INTERNATIONAL SEMINARS ON PLANETARY EMERGENCIES

Executive Summary Plenary Report

57th Session

7th – 13th August 2025

Chairman: Antonino Zichichi   Co-Chairman: Cristian Galbiati

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Overview

The 57th session of the International Seminars on Planetary Emergencies at the Foundation Ettore Majorana and Centre for Scientific Culture[1] (FEM) took place between 7-13 August 2025 in Erice, Sicily. The Seminars began in 1981, in midst of the Cold War. Each year, nuclear physicists, and advisors to leaders of the most powerful nations had the opportunity to freely exchange ideas and have discussions, at times very heated, thinking about the possible benefits in finding room for positive collaboration among nations that were on the brink of war. One significant result of those discussions was the historic Seminar in August 1987, where Professor Zhou Guang Zhao (Scientific Advisor to Premier Deng Xiaoping), Professor Edward Teller (Scientific Advisor to President Reagan), Professor Eugenij Velikhov (Scientific Advisor to President Gorbachev) and Professor Antonino Zichichi (Chairman of the International Committee 'Science for Peace', President and Founder of FEM), reached an Agreement for International Scientific Collaboration East-West-North-South without Secrecy and without Frontiers.

The Seminar this year had eight sessions in which 95 scientists, from 25 nations, participated and spoke. The following topics were discussed among a multi-disciplinary assembly of scientists, policy analysts and other experts:

- managing international conflicts and arms control, pandemic treaty,
- biomedical discoveries, therapeutic strategies and risks,
- the biological and social factors underlying metabolic and neurological diseases,
- data centers and small modular reactors,
- combating wildfires and the WFS wildfire project,
- recovering from disasters,
- mitigating risks from solar maximums,
- challenges of cybersecurity and AI,
- environmental dangers for human health, biodiversity and sustainability,
- batteries, mineral mining, and
- the water crisis.

The key messages of each of these eight sessions are in the next page.

[1] https://ettoremajoranafoundation.it/

Professor Zhou Guang Zhao (Scientific Advisor to Premier Deng Xiao Ping), Professor Edward Teller (Scientific Advisor to President Reagan), Professor Antonino Zichichi (Chairman of the International Committee 'Science for Peace') and Professor Eugenij Velikhov (Scientific Advisor to President Gorbachev), shaking hands after reaching the Agreement for International Scientific Collaboration East-West-North-South without Secrecy and without Frontiers.

Keynote Address
Cristian Galbiati[2]

For this keynote lecture today, opening the 57th session of the International Seminars on Planetary Emergency, I would like to speak about Enrico Fermi.

Enrico Fermi is one founding reason why we are here today. As you know, Enrico Fermi is credited for being the greatest Italian physicist after Galileo. He had a profound impact on the world of Italian physics and science. The school of physics that he created in Rome in the 1920s and 1930s is still today producing profound effects on Italian physics and on Italian academics. Istituto Nazionale di Fisica Nucleare, which was presided by Antonino Zichichi in its moment of greatest expansion and greatest impact in Italy, has a deep connection with the Fermi School: Amaldi, one of his beloved students, played a key role in the foundation of the Institute. The presence of INFN in the post-war period allowed to establish a strong presence for Italy in the world-wide community performing fundamental research in particle physics. Thus group "Ragazzi di Via Panisperna", through the influence of Amaldi and colleagues, played a critical role in shaping in Italy innovation, invention, and creativity in science across two eras, before and after the war.

When we speak about Fermi, we should remember his strong association with the "golden standard of physics". Fermi was known by his students as "Il Papa", for sharing the one trait that is attributed by to the Pope by a dogma of the Catholic church, which is infallibility when speaking ex catedra in matters of doctrine (of course, in matters of physics in Fermi's case).

Fermi was indeed very close to infallible. But perhaps not the fastest nor the most brilliant. It was reported by Majorana was outshining Fermi in certain matters pertaining to theoretical physics.

