think the timing issue is very tricky, which is why determining what we should do right now is so important.

T. Johansson
Trial calculations that we made a number of years ago suggested that a massive investment of US$30–40 billion would be needed to reduce solar power generation costs. At the same time, governments around the world are paying out some US$200 billion in subsidies every year for conventional energy sources. The climate change cost too is between 5 and 20 percent of GDP and could go even higher. Even costs within the 1 percent mark translate into an impact at least 10 times greater than that, and these factors too require a cool appreciation. We also need to look for systems that can ensure that sufficient action is taken on restraining emission volumes.

In other words, places like Sweden, other European countries, and Japan must reduce their greenhouse gas emissions to zero by around 2040. The backcasting referred to earlier is exactly what we should be doing to reach this goal. However, at this point we don't have the necessary accompanying economic systems. Innovation is not just a matter of technology but is also intimately related to the design of economic systems, yet these are not being adequately addressed. I think this is a major problem.

H. Ishitani
Solar energy costs are currently three to four times greater than oil energy costs, but they account for 2–3 percent of GNP in terms of energy cost, while their added value is around 2 percent. Even if that cost tripled, it would still only be around 6 percent, which is far cheaper than the damage cost of 20–30 percent that Dr. Johansson has noted. What stands in our way is the ongoing inconsistency in international collaboration observed earlier, but there is little point discussing that issue here.

T. Ikoma
I disagree. I'd like us to put forward proposals on this issue and make an appeal to the international community. Japan was the first country to start developing solar power with the launch of the Sunshine Project back in 1974, but little effort was made to stimulate the market. Germany, on the other hand, stimulated the market first, using Japanese technology to widen it. That's why market penetration is so high over there. In other words, Japan's mistake was to connect the issue of solar power to science and technology policy rather than innovation policy.

What should the world do in the coming years to reduce emissions by 2050? What should be done about Africa, India, and China? China has a lot of desert area. Europe will probably take Africa in hand. I'd like to see discussion of these global issues.

K. Tanaka

In the time remaining, I'd like to ask you to focus on international frameworks. I refer here to the need for national education systems to inform civil society about why individuals need to reduce their carbon footprints, as well as international education and awareness-raising systems to that end. Another issue is that various countries are likely to be involved in creating large-scale PV plants in places like deserts; what kind of vehicle would be needed to realize such projects, and how could consensus be developed?

There is of course the International Energy Agency, which is made up primarily of the member countries of the Organization for Economic Co-operation and Development, but including developing countries and building something in a large desert will, I think, require a consensus-building process and some sort of organization. In that sense, I wonder if a task force might be needed. That's my first proposal.

Second, to boost Japan's competitiveness, I wonder whether we don't need a research institute to handle not just solar cells but natural energy as a whole, or a research institute with a slightly broader framework.

Third, to help the whole human race understand the significance of carbon reduction projects, how about creating an international network whereby the various countries select eco-friendly model cities and work together toward common goals on the basis of their respective cultures? Your views on these points would be greatly appreciated.

J. Fujino
The answer is easy. If we attach a clear price to carbon, concrete climate change measures will proceed apace, and solar power too will be much more easily absorbed. Putting a five-yen charge on plastic carry bags in shops has seen 80–90 percent of people decide that they don't want these bags. We just need to make the cost visible.

As for the EU's rulemaking, industry too is in fact heavily engaged in policy creation and indicating what kind of rules industry wants to see in place. For example, at the IPCC scoping meeting on renewable energy sources and climate change mitigation, industry successfully lobbied to have emission reduction burden quotas substantially reduced in sensitive areas like steel.

There are already various regional networks in place, and I think the issue will be how to exploit these. For example, the Economic Research Institute for ASEAN and East Asia (ERIA) has been set up to serve as an East Asian OECD, and the key there will be to develop a solid vision.

T. Johansson
To encourage civil society participation, it's extremely important to discuss carbon emission volumes from not only the production but also the consumption side. Thought also needs to be given as to what emissions are produced through the consumer activity segment of the product lifecycle. Livestock's Long Shadow notes that world livestock production is the cause of 18 percent of greenhouse gas emissions. In light of the fact that transport as a whole accounts for 14 percent, this is an area requiring careful consideration. If a system can be designed that accurately identifies issues in our individual behavior as consumers, I think we'd also get a better sense of what means could be used to bring about change.

H. Ishitani
Transportation is being addressed in a different session, but it is certainly heavily impacted by energy supply.

Y. Kuwano
Annual solar cell production in Japan is 1 GW, which accounts for two-fifths of world solar cell production currently totaling 2.5 GW. One GW of solar power can bring about a reduction in CO2 emissions of around 1.1 million tons annually, so over 20 years it would mean a massive potential reduction. To meet Japan's Kyoto Protocol commitments, we need to reduce our CO2 emission by 130 million tons. If we crammed in solar cells wherever we could around Japan for that purpose, we could meet that commitment quite adequately.

