Panel 2: Discussion Session

The following is an edited transcription of the discussion session during Panel 2 of the Schiller Institute conference on September 5.

Before taking questions from the audience, the panelists were given a chance by the Moderator, Megan Dobrodt, to respond to what they had heard so far from the other presenters.

Jason Ross: I thought that this panel was a really profoundly inspiring image of the future that we have gotten from the expertise that is here on nuclear power, on fusion nuclear power, on space science. I saw in the YouTube chat, people were saying, "Wow! Why didn't I know about this? Why isn't this the top thing on the news?" when they heard about how huge ITER is and the international cooperation that makes it possible.

I had a question for some of the other speakers which maybe we can take up now or later, which is to what extent fusion is an engineering versus a science problem. That is, to what extent do unexpected outcomes in fusion experiments create the next generation of fusion experiments? When we create these tokamaks or these other devices, how much of what happens is a surprise to us, versus how much is what we would expect, confirming the knowledge we already have?

Dr. Bernard Bigot: The development of hydrogen fusion from my point of view is both a scientific and engineering issue. We have to assemble all these components in very precise conditions. It has never been done before, so really, engineering as a capability is absolutely decisive. But we are exploring, I would say, *terra incognita*. Never in the world has somebody been able to have a burning plasma, a self-sustained plasma. At 150 million degrees, there will be some turbulence, some different events. We know it will exist, but have never had the experience on this scale. So, from my point of view, it is both, the need for science development as well as for engineering.

Dr. Stephen O. Dean: Thanks, Bernard. We all admire you all over the world for the job you are doing on this incredibly large, complex construction project. We're looking forward to the day when we're actually studying the plasma.

I would just add or perhaps expand on what Bernard was saying. Fusion and fusion science and engineering are in many ways not dissimilar from the history of science and engineering and technology over hundreds of years. We're at the very early stages of learning how to do this, and we have to expect that the first thing we do is not going to be the last thing that we do in terms of improvements and finding new ways to do it, and finding new understandings, and so on. When ITER operates, and when fusion is really there in the laboratory, it's really the beginning of probably a couple of hundred years' worth of things that you can't even hardly imagine. Just like you can hardly imagine our cell phones today, a hundred years ago.

Dr. Kelvin Kemm: It's important to note the advances that have been taken in nuclear developments. The fusion machines, the advanced tokamaks, the space engines that are going to enable us maybe to get to Mars. There are great advances being made in nuclear and far-advanced nuclear—fusion and so on. In the meantime, a lot of work has been done on things like small modular reactors, advanced-generation reactors and so on. There mustn't be brakes put on the development of these nuclear solutions and their deployment into countries like African countries.

What I noted from Dr. Pulinets is that we've got to look at our planet now, we've got to look at a lot of the politics of society. There's the potential of global cooling coming, with which I agree; it's indicated by the sunspot activity. But what we find is, there are psychological and social pressures being exerted to put in wind and solar to supposedly saving the planet from carbon dioxide. Yet indications are that the little bit of global heating that has been detected since the time of President Abraham Lincoln is probably due to magnetic activity on the Sun and is not actually due to human-induced carbon dioxide at all. Scientists have got to much more get in contact with society at large. We need to get the politicians to listen, and we need to try to be realistic. This is very difficult.

Dr. Pulinets pointed out this move towards electric vehicles, for example, and quite correctly, to my mind, said, it'll probably generate more CO_2 to produce an electric vehicle than to just use the petrol [gasoline —ed.]. There are also the sociological effects of children being used in the lithium mines, the cobalt mines, and so on; and this is not noticed. Paul Driessen made mention of this, of the chasm between rich countries and other countries.

It's just not reasonable for African countries to be told they've got to stay in an archaic state because somebody in the First World thinks they've got an answer which probably is suspect anyway—this carbon dioxide argument. He made it quite clear that people are not realizing what's going on. The death rate from malaria, for example, is high in Africa because DDT has been blocked from being used. There's a lot of human cost going on. We somehow need politics and we need sociology, and we need people like the bankers to pay more attention to scientists. The scientists may be able to speak their language and explain to them what it is that we need.

There are nuclear solutions along the way, and I feel the fusion researchers are at the leading edge at the moment. But trailing behind that is the practical solutions that can be employed today, such as Pebble Bed-type reactors, gas-cooled reactors that are ideal for deployment in African countries and many other countries around the world as well. So, I think it's very important to listen to Dr. Pulinets' arguments about the politics and the sociology and science coming together to find adequate solutions. thank you.

Dr. Sergey Pulinets: I'm happy that what I am talking about found a common language with representatives from Africa. And I forgot to say that if we look at the total cycle of mining of the metals for the accumulators [storage batteries] for cars, then we should think about the utilization. We know that all the small batteries which we have in our phones cannot be disposed of with normal waste; we must take them to special places.

Now, imagine how extensive a technology we will need to handle all the batteries from electric cars. We will have to develop a special industry to deal with these accumulators. The number of these cars is growing to a geometrical extent, and it will create a large problem for the environment.