Much of the credit for the success of Italian physics today is due to the scientist Enrico Fermi. Most certainly, without Fermi, we would not have had Ettore Majorana. We would not have had the beautiful centre in which we are hosting this important event today.

It is thus very important to talk about Fermi and remember his legacy. And it is sad to have to do it because of one of the major emergencies affecting the world today: the epidemic of misinformation. Recorded history shows us that misinformation in politics

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has been around since before the Roman Republic and other ancient societies, often to justify conquest and war. That's part of the human story that probably goes back to pre-historical societies. However, we've seen misinformation having a more insidious role in areas that we used to think were exempt. We've seen misinformation playing an important role, not only in the politics and the social sciences, but also in science, giving extremism and extreme ideas more credibility than they deserve. This is something that we need to discuss and address, in the great tradition of Erice, where our inquiries are based on facts and collaborative discussions, not ideology. Our meaningful confrontations lead to new ideas and progress in the political and scientific discourse. But this is not always the way in the real world out there, where extreme positions are not only taking over the political discourse, but are also contaminating scientific debates.

I would like to use as an example, vicious statements on Enrico Fermi that appeared on the most important Italian newspaper at the beginning of this week. I am talking about the op-ed by one of the most influential physicists-influencers, Carlo Rovelli, appearing on Il Corriere della Sera. The op-ed, focusing on the history and the birth of nuclear weapons, contains some truly vicious and unfounded attacks and assertions about the beloved figure of Enrico Fermi. I will take the liberty of translating in English a few sentences from the op-ed, which can be found at https://tinyurl.com/32ytmaj4:

I fisici teorici, come me, hanno fatto all'umanità un regalo avvelenato. Le armi nucleari che oggi incombono su di noi come un incubo, nascono da un errore di Enrico Fermi, fisico italiano. Nel 1934 Fermi, iscritto al partito fascista, nominato da Mussolini membro della Reale Accademia di Italia, massone della Loggia del grande Oriente d'Italia, insieme con il suo gruppetto di brillanti studenti, i cosiddetti "ragazzi di via Panisperna" perché lavoravano in un laboratorio in via Panisperna a Roma, crede di avere scoperto un nuovo elemento chimico, anzi, due.
La scoperta viene annunciata al mondo intero. Il regime fascista si inorgoglisce. Nel 1939 Fermi riceve il premio Nobel per questa scoperta. La motivazione del premio è "la scoperta di nuovi

Theoretical physicists like me have provided to humanity a poisoned gift. The nuclear weapons that today stand upon us like a nightmare, they were born from an error of Enrico Fermi, Italian physicist. In 1934, Fermi, a member of the fascist party, appointed by Mussolini as a member of the Royal Academy of Italy, a mason of the Lodge of the Grande Oriente d'Italia, together with his group of brilliant students, the so-called "Boys of Via Panisperna», because they were working in this lab in Via Panisperna in Rome, he believes to have discovered a new element, or even better, two.
The discovery is announced to the entire world. The fascist regime takes pride in it. In 1939, Fermi receives the Nobel Prize for this discovery, and the motivation of the prize is this discovery of new

elementi". Fermi li battezza Ausonio e Esperio. I nomi vengono da Ausonia e Esperia, antichi nomi dell'Italia. È un omaggio alle glorie italiche che canta Mussolini.

elements. Fermi christens them Ausonium and Hesperium. The names come from ancient Italian history. This is a gift to the Italic glories promoted by Mussolini.

These statements by Carlo Rovelli contains some unfounded claims. The 1939 Nobel Prize for Physics was awarded to Fermi with more profound and very solid motivations. It is true that at the time of the Nobel Prize not only Fermi, but the entire scientific community, believed that the work of Fermi and others had produced transuranic elements, which is to say, elements heavier than uranium. But the real motivation for the recognition of Fermi's work was different: Fermi and his group had discovered, in the most brilliant of fashions, that to trigger a certain set of nuclear reactions it was necessary to slow down the neutrons till they reached thermal energy.