Of the world's current primary energy sources, oil accounts for 34 percent, coal for 25 percent, LNG-fired power 21 percent, and nuclear power 6.1 percent. In 2100, however, when there are no more fossil fuels, it's my personal view that photovoltaic power will come to account for around 50 percent.

As for my views on Dr. Tanaka's comments, firstly, I think an international task force is absolutely vital. That was my intention when I proposed the Silk Road GENESIS project, but there hasn't actually been any movement on this yet. As for his second point, which sounds like a Japanese NREL, I believe that the programs currently being undertaken by bodies such as the AIST and the NIES need to be brought together to further accelerate Japan's technology development, so I am in agreement with him there. When it comes to eco-models, I think we need to really push this idea in the form of eco-towns.

H. Ishitani
Biomass presents the same kind of challenges. In that sense, I think Dr. Tanaka's third proposal would be a great direction to move in. As for his first point, the United Nations is currently doing a lot of work with Africa and the developing countries on issues like poverty and food, so energy could be added to that agenda. In terms of the second point, I think this could be adequately addressed through a slight change in our perspective on what the NIES and the AIST are currently attempting.

Ikoma: In regard to Dr. Tanaka's second point, are we going to restrict ourselves to Japan? It was suggested that solar cells could be laid out across Japan, but I don't think we want to use Japanese land. In addition to the issue of food self-sufficiency, land is expensive, and we'd run out of living space. I think we need a different concept. One possibility might be to build power plants in the Chinese desert and bring power across using a thin superconducting cable. In that sense, we might want to create a natural energy laboratory or a hub coastway in Asia, or even build something on a marine platform.

Konagai: Dr. Kuwano put forward all those ideas some 20 years ago, and now we need to start getting them underway. I agree with Dr. Tanaka's second proposal about the research institute, but I'd like to see research centers within universities attached to this as satellites to create a wider network.

T. Ikoma
The research institute needs to be set up in the wider area of Asia.

J. Fujino
My dream is to create an Asian low-carbon society research institute.

H. Ishitani
The problem is that if countries like China and India don't adopt the same stance, all our efforts could just fall flat, and Japan must bear this in mind when putting forward proposals. So whether it's a taskforce or whatever, joint research really must be conducted on a joint basis. Industry, of course, will be engaged in competition, but in a different arena.

K. Tanaka
In the case of research institutes, I think we need both. I suggested creating a research institute in Japan because at present, people working on solar cells have no contact at all with people using sunlight to make hydrogen, whereas in the U.S. and Europe they have places like the NREL and the Fraunhofer Institute that take a more holistic approach.

H. Ishitani
What's the EU doing in Europe?

T. Johansson
One of the key aims of the European Commission's research is to foster cooperative relations, so there are always at least three countries involved in every project. Most programs are also being conducted by various types of national institutes and universities, and the trend there is to create partnerships from an educational perspective as well. Universities are also working together on European Commission (EC) special programs.

K. Tanaka
Is there one focal institute that covers energy and the environment as a whole?

Johansson: Not on a pan-Europe basis, because what the EC is basically trying to do is essentially integrate existing research programs. I don't know whether there are places where energy and environment-related research is being conducted in the same building or whatever, but certainly the university where I work has an energy portal connected with 20 or 30 departments in other universities with which we can cooperate.

H. Ishitani
Would an organization that did research on natural energy in Asia and discussed cooperation mechanisms in that regard be useful for Thailand?

P. Sichanugrist
Thailand proposed a number of years ago that pan-Asian workshops be held. In Thailand's case too, we're working to bring down the price of solar cells and we have a feed-in tariff system. However, because 40 percent of Thailand's energy is used in transport, our priority is on developing biodiesel and biofuels rather than solar cells, so our approach has to be shaped to how solar cells can assist in this.

In addition, the NSTDA has signed a Memorandum of Understanding with the TIATR, an Indian institution, to do research on PV/Ts and supply machinery to India that produces both heat and power.

H. Ishitani
Natural energy tends to be very localized, so its merits and demerits are entirely different depending on local conditions. Solar cells have been highlighted in advanced regions like Japan and Europe because they have very high land efficiency and will definitely be essential over the long term. However, when it comes to international schemes, solar cells may not be enough.

Dr. Sakanishi spoke earlier about LCAs. I wonder if biofuels recently haven't in some cases been used in a way that incurs major internal losses.