Michael Paluszek: I've enjoyed listening to all the speakers.

A question for Dr. Bigot: *With the beginning of the assembly phase of ITER this summer, French President Macron made a speech in which he said, "There are times when the peoples and countries of the world choose to overcome their differences, to rise to the historical challenge of their times. The launch of the ITER project is one of such moments. ITER is a promise of peace." From your perspective, Dr. Bigot, what does Macron mean that ITER is a promise of peace?*

Dr. Bigot: On July 28, we were very pleased to hear the views expressed on the ITER project by the heads of state of the seven ITER members, as well as on the significance of the start of the assembly phase. French President Macron stated very clearly that the world needs energy; energy is life. Without energy, there is no biological life, nature, or economic life, or social life and development.

The world's energy supply is not well distributed. Some countries have quite favorable resources of fossil fuels; some others have quite favorable conditions for renewable energy. But many have difficulties ensuring a long-term national energy supply. Fusion uses a raw material, seawater, and a very tiny quantity of lithium, both of which are widely distributed. So, with fusion we will avoid competition and confrontation as in the past when people tried to get energy from some other part of the world. It was the reason that we are developing hydrogen fusion, and as it now agreed, fully shared among all the people. The intellectual property will be fully shared with all ITER members and more broadly. It could be a breakthrough for long-term peace for the world, if I correctly understand the meaning of President Macron's statement.

From a science professor at a college in New Jersey: *We have already employed fission in space missions. Besides propulsion, what other uses would fusion bring to our space-faring society? For example, could fusion aid in* in situ *resource utilization?*

Dr. Paluszek: Fusion can be used just like fission for both power generation and propulsion. Fission is interesting, because one option for fission propulsion is nuclear thermal, which can produce fairly high thrust. Fusion typically is going to produce—the technology we've looked into—would produce much lower thrust. It's only really suitable for in-space and fairly slow missions. But both types of reactors can be used for Mars bases or lunar bases. NASA is pursuing fission right now, because the technology has been developed to a fairly high level of development in the Kilopower Program.

Fusion is quite a bit off in terms of time; you're talking about 15-20 years before you could use fusion technology for the same kind of thing. I imagine that the first application of nuclear power in space will be either nuclear-electric, which is being proposed for some missions, or also as power for bases on the Moon or Mars.

Ross: One thing on resource utilization that comes to mind is how both fission and fusion differ from using chemical power or solar power, with respect to what you would need on another planet: That's the processing of materials. We're trying to essentially use the crust of the Moon or Mars and extract the resources from it.

It's difficult to pull metals apart from oxygen that's combined with them chemically. Here on Earth, we use coal to do that; both to provide the heat, and the carbon is able to pull out the oxygen in the form of carbon monoxide and carbon dioxide. We're not going to be using carbon for that purpose on another celestial body. Having a very intense supply of energy means that it is possible to find another way of separating the metals from oxygen so that we could more effectively make use of that on another celestial body.

A question for Dr. Kemm: *Had fusion been available as a power source by the 1990s, what do you think the population of the planet and the continent of Africa might be by now?* [Audio problems delayed Dr. Kemm's answer until later in the discussion.]

Dr. Bigot: The development in Africa, and everywhere in the world, is definitely depending on energy in order to develop, for example, hospitals and medical things. I am pretty sure that if there were easy, safe, clean energy in Africa, everywhere in the world, the development of Africa would have been much safer and much steadier. But it's very difficult to predict the population because it is dependent on development, education, and also individual behavior. My understanding is that it would have been much safer development if they had had more reliable sources of energy.

Question: *How can we go to Mars or even to the Moon when we're facing a major constraint, which is to be able to cross the Van Allen radiation belts?*

Dr. Pulinets: It's a problem, but we can select the trajectory of the space vehicle to pass in the polar regions where the magnetic field lines go inside the magnetosphere, and between them, we can send our space vehicle. Essentially, this was the way our polar missions were sent to the Moon. Yes, the radiation belts are a problem, but it is possible to select the special trajectory of the space vehicle to avoid danger to the astronauts.

Various partner nations' contributions to ITER are in the form of manufactured components, such as magnetic coils, vacuum vessel pieces, and so forth. Today, there seems to a trend of placing sanctions on companies from some of the nations involved in ITER. Has this impacted ITER, and if so, how have you dealt with it?

Dr. Bigot: Seven nations have signed the ITER Agreement, with a total of thirty-five countries joining forces because they know there is no alternative option for them to develop fusion. Since I have been involved in the ITER project, whatever political debates happen among the members, ITER has not been impacted. They all realize that they have to preserve fairness among them in order to succeed. So, for the time being, I have not experienced any difficulty about what you said, about the banning of some companies. So far, it has never happened, and work has been proceeding in the best way.

The ITER project is a good illustration that when there is a common understanding among all the nations and the political leaders, that there is no alternative option for them but to join their forces, sincerely, so that work can be done. From my point of view, it's a very good example for many other issues the world is facing, for example, about food, medical, disease, all these things. I ask you to pray to preserve this type of cooperation in ITER, as well as in many other fields.