Some of you may be aware of the story of the fountain in Via Panisperna. Neutrons, produced as very energetic particles, were paradoxically found to be most effective in transforming elements and creating new elements when slowed down by interactions with the hydrogen of the water coming from the fountain, or hydrogen contained in wood or paraffin. The beginning of the discovery is credited to an incidental annotation of Bruno Pontecorvo, who noted that the effect of neutrons was stronger when their source was placed upon a wooden table instead of using a stone table. It was a profound discovery, product of the great ingenuity and capability to innovate of Fermi's group. This unexpected discovery was immediately recognized as a huge contribution to the development of nuclear physics, as it unlocked the power of neutron-induced nuclear reactions. All major developments in nuclear physics in the decades to come, including the nuclear pile, the nuclear power reactors, and the nuclear bombs, directly owe to the discovery performed by Fermi and his group in Via Panisperna.

When Fermi was given his Nobel Prize, it was not 1939, but it was December of 1938. Everyone physicist involved in the priming field of nuclear physics thought in good faith that the radioactivity measured in Fermi's laboratory was likely due to the neutrons being captured on uranium and producing more massive elements, the so-called transuranic elements. Only a few months later, in 1939, Otto Hahn demonstrated that some of the radioactivity measured in a replica of Fermi's first experiments was not due to transuranic elements, but to the nuclei being split in parts, the so-called fission products. And only three years later, in 1941 in Berkeley, American physicists demonstrated that fission products are indeed the major source of radioactivity revealed by Fermi's experiments. Nonetheless, the reactions studied by Fermi were later confirmed to create, albeit at a slower rate, transuranic elements. The first transuranic element is neptunium, formed by the absorption of neutrons onto uranium. So the above critique of Fermi's work contains some misleading and hodgepodge facts.

Regarding politics, it is undeniable that Fermi was a member of the fascist party, at a time when time when 99% of Italian academics were either forced or coerced into it. Fermi was married to a Jewish woman, and when the push came to shove, he had no hesitation. When the racial laws were passed in Italy, Fermi took the opportunity of the trip to Sweden to attend the Nobel prize ceremony and left once and for all Italy to become a citizen of a liberal democracy: the United States of America.

Rovelli's critique continues:

Ida Noddack smentisce Fermi: nessuno le presta ascolto. Non è vero niente. I nuovi elementi Ausonio e Esperio non esistono. Fermi si è sbagliato. Ad accorgersi dell'errore è una chimica tedesca, Ida Noddack, che se ne accorge già nel settembre del '34. Sostiene che quello che è successo in via Panisperna non è stata la creazione di nuovi elementi: i ragazzi pensavano di avere creato dei nuovi elementi più pesanti dell'uranio, irradiandolo con elementi radioattivi. Ma non era questo che succedeva. La radiazione non trasformava l'uranio in qualcosa di più pesante, faceva altro: spezzava gli atomi di uranio in due più piccoli. Noddack per diversi anni non viene presa sul serio. È una donna, e gli uomini si sentono superiori alle donne; è una chimica, e i fisici si sentono superiori ai chimici; e Fermi ha un Nobel, e chi ha riconoscimenti scientifici è considerato più affidabile di chi non li ha. Soprattutto, l'idea che un atomo, il nucleo di un atomo, possa spezzarsi in due pezzi sembrava implausibile. Invece ha ragione lei.

Ida Noddack denies Fermi: no one listens to her. It's completely untrue. The new elements Ausonium and Hesperium don't exist. Fermi was wrong. A German chemist, Ida Noddack, realized her mistake as early as September '34. She claims that what happened on Via Panisperna was not the creation of new elements: the students thought they had created new elements heavier than uranium by irradiating it with radioactive elements. But that was not the case. The radiation did not transform uranium into something heavier, but it did something else: it split the uranium atoms into two smaller ones. For several years, Noddack was not taken seriously. She is a woman, and men feel superior to women; she is a chemist, and physicists feel superior to chemists; and Fermi has a Nobel Prize, and those with scientific recognition are considered more trustworthy than those without. Above all, the idea that an atom, the nucleus of an atom, could split into two pieces seemed implausible. But she was right.