K. Sakanishi
The drive for biofuels is overheated at the moment. In Europe too, covering around 10 percent of primary energy with biofuels would be appropriate when it comes to sustainable use. Another issue is the energy price, or in other words, the price of water, food, energy, and the environment. While oil prices may have risen, water is still more expensive again, and food too is in fact more expensive than ethanol. From an LCA perspective, the food, water, and virtual water issues presented by biofuels mean that going too far with these as an oil alternative could conversely cause environmental destruction. We need to revisit current trends from the perspective of LCA, environmental and social impact, and biodiversity, and both the UN and the IEA have in fact launched programs in this regard.

I personally believe that the developed countries, which depend on coal and oil, as well as China and India, which rely on coal-fired thermal plants for most of their power, need to be looking not at solar cells but at how they can reduce the carbon emissions of their existing power plants. In the case of Asia, given the abundance of biomass there, plans need to be made to shift from coal and oil to biomass over the next 5 to 10 years, and then over the long term, by 2050, looking at the introduction of solar, hydrogen, and fuel cells.

J. Fujii
I am using a world model to create a 100-year simulation, and it seems that while biomass has been introduced to some extent, this is not going to happen with solar cells even if they do become cheaper. This is because linking a new energy source into the energy chain is expensive. Because energy is an extremely cheap good, cost is possibly the most critical piece of information, so energy sources need to be made as cheap as possible. That's why there is work to be done in electrical engineering.

H. Ishitani
Because that whole issue is currently being pushed off on to power companies, nothing is being done in Japan at all, and in that sense thought needs to be given as to what technologies would enable a good balance. In your model, do solar cells always lose out?

Fujii
The cost problem always remains. Even carbon capture and storage (CCS) would seem the more economic option.

H. Ishitani
Back when the second IPCC report came out, there was a lot of discussion on CCS, but ultimately it didn't seem the best option. In Europe at the moment, in the Netherlands and elsewhere, they're pushing CCS very hard. How viable is this from the viewpoint of sustainability for Europe as a whole?

T. Johansson
To reach the emissions reductions goals that Europe is seeking, CCS is undoubtedly essential. There are currently 15-20 field trials underway, so progress is being made, albeit slowly.

H. Ishitani
Isn't there a lot of discussion about seabed storage?

T. Johansson
I think we should start from the least complex issues. There is almost no talk about saline aquifer or enhanced oil recovery. Certainly, CCS always poses the problem of high costs. However, if costs are going to be compared, they should be compared against the case where carbon emissions continue. As far as we have determined, the cost where carbon emissions continue will be far higher. So our responsibility as a society is to find ways to cover that cost.

T. Ikoma
If you start thinking about cost, you don't get innovation. Cost is determined through economic mechanisms, so early models are always expensive. In Germany's case, the high cost is covered using price, so someone is paying. So whether the free market determines who will pay, or whether this is artificially determined, I believe that as long as more is at stake than cost, this is an issue that can be overcome.

H. Ishitani
Particularly with CO2, we don't know whether the current cost is the real cost. However, when it comes to energy systems, the situation is entirely different from the age when they started introducing televisions where there had been no televisions. We have to battle and win with what we've currently got, but there are some major obstacles in the way.

T. Ikoma
That's where we need to develop a global innovation eco-system and change social systems. In other words, we have to even change people's mindsets. That's what we want to propose.

J. Fujino
The key issue in creating a low-carbon society is what people want. If we don't think about what services are really necessary, they won't be accepted by the market, so that's where we need to innovate.

T. Ikoma
Our aim is to develop concepts like that out into proposals, and that's what they're doing in the next room.

H. Ishitani
In that sense, in Shanghai in China, they have banned the registration of scooters on environmental rather than energy grounds, so now around half the scooters in Shanghai are electric. However, in rural China and amongst the urban poor, the priority has to be on economic expansion. As this was also the case for many years in Japan, we can't just blithely advise them against a practice we view as undesirable. It was relatively easy to persuade the Chinese in regard to air pollution, but the CO2 issue is much harder to sell.

J. Fujino
In China at the moment, the new coal-fired plants are all super-critical, with better efficiency than Japan's old power plants. Because China imports all its oil resources, the government wants to ensure that they're used as efficiently as possible. What Japan can do here is supply technologies like integrated coal gasification combined cycle to the greatest extent possible. But proper mechanisms need to be set in place to ensure that we get a return on the technology we develop, so that the ground can be laid for the next round of innovation.

T. Johansson
China's energy efficiency improvement targets are the most ambitious in the world, well above other countries. They have also set extremely ambitious targets in regard to sustainable energy. This isn't for the sake of the climate, but rather for other extremely valid reasons. Mr. Fujino was talking about making it possible to utilize technology to improve energy efficiency within tolerable cost limits. Governments in the U.S., Japan, and Europe, which are among the most advanced, should earmark funds and promote technology transfer.

H. Ishitani
Thank you for that valuable closing comment. Here I'd like to conclude the debate.