Dr. Pulinets: Scientific cooperation has always prevented military conflict. We remember the Soyuz-Apollo common space project between the United States and the Soviet Union. Now, we are many countries working on the medical vaccine against COVID-19, and so on. It is very nice to hear of a large scientific project which unites different nations, even if they have some conflicts in different issues. For example, China with India, and so on.

A question directed to Dr. Dean, Dr. Kemm, and Dr. Pulinets: *What about a 15-year program for building a new design for a nuclear fission plant, including*

Pebble-Bed and thorium designs, moving to fission-fusion hybrids, and then fusion at the point of feasibility? As better technologies come online, we discard the old, but we evolve from fossil fuels as much as we can. We can, if we wish, use as much oil or coal as we want, because we have a vision of where we are going.

Dr. Dean: I think the development track that was just described is a possible track, except for the last point you mention. Which is, we can then use as much fossil fuels as we want, because we have a carbon problem into the atmosphere that needs to be dealt with in the next several decades. But in terms of the technology path of coupling fission and fusion, and then going on from there to pure fusion, that is definitely a possible development track. It is not a track that either fission people or fusion people seem to be pushing for. They each like their own separate tracks, but it has definitely been looked at from time to time, and it is technically a track that could be followed.

Dr. Pulinets: I think that in addition to development of the traditional nuclear power plants, you probably know that in Russia we developed fast neutron reactors. The advantage of these reactors is that they can use all radioactive elements which remain after the first reaction. So, there is no waste after elaboration of products inside this reactor. It is a completely pure technology. Before we reach essential results on fusion, we can use instead these fast neutron reactors.

Question: *How does the increase in scale change the internal plasma confinement geometry of the fusion reaction? Does the ITER design take the unknown variables of this very complex process into account?*

Dr. Bigot: The ITER design has been developed during nearly 15 years. It was based on the decision of President Reagan and Secretary Gorbachev to launch a large international research cooperation. So, the physicists, based on many years of experience, including in the U.S. as well as in European tokamak, decided to shape the plasma as a D shape, which offers the best stability as well as the best way to collect energy. For a large plasma vessel like ITER, as I mentioned—it is over 800 cubic meters—this shape is very well suited. On some other design, maybe the shape could be different. There is not a single way to proceed, but from my point of view, this selected shape for the ITER tokamak is appropriate for the size we have right now.

Dr. Dean: I think there are some things which were developed over the years from dozens of tokamaks of various sizes. So, there's a lot of back-up from a lot of experiments from small to larger tokamaks that have gone into the optimization of the ITER geometry.

Dr. Bigot: We are fortunate now to have what we call the modelling, simulation. With a large computer and appropriate software, we can model very well the plasma behavior. So far, with this modelling, nobody has found a better shape for the ITER than the one we have selected.

But as a research program, certainly if there are some changes, we will accommodate, we are able to accommodate. It is a research project to optimize the fusion capacity in order to offer the best option for the world energy supply when we will have completed the research program.

Ross: The ITER is enormous; it's an international project. Space is an international concern. There's one space and it's for all of us. I was wondering, Dr. Pulinets, if you had any thoughts about if there's a conflict between the military use of space, and then, civil uses. One of the fields I know you've been studying a great deal, Dr. Pulinets, is earthquake forecasting using the ionosphere. Is there a big conflict between these two uses of space? Do you have any concerns about the militarization of space?

Dr. Pulinets: No, I don't think there is a conflict between these directions inside the same country. Every country has its scientific program of space research and some part of the military program. But when we go to the international scale, here appears the source of conflict because we are developing technologies which give possibility to change the orbit of space vehicles and to approach different space vehicles. Everybody feels a threat that somebody could do something with his vehicle. I think the only way, is to develop wider international cooperation, to make common projects.

For example, our Space Research Institute put several devices on the European mission to Mars which is working now. We put devices on the mission to the Moon. Russia launched a regular telescope and had two devices from Germany. This is the way. Then, the scientists meet together, do common work, and this is the best way to avoid the military conflicts. To avoid these conflicts, we should create good agreements on the peaceful use of space. Unfortunately, recently the United States left some of them, and this creates an unstable situation.

A question for Dr. Paluszek: *My question is on the implications of Direct Fusion Drive (DFD) for Artemis, the Gateway, and Moon villages. Where does DFD stand in relation to these projects?*

Dr. Paluszek: That's a great question. Remember, Direct Fusion Drive is many years off, so if we're landing people on the Moon by 2024, 2028, it really won't be ready to support that. One architecture where DFD could be valuable is as a transport of materials. If you wanted to move a lot material between Earth orbit and lunar orbit, and had enough time to do it—in other words, it was not a vehicle with people on it, because you would not want to expose them to cosmic rays for long periods of time—then it would be a way of moving a lot of mass so that we could expand lunar settlements. But at the moment, it's really not in a position to support Artemis as it's going on now, which is pretty much following the Apollo template.