This is also a mixed concoction of hodgepodge facts. First of all, neutron-induced reactions on uranium do produce transuranic elements, albeit at a slower rate, and they produce transuranic elements via same reactions studied by Fermi and with the Ragazzi di Via Panisperna, as later confirmed in America. Second, no one was brushing away the suggestions of Ida Noddack. At the time Fermi was offered the 1939 Nobel Prize, he was also very hesitant about the production of transuranic elements.

The reality is, in December 1938 no one had yet measured the chemical properties of the elements produced in the interactions of neutrons with uranium. The first results would come only in 1939 by Otto Hahn, who is credited with the discovery of fission. No physicist, and certainly not Fermi, was ideologically against the idea of fission. Simply, no one had measured the atomic properties of the products of this reaction, and nobody knew if it was fission, or was new transuranic elements. The two possibilities were equally open at the time Fermi received his Nobel Prize, and were later demonstrated to co-exist.

For this reason, it is incorrect to characterize Fermi as rejecting the idea of fission on an ideological basis. Fermi never did that and was instead among the first in appreciating the importance of fission. In the span of a few years, the became the first physicist, managing to control, peacefully, the nuclear reaction chain, and to operate, under the stadium of the University of Chicago, the first atomic pile. Fermi was the first physicist able to take this gift of nature, nuclear energy, and to turn it into something useful and peaceful, a controlled reactor.
What I find most outrageous is the closing paragraph of the Rovelli critique:

Lo scellerato test con "cavie umane".
Gli esseri umani, barbari, si gettano a pesce sulla gioia di poter avere il potere di poter bruciare vivi, centinaia di migliaia di loro fratelli e sorelle. La scienza vede l'orrore. Qualche anno dopo, il 2 maggio 1945, il presidente Truman approva la formazione di un Comitato ad interim per riferire sull'uso della bomba atomica. Il comitato è composto da otto persone, consigliate da un gruppo scientifico composto da Robert Oppenheimer, Ernest Lawrence, Arthur Compton e Enrico Fermi. In un rapporto del 1° giugno, il Comitato conclude che la bomba debba essere utilizzata il

The infamous test with "human guinea pigs».
Humans, barbarous beings, jump at the chance to burn alive hundreds of thousands of their brothers and sisters. Science sees the horror. A few years later, on May 2, 1945, President Truman approved the formation of an Interim Committee to report on the use of the atomic bomb. The committee was composed of eight people, advised by a scientific panel composed of Robert Oppenheimer, Ernest Lawrence, Arthur Compton, and Enrico Fermi. In a report dated June 1, the Committee concluded that the bomb should be used as soon as possible against a

prima possibile contro un impianto bellico circondato dalle case dei lavoratori e che non deve essere dato alcun avvertimento o dimostrazione. Non so in che direzione Enrico Fermi abbia spinto. Che io sia al corrente, non ha manifestato pubblicamente alcun dissenso. Il regalo avvelenato dei fisici teorici all'umanità viene aperto ottanta anni fa, su Hiroshima, e Nagasaki.

weapons installation surrounded by workers' homes, and that no warning or demonstration should be given. I don't know what direction Enrico Fermi pushed. To my knowledge, he hasn't publicly expressed any dissent. Theoretical physicists' poisoned gift to humanity was opened eighty years ago, on Hiroshima and Nagasaki.