A question for Dr. Paluszek: *Your design is quite small, compared to ITER. And it obviously has a slightly different purpose. Do you think that work being done on fusion for space propulsion and space power could help make advancements for the development of fusion here on Earth?*

Dr. Paluszek: Absolutely! The work being done on ITER helps us; we read all the technical papers and all the plasma physics. The areas of controlling the plasma in ITER are directly relevant to us. Any time you look at an area in plasma physics, whether it be our machine, which is one type of configuration; there are mirror machines, there are stellarators, everybody benefits. Anytime you look at something from a slightly different point of view, you may discover new things. We're always talking to people who work on tokamaks, the plasma physics lab, they have a different configuration, the national spherical tokamak experiment. We're constantly exchanging information and ideas with them. The more people there are working in this area, the better off everybody is.

Two questions from Berlin: *When will the first fusion power plants be finished for using electric energy? When will mankind settle on the Moon and Mars?*

Dr. Dean: We do get the joke: "Fusion has always been 30 years away, and always will be." It's taking a while, and it's going to take a while longer. My personal opinion is that we don't really know. I think it could be done in 15-20 years, and it could take 30-40 years. We're all watching to see how ITER goes, and we're all looking at a bunch of—as I mentioned in my talk—a bunch of ideas to see if we can get fusion with something a little smaller that might be able to be built faster than ITER. ITER has really advanced the capabilities around the world to make the kinds of equipment that any fusion machine in the future may need. So, it certainly allows any idea that people have, for moving faster to a timeline goal more doable.

The truth is that right now none of the countries have a commitment for any kind of a timescale to say, "We're going to have fusion on the grid by such and such a time." You will hear various advocates of various concepts, especially in the private sector, say that in 10-15 years they'll be making some electricity, but that's sort of about the fastest you can imagine doing it. But it could well take longer.

My personal opinion is that maybe by the year 2045 or 2050, there will be at least one fusion reactor putting electricity on the grid. But there's not going to be a hundred of them. A few fusion reactors are not going to make a dent, percentage-wise, in the world's energy needs. So, even when you have the first one, say in 15-20 years, it's going to take decades before fusion is making 30% of the world's electricity.

Ross: Did it have to take this long? Steve Dean just brought up this joke that fusion is always some number of years away. Why is that a joke? In other words, was that correct when it was said, say 30 years ago? Were those estimates unavoidably wrong, or was this just a lack of a commitment to make a breakthrough that could have already happened by now?

Dr. Bigot: If I may comment to Steve. From my point of view, ITER is a very sizable piece of equipment. It takes nearly 25 years with seven ITER members, which represent quite a large share of the world industrial capacity, to build it. So, it took quite a long time in order to assemble this large coalition.

From my point of view, this is the first question—people know from the beginning that we need quite large equipment in order to be able to demonstrate the feasibility of hydrogen fusion.

Second, the quality of the work which has to be done in order to ensure the condition for this burning plasma is quite strict. For example, just to manufacture one of the nine vacuum vessel sectors, which are double-walled stainless steel pieces weighing more than 450 tons, nearly 20 meters high, by the best company in the world, took nearly six years.

We are now passing a point where the feasibility of this development is quite predictable, to achieve a first plasma by 2025, but still it is a challenge. After that, we will proceed according to what we call a staged approach, where we will complement the installation in order to have, for example, the recycling of the fuel and also the breeding system of the tritium. In this way, we are complying with our goal of full fusion capabilities by 2035.

My belief is that engineering capacity and industrial capacity will take over as a result and develop fusion power more rapidly than some people believe. That's why I am fully online with what Steve said a few minutes ago. By the middle of this century, we will be at a turning point where this technology will have demonstrated its capability or not. If it has demonstrated its capability, it will be developed very rapidly. We cannot sustain burning fossil fuel as we do now. So, we know whatever development is available in energies, we will need a complementary way of producing predictable, massive power.

In the past, it was right that fusion was always 50 years ahead, because we have not taken the proper measures. Now, I do believe we have taken the proper decision to move in a steady way to demonstrate the capacity of hydrogen fusion.

Dr. Pulinets: On the second question, about the Moon and Mars. It is connected with the previous one about radiation belts. It is not a problem to bring the people to the Moon and Mars, because it was already done. But still remains the problem of the long stay of people on the Moon and Mars; it is solar radiation. We have not enough good measures to protect people from radiation. So, I suppose the main problem will be not the transport of people to the planets, but to protect them from the solar radiation.

A question for Dr. Kemm: *How is it that South Africa has been able to secure such a vastly different standard of living than other nations in Africa? Why has South Africa been able to develop nuclear power while other African nations haven't? Is it because of the historic economic advantage, a conscious fight against supranational institutions like the IMF and other efforts to impose constraints on development?*

Dr. Kemm: I think that's a difficult question to answer. One of the things was, of course, that the Cape sea route was very important since the late 1400s, when Portuguese explorers first rounded the Cape on their way to India. So, there was a lot of economic activity that occurred around Cape Town.

Because of the importance of that, the British moved in, the Dutch moved in, the French moved in; there were a whole lot of people that came into South Africa. Some of the early Dutch settlers were only interested in settling on farms and having their cows and their crops. They were very religious people who left Holland.