Associating Fermi and other physicists of the Los Alamos group with the joy of burning hundreds of thousands of people is wrong and totally disproved by the facts. I never met Enrico Fermi, but I had the opportunity of working closely with Martin Duetsch, professor at MIT who was a great friend of Professor Antonino Zichichi as the two collaborated on the LVD experiment at Gran Sasso Laboratories. Martin was one of the youngest physicists in the Los Alamos group. Martin hailed was from a Jewish family in Vienna, Austria, and was the son of Helene Deutsch, who was one of the favored pupils of Sigmund Freud. At age 16, with all the political turmoil hit in Germany and Austria, Martin was already a political member of the Socialist Party, fighting against the Anschluss. He had to leave his hometown of Vienna and his studies to flee to Switzerland at the age of 16. At the age of 17, he left for the United States to study at MIT. Many of his colleagues in Los Alamos, like him, were Jewish physicists chased out by the Germans and Austrians: they considered themselves as fighters for freedom, against the Nazi regime in control of most of Europe. When they were gathered in Los Alamos to develop the bomb, they put their best effort into it because they believed in freedom and in liberal democracy. They were in a race to develop the nuclear bomb before the Germans could do it under the direction of Hitler. The Los Alamos scientists, Fermi amongst them, were certainly not working for the joy of "burning people alive": they were fighting for freedom and to bring the war to the conclusion as soon as possible.

Martin Deutsch described to me also the heart-wrenching days of the decision on the use of the atomic bomb. Germany had just surrendered, but Japan, the insulated and insular imperial power was determined to prolong the war through its bitter end. It was a very difficult decision: nobody wished to be in the seat of Truman or that of the committee reporting to him. But in the eyes of the Los Alamos scientists, it was a choice between dropping the atomic bomb and a prolonged war with Japan, likely

requiring land invasion and the loss of many other millions of lives.
I think it's important for us to remember these facts as they happened.

In our era, the most vicious and the most damning of epidemics, is scientific misinformation.

It was really stunning to see the honor and the scientific integrity of a beloved figure like Fermi to be attacked in such a vicious way, not on a fringe outlet, but on the most important Italian newspaper.

So, I thought it was important today, as we celebrate the start of our 57th session of the International Seminars on Planetary Emergency, to put these statements on record.

Thank you for your attention.

Session 1: Risk assessment and arms control in the information age

Session Chairman: William A. Barletta[3]
Speakers: Francesca Giovannini[4], Tariq Rauf[5], and Lydia Wilson[6]

William A. Barletta

The PMP on the Mitigation of Catastrophic Risks has two overarching themes: The first is reducing the chances of and consequences of armed conflict involving nuclear weapons through arms control measures, the prevention of the proliferation of nuclear weapons, and understanding the roots of regional conflict that may bring nuclear weapons states into confrontation.
The second theme of MCR studies, is the application of engineering (in its broadest sense) to mitigate the consequences of major societal risks both natural and man-made. The aspect discussed this year were presented in Session 4.

Session 1 presented the first pillar of MCR studies, risk assessment and arms control in the information age, with a focus on whether the present nuclear arms control environment can remain stable. Current and emerging disruptive trends include:

- Fraying of the "rules-based" international order such as the UN Charter, International Humanitarian Law.
- Erosion of arms control/disarmament norms and treaties via non-compliance with those norms and treaties.
- Wars in Africa, Middle East, Europe and new threats to use nuclear weapons.
- Decline of the post-WWII strategic power constellations including the influence of the IMF, World Bank, NATO, G7, NAM/WEOG/EEG/G77.

Over the past two decades, several arms control treaties and less formal agreements have either expired or had a signatory withdraw. With respect to strategic nuclear weapons and their delivery systems, only the 2010 New START treaty remains in force between Moscow and Washington. New START will expire on 5 February 2026 with no provision for further extension, thus creating the potential for an open-ended nuclear weapons buildup. At the same time, China declines to negotiate concerning its nuclear forces while it is increasing its nuclear and conventional forces aiming at rough parity with the United States and Russia, thus creating the potential for tri-polar nuclear escalation. The Democratic People's Republic of Korea continues provocative ballistic missile flight

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[4] Executive Director of the Project on Managing the Atom, Belfer Center, Harvard University, USA.
[5] Former Head, Verification and Security Policy Coordination Office at the International Atomic Energy Agency (IAEA), Wien, Austria.
[6] University of Cambridge, Cambridge, UK.

tests that overfly Japan or the Republic of Korea with the aim of a reliable ICBM that can strike the west coast of the United States. Added to this are the ongoing confrontation between India and Pakistan, Israel's undeclared nuclear weapons arsenal, the potential for a nuclear weapons breakout by Iran, and the terminations of other important treaties over the past twenty years.