Two internal republics deep in the country were formed; one was called the Transvaal and one was called the Orange Free State. There was a rural lifestyle there, based on farming. Then fortunately or unfortunately, depending on whose point of view you look at, diamonds were discovered in one, and gold was discovered in the other. That attracted the business people, the industrialists, and that ended up in the famous Boer War at the end of the 1800s, into the early 1900s.

Interestingly, Russia came and fought on the South African side, and so did the United States, and so did some French people. There was a famous French general who came and fought for South Africa.

There was this complete mixture of people, and this was to do with the discovery of the wealth. I think that catapulted the country forward a lot. It didn't happen to some of the African countries that were deeper in. Then over the years, South Africans have shown a lot of initiative, and we've been frequently isolated and so people found their own solutions.

South Africa is, I think, the third oldest nuclear country in the world; we were in on this very early. The South African Atomic Energy Corporation, the nuclear energy corporation, was established in 1948. The Atomic Energy Commission in America was established in 1946. So, we were only two years behind. Nuclear has been going for a long time here, and there's just been a lot of interest. Even now, there's a youth nuclear society of a couple hundred young people who see nuclear as a career option.

Part of what we see here, is this unreasonable attack by extreme Green organizations trying to prevent African countries from getting into nuclear technologies. Not only African countries, many countries, supposedly to save the planet. It does not appear to be the case at all that the carbon dioxide produced by mankind is actually the problem, as Dr. Pulinets pointed out.

Part of what we need is, we need society to listen much more to scientists. We need scientists to talk to society. There's been a traditional divide there. Scientists talk very technical language to each other. They think they're reducing the language sometimes when they go from post-graduate level to just under-graduate level. But that's still about four or five years ahead of what the average member of the public can understand. Then it's the politicians and the people holding the money like the bankers, who are the ones who largely determine where a society goes.

So, I think it's terribly important that science must much more explain to society what's going on. Things like tokamaks, things like nuclear-powered engines for space and so on—that's the leading edge of thinking which one of these days will lead to nuclear reactors on land which supply power for the lights in the street. It's this sort of thing that is going to advance society, and that's what we need to get right. It's important.

At the moment Africa desperately needs more electricity, and they've been told to go for things like solar and wind options, because that's supposedly in the interest of the planet. But it plain and simply isn't. As Paul Driessen pointed out, it's killing people here in Africa. They're dying because they do not have fundamental electricity deeper in Africa. Many of the countries there are 15% electrified, for example. It's immoral to tell them they can't get more electricity.

At the moment, it looks like one of the best ways to do it is small, modular reactors of various types, of which the South African PBMR and another variant, the HTMR-100 that has also been developed here—a simpler version of the PBMR—are solutions for Africa and elsewhere. So, we need to put those solutions into operation.

We can't be held back because somebody else's politics are holding us back. I think countries like Russia—I've been to Russia a number of times—they have very similar problems to us socially. You see it in South America, you see it in Indonesia, you see it in India. There are many countries that are in the same position. We have a very advanced First World element to South Africa, but on the other end, we have people living in mud huts. We better bridge this divide. That is the situation faced in many parts of the world, and it needs attention.

A question for anyone on the panel: *How could the development of fusion power affect mankind's ability to deal with the dangers of asteroid and comet collisions with Earth—what is sometimes called the Strategic Defense of Earth?*

Dr. Paluszek: A fusion rocket will allow you to intercept an asteroid earlier, and the earlier you intercept an asteroid, the easier it is to push it, so it won't hit the Earth. So, that's one of the potential advantages of fusion technology. You can also do it with other kinds of technology—nuclear thermal, nuclear electric—but fusion would allow you to do it.

Dr. Kemm: I think what's also important there, in dealing with something like fusion and so on, it's the leading edge of thinking, and you need to encourage the leading edge of thinking.

We've been hearing for a while about this fourth industrial revolution. What the fourth industrial revolution is, is to take the tools at your disposal and see what ideas you can come up with. If you've got more tools at your disposal, whether it's fusion technology or more advanced fission technology, also better telescopes and mechanisms for looking into deep space to detect asteroids and so on when they're still far away, the navigation to get there very accurately. All of that needs to come out from the advanced thinking which needs to be encouraged.

Once you have much more information at your disposal and more tools to deal with it, then you can go out and get those asteroids early. Because what happens with the asteroid if you detect it early enough, with a small deflection, you can send it away. But if you get it too late, then even if you blow it up, you still effectively [allow the fragments to] blast the Earth with a shotgun blast.

We need to be able to advance technology generally, and that means fusion thinking and many other types of thinking should be encouraged. Because that's where the Earth is leading, where the gulf becomes even greater between what the scientists understand and what the public understands of what the scientists are trying to tell them. So we need to be aware that that gulf is dangerous if we don't make efforts to inform people of what's going on.

Ross: I have a question for Dr. Kemm. If fusion had been achieved in the 1990s, what would Africa look like today?