Presently, six of the eight nuclear weapons states are engaged in a direct/proxy manner in the war in Ukraine: on one side is Russia, China, and the Democratic People's Republic of Korea, and on the other hand France, the United Kingdom, and the United States. On multiple occasions, Russia has threatened to use nuclear explosives in this conflict. In the Middle East, two weapons states (the United States and Israel) are engaged in a two-year war against Iranian proxies of the Islamic Republic of Iran and have bombed Iranian uranium enrichment facilities and scientific personnel. Although in its most recent report, the IAEA had also concluded that Iran had violated the NPT, it also stated that there was no public evidence of a "structured nuclear weapons related programme."[7] In 2024 Iran had signed a mutual defense treaty with Russia and has very close economic ties with China. Of particular concern is whether the nuclear non-proliferation regime–centered around the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)–can survive in the face of unprecedented challenges as nuclear arsenals grow. Despite 191 State parties to the NPT, the regime's survival hangs in a delicate balance between established norms and emerging threats.

The global nuclear arms control and disarmament regime inter alia emanating from UN General Assembly resolution I (1945) that called for the elimination of nuclear and other weapons of mass destruction, is structured around the 1970 NPT with 191 States parties and its associated nuclear verification system implemented by the International Atomic Energy Agency (IAEA), supplemented by the 1996 Comprehensive Nuclear-Test-Ban Treaty (CTBT) with 178 signatory States. The 2017 Treaty on the Prohibition of Nuclear Weapons (TPNW) with 91 States parties continues to be opposed by all nine nuclear-armed States and their allies (NATO, Australia, Japan, South Africa).

[7] Chair's note: While the IAEA has consistently stated it cannot certify the complete absence of such activities, one should note that aside from its use in nuclear weapon or nuclear submarine propulsion, there is no credible use for hundreds of kilograms of 60% enriched 235U. It is uncertain whether Iran will develop nuclear weapons or how long it would take. Principal uncertainties include the inventory of centrifuges and 60% enriched 235U that survived the U.S. attack, Midnight Hammer. Iran's intentions and the countermeasures that might be taken to deter Iran's progress towards a nuclear weapon are also uncertain.

The NPT is universally affirmed by its state signatory parties as the cornerstone of the current nuclear arms control regime and rests on three pillars: nuclear non-proliferation, nuclear disarmament, and cooperation in peaceful uses of nuclear energy under IAEA verification. The NPT requires all non-nuclear-weapon States parties, currently 186, to place all of their nuclear material and nuclear activities under comprehensive safeguards (verification) administered by the IAEA, established in 1957 headquartered in Vienna.

It is generally accepted that despite 85% reductions in nuclear warheads over Cold War highs, the five nuclear-weapon States parties to the NPT (China, France, Russia, UK, USA) are not fulfilling their NPT obligations and commitments to eventually achieve the complete elimination of nuclear weapons. Since 1945, approximately 110,000 nuclear warheads have been produced primarily by the United States and Soviet Union (now Russia). Approximately 12,100 nuclear warheads remain in the nine nuclear arsenals, with more than 90% held between Russia and the United States–of which nearly 2,000 are on immediate ready to launch status thus with attendant risks of accidental or inadvertent use.