Dr. Kemm: I think if fusion had been achieved, of course, we would have been able to produce incredibly cheap electricity in great volumes. In South Africa, nuclear power today is the cheapest power by far, but there's political resistance against it.

But certainly, if fusion had come about in the 1990s, for example, such that it was economically viable—and you could place them wherever you want to and get fuel, which is effectively from seawater—those problems would have been solved, and it would have led to very cheap electricity. That should be an objective to try and get the cheapest possible electricity that we can, that's as distributable as much as possible. Because that enables people to think and to come up with solutions to solve the sociological problems which we have.

When we get people now, as Paul Driessen said, who come along and say, in the interest of the planet they're going to put the brakes on development, it just causes many more people to die.

In fact, I believe that if many more coal-fired power stations were built in Africa, it would *reduce* CO_2 emissions. That sounds back to front. The reason why, is that there are tens of thousands of people who have cooking fires outside informal dwellings, and they just burn wood, charcoal, dung, anything they can get hold of. That's producing a lot more atmospheric pollution and a lot more CO_2 than a controlled, high-efficiency, coal-fired power station.

One has got to look scientifically at what are the solutions for mankind, and we ought to stimulate all over, which includes the physics of tokamak development and toroidal devices one way and another. And fusion and so on, because it's that leading-edge science which eventually becomes the economically viable science that goes into everyday devices. So, we need to encourage all of it.

Ross: The whole platform overall of electrification. Leaving CO_2 aside for a moment, if you talked about air pollution in terms of having an immediate effect on human health, building coal-powered plants in areas that don't have electricity, *of course* reduces air pollution. Certainly, experienced air pollution, compared to a fire in your home? That's a lot of pollution right there.

Dr. Kemm: This is why nuclear is a solution for Africa. There are too many people who see big nuclear as being for the advanced First World, and it's not the case. Building pebble bed-type reactors, small modular reactors of 100 MW even down to 10 MW—there are designs for 1 MW. I believe there will be nuclear power on Mars, for example. There's not any other alternative. So, going for small nuclear, and understanding that nuclear is the future.

I'm convinced that in 100 years' time, 200 years' time, children will be taught, "Way back at the beginning of the 2000s, when mankind wasn't sure about the transition to nuclear." Just like now, we look back a century and say, "Good heavens! Horse-drawn carts in London and places like that gave way to trams and motor cars." These were all considered hare-brained schemes. Wooden sailing ships gave way to steamships. All of these at the time were massive transitions in the psychology of society. I believe we're right in one of those now. We're in a psychology where we've got to understand that nuclear is the right answer.

You find, for example, false impressions that are there around the world. Look at Fukushima. At Fukushima, *not one single individual was killed by nuclear radiation;* not one single individual was *harmed* by nuclear radiation. No private property was harmed by nuclear radiation. People died because of forced removal, because they had heart attacks when they were forced to move out of their houses in a hurry. But nobody died from nuclear. So, Fukushima was not a nuclear accident; it was a conventional industrial accident as happened at the oil refinery down the road and has happened at the airport and the shopping center and many others.

Chernobyl as well; the same thing there. The total deaths in Chernobyl were something like 50. But the figures that go around the world in some circles are thousands and millions, and so on. The psychology that's created to be anti-nuclear and is effectively anti-progress is huge. Dr. Pulinets mentioned that type of thing very much.

I've talked to many senior politicians and bankers, and often I walk away appalled at their lack of understanding. Then I say to myself, "But what have we told them?" You find bankers haven't the faintest idea of how nuclear works. They vaguely read about it in *Fair Lady* or *Vogue* or something like that maybe, but they really have little understanding. This gulf is getting bigger. The gap between somebody talking about toroidal fusion devices, tokamaks, and so on, and then talking to some person in the pub—it's huge. We've got to address that problem; otherwise, there's a scare reaction. People say, "I don't understand it, so I'm opposed. Let's block it." We can't allow that to happen, so we better much more talk to people and get them to understand what's going on.

Nuclear medicine was mentioned earlier. South Africa exports nuclear medicine all over the world, to over 60 countries. There too, when you say to people, "I want to deliberately inject you with some radioactive material," a lot of people get scared. You must explain to them beforehand, that it is very mild, it all disappears within a few days, and it's highly beneficial. But the whole system at the moment of medical aid and so forth, doesn't make that easy. The system can be very easily deployed, and where it is working, it's working exceedingly well.

But we need to really go out and do a much bigger campaign to explain to people why these things are so important and why they have to believe in them and believe in the scientists such as you fellows who are here today that know what you're doing. But it's difficult to get ordinary people to understand what's going on.

Question: *What would be the advantages of moving to helium-3 as a fusion fuel? And what are the prospects of mining helium-3 on the Moon?*

Dr. Bigot: Helium-3 is also one of the possibilities for fusion, definitely. But as you know, it is a very tiny quantity in the world. So, if there are larger sources of helium-3, yes, it could be an option, replacing for example tritium. It has been demonstrated on some of the sites. But, so far, there is not. So, yes, if there is an easy way to get this material from the universe, it would be interesting. I know some people are thinking about that.

Dr. Paluszek: Our design uses helium-3, but our device is much smaller than ITER. And a lot of the advantages of helium-3 reside in smaller designs. One of the problems with the helium-3 deuterium reaction, well, that has no neutrons. You do have [some neutrons from] side reactions. The other problem is that you have to get the very high temperatures. The Tokamak Fusion Test Reactor [at the Princeton Plasma Physics Laboratory] reached about 50 kiloelectron volts; you need to get closer to 100. So, that is a problem which deuterium-tritium does not have as much. They don't have to be heated to quite as high a temperature.

But as pointed out, the supply of helium-3 on the Earth is very small. If you were to use it now, I suppose you could actually burn it in a reactor. You're talking about 100 MW of power, which is a tiny fraction. Perhaps valuable for some very high-value applications, but not for general power.

In terms of helium-3 mining on the Moon, there is helium-3 in the regolith; it would be expensive and complex to mine, as an economic problem. What is the cost to get helium-3 back from the Moon to the Earth? No one really knows; there have been a lot of studies, but they're just speculative.

Also, the gas giants have helium-3 in their atmospheres, and that's another possible source. But again, it's something where people have done a lot of paper studies, and they're good quality studies, but until you actually start building the technology to do these kinds of things—to mine the Moon, to go to the gas giants and extract helium-3—it's all very difficult to know whether or not it could have a major impact on fusion energy development. Right now, the D-T [deuterium-tritium] approach is good, because deuterium is widely available, and tritium can be bred. So there is an ample supply of those fuels, and that's why all the mainstream fusion efforts are using D-T.

Dr. Dean: I think the subject was thoroughly and correctly just covered.

A question from a young person from the Bronx, New York: *I want to suggest that we have a panel like this, which can be several hours long for young people, just on this question of energy and the direction of the future. I have talked about the idea of a space Civilian Conservation Corps, which means space research centers built inside the Bronx where I live, and other poor areas. This should be done all over the world. But young people need to get on a Zoom platform with many of you and ask questions. Will you do this?*

Dr. Kemm: Yes, absolutely. This is the type of thing that you do need to do. This is what I've been saying, and I've quite a lot gone around to various schools and places like that, and chatted to people. What you find are some very well-meaning people who have got such incredibly misguided ideas. It's not that they're trying to be negative, it's just that they so don't understand something that we take for granted, that they come to such incredibly false conclusions. People believing that radiation is something like honey that will drip down off a table onto the floor, or something. You try and explain that it's got to go in straight lines. That one actually happened to me, and there's numbers of others as well.

You just cannot believe what people believe, the lay person. You say, "Who told them the truth?" And we don't. So, I think it's very important for these young people to get this. Because what do we see on the other side, like with the extreme Greens, to put it bluntly? We see school children marching in the streets, telling they're not going to survive to the end of their lives of their natural generation because the planet's going to collapse, and so on. So, there's a lot of problems like this.

I think space advance is going to go a lot faster than we think. If you look at the SpaceX rockets that have been launched now—there's one going up about every 10 days. They've been made to reverse down. Just a few years ago, if somebody had said, "Imagine a vertical rocket that takes off, goes all the way up to space, and then reverses backwards and lands on its own legs on the place that it took off from." You'd say, "No, that's science fiction; that's not going to happen." But it has.

The Mars Starliner has launched a couple of test flights now. It comes back and lands. That's going to go to Mars, and it's designed to carry many people. I think we'll see a Mars base in no time. I think we'll see the mining of the Moon; we'll see the mining of asteroids. The gas giants may be supplying helium-3. I think a lot of these things are going to come about.

Just cross your mind back only a few years before GPS on your cell phone. If somebody had said, "Do you know about GPS?" I knew about that when I was student, but that was aircraft carriers with two-meter diameter antennas aimed at satellites. Multi-million-dollar systems for an aircraft carrier. If somebody had said, "You can have GPS in your car," I would have said, "No, that's impossible. You'll never be able to do that; it's beyond good sense." But we do it today.

Emails, so on and so forth. It's unbelievable what we now accept as reasonable, which only a few years ago completely wasn't reasonable to the man on the street. We as scientists know that in the not-too-distant future, the next 5-10 years, there are other things which are going to come about which sound now completely unreasonable; let alone what's going to happen in 20-30 years' time. There are things we can't even believe are going to happen. Even more reason to keep the research going on fusion, tokamaks, toroidal, all sorts of devices, and any ways like this, too. Because things are going to happen that you just can't conceive of now.

So, yes, we need to chat to young people and say, "Try and use your imagination to try and understand what we conceivably have in the pipeline. Because it's there, it's coming."

Dr. Bigot: Reacting to what the young fellow from the Bronx said, I do believe we need much broader education efforts. And these new electronic devices offer us a unique chance to share directly the ideas of the ones who are now in charge of developing some research for preparing the future of the world, with the young generation, to motivate them to consider science—as it was stated a few minutes ago—a real asset for the world to overcome the difficulties we face. It's why I am pleased to see all the speakers today spending four hours of their time and answering questions from the public. Maybe this will be widely broadcast and produce new motivation.

As part of the ITER organization, I receive a lot of requests from the younger generation. Every week, I pick one or two of them, and I offer a 15-minute Skype call with me. I can say that these calls are usually very interesting.

Dr. Dean: I'd just like to add that Bernard is to be congratulated. He's in the midst of a very difficult construction management task, and yet he has shown so much willingness to broaden out and make opportunities available to young people through his internship programs and various other things like he just described.

In closing, I would like to say that I've enjoyed the few hours here that we've had together. Hopefully, we can all keep in a little better communication together as we go forward.

Dr. Paluszek: I think it's important that young people get involved in science and technology. It is the obligation of everyone who is doing research and development of it, as we all are doing, to make sure that happens. We hire a lot of interns, and we find interns are a great source of enthusiasm, and oftentimes really great ideas. We talk to elementary schools, middle schools, so this is all an excellent thing to do. The important thing in general is to make sure that the people are educated consumers of the information they get so they can make decisions, so they can support technologies or things that are good for society. And they're able to make their own decisions, because they're getting all the information.

Dr. Pulinets: I support Professor Kemm; we should make wider scientific outreach to young people. We should bring these ideas to young people. They need to understand what we are proposing. This is the first thing. Secondly, we discussed energy, how to support human life on our planet. We see the perspective for fusion is only the middle of this century, and we have discussed what to do during these 30 years between today and the middle of the century. Again, I want to support Dr. Kemm on that. Nuclear power is the only possible alternative to thermal power plants and the use of oil, coal, and so on. This technology is safe and will provide the energy to different countries, especially for Africa, which needs this energy.

The last thing is that we should develop the wider scientific cooperation like ITER. We have many areas for such cooperation in physics, medicine, space, and so on. We should provide a force to organize this widest international scientific cooperation. Thank you very much.

Ross: I'm very happy with the request from our young person in the Bronx, I'm happy to help in any way I can on that. Look, something very bad happened 50-60 years ago, through the 1960s, between the time of the assassination of President John Kennedy, the assassination of other leaders, the creation of a total shift in culture. A projection of the past, some of that was correct, but much of it wasn't. A tendency towards thinking that development is a problem; that the Earth is imperiled in a dramatic fashion; and that the way to fix these things is to hold back on technological progress; or that science is creating problems, or development is creating problems.

In fact, it's exactly the opposite. As Kelvin Kemm discussed the use of dung and what have you, for fuel, that's very bad for the local environment inside your home if you're burning wood in the middle of it. The worst kinds of conditions, as described by Paul Driessen, in terms of resource extraction, of children working in cobalt mining, the poor conditions for that in the Congo. These are relatively poor areas. Whereas, in areas that are more developed, you find in general a much cleaner living situation; a much improved one.

Progress was really hijacked as a concept from what it used to mean in the 1940s and '50s, which was getting power out to people; getting power out to farmers; bringing electricity to the world; ending colonialism and imperialism at the end of World War II. President Franklin Roosevelt intended that he was not planning to defeat the Nazi and the Japanese empires to let the British Empire just keep doing its thing. He totally opposed that. He said, "We're going to free all of these colonies, including yours, Winston Churchill."

In now saying, "We've gone too far, let's go back," the effect of this has been, especially on the poorest people within the United States and especially around the world, the withholding of energy sources that can make their lives much better. This is unconscionable and has to be rejected.

Achieving international cooperation on big things like ITER is great. We should be doing it on so many broader levels. The Chinese Belt and Road Initiative that Helga Zepp-LaRouche described in the first panel, the big push towards cooperation and infrastructure with neighbors. Where is that sense of huge infrastructure advancement in the United States or Europe right now? We don't have them in the same way, and we would benefit so much from these broad projects, from dramatically increasing the funding for science, for space.

The optimism that creates, from seeing new breakthroughs, seeing these new developments, from seeing poverty eliminated from year to year around the world, will be a balm for people, and I think it is a very important part of reconnecting around what it is that makes us human: The shared ability to make improvements in the lives of literally everyone on the planet. That is the kind of real direction to create, to displace this promoted tendency right now to break apart people's identities into small pieces, to look for micro-aggressions, all this kind of stuff that we're familiar with.

Part of what makes that possible is an education system that puts too little emphasis on recreating discoveries; that focusses more on assessing people with just countless tests; assessing people based on having the right answer to questions, and not really having the time or the freedom to say, "Let's go through and let's remake a discovery. How did Eratosthenes discover that the Earth was round, and measure it? How did he do that thousands of years ago? Let's do that in our school now, with another school." That's something every kid should go through.

Is the Pythagorean theorem true? The geometry isn't hard, but it's almost never done, so people just get this habit of thinking they know things, when really, they don't. The real problem in that is that acquaintance with the discovery process itself is something we really need to cultivate in young people to have the most fruitful next generation of scientists and thinkers and people who are able to understand and appreciate what we have in common as human beings on this planet, and what sets us apart from the animals.