Optimistic and pessimistic possible futures of the nuclear non-proliferation regime could be:

1) Regime Adaptation (Optimistic): Renewed commitment to disarmament negotiations and confidence-building measures leading to further nuclear weapon reductions; integration of emerging technologies into arms control frameworks (AI, cyber).
2) Regime Collapse (Pessimistic): Domino effect if additional States proliferate; breakdown of non-proliferation norm altogether if nuclear-armed States continue with modernization and build-ups; fraying of existing nuclear arms control and disarmament treaties such as the NPT, and CTBT and the opposition of the nuclear weapons states to the Treaty on the Prohibition of Nuclear Weapons (TPNW).
3) Looking deeper for root causes of the emerging crisis, one needs to examine how contemporary conflicts have disrupted the international world order that was established in the wake of World War II. The present rules-based system of treaties, conventions, international law and international institutions was partially driven[8] by the 60 million deaths during WWII, roughly two-thirds of which were of non-combatants and the subsequent reckoning over the various atrocities directed against civilians during that conflict, including the Holocaust. Since the period of their codification, the principles and rules of the UN Charter and international law had been broken regularly during and after the Cold War, but never before with such impunity.

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[8] Chair's note: The second major driver was the failure of the League of Nations.

The consequences for the future will be important:

1) The geopolitical concerns in what seems to be either unstable multi-polarity or an emerging, new bipolar configuration will see an ever-greater emphasis on national security over peace-building, and on forming new alliances that may prove less durable.
2) The widening feeling of populations being at odds with the national leaders could fuel more small-scale violence, as people "take matters into their own hands".

We need to study and address both ends of the spectrum of effects, from the geopolitical to the micro-local, to understand the world after the eventual end of the wars in Ukraine and Gaza, the humanitarian crises that surround the present wars in Africa, Europe and the Middle East, the causes of and consequences of large-scale migration driven by economic, political-conflict, and environmental forces, and the incipient crisis in the South China Sea.

Session 2: Biomedical discoveries, preventive/therapeutic strategies and the risks

Chairman: Franco Maria Buonaguro[9] (Chairman, Medicine and Biotechnology PMP)
Speakers: Massimo Ciccozzi[10], Sofie Nyström[11], Emanuele Buratti[12], Felice Iasevoli[13], Neal S. Young[14], Sam Mbulaiteye[15], Ishwar Gilada[16], Per Hammarström[17]

Franco Maria Buonaguro
Introduction

Biomedical discoveries in the preventive and therapeutic fields have been significant and frequent over the past 50 years. Have they been risk-free? The latest COVID experience is the most recent we have all witnessed. Although the COVID pandemic appears to be over, with the exception of some still unresolved questions related to long COVID, the two main aspects that continue to intrigue the scientific community are (a) the potential role of laboratory manipulations as a source of a highly pathogenic SARS-CoV-2, and (b) the amyloidogenic role of the virus's spike protein and even the recombinant spike protein expressed by the recently developed mRNA vaccine. Furin plays a role in both. Furin is the first human proprotein convertase (PC), identified in 1986 [1]. It is widely distributed in all human tissues and involved in various metabolic and pathological processes, including the maturation of over 150 proproteins, particularly virtually all hormones and neuropeptides [2,3]. Furin is also exploited by viruses to increase transmission efficiency and viral tropism [4,5]. In addition to the COVID pandemic and strategies to contain it, this session reported and discussed new developments in neurodegenerative and neurocognitive diseases, as well as rheumatological diseases and rare cancers such as Burkitt's lymphoma. We must improve our preparedness for potential new epidemics, as highlighted by Ishwar Gilada, but we must also contain the risks associated with our technologies, as warned by Per Hammarström.

Massimo Ciccozzi
The Spike and the FCS evolution in Coronaviruses

In the last years several studies have been performed on the evolutionary processes of the

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[10] Full Professor of Molecular Epidemiology and Biostatistics, Università Campus Biomedico, Rome, Italy.
[11] Associate Professor of Chemistry, Dept of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden.
[12] Scientific Coordinator & Group Leader of Molecular Pathology, International Centre for Genetic Engineering and Biotechnology, Trieste, Italy.
[13] Associate Professor, Department of Neurosciences & Reproductive Sciences, "Federico II" University, Naples, Italy.
[14] Senior Investigator, Hematopoiesis and Bone Marrow Failure Unit, NHLBI, NIH, Bethesda, MD, USA.
[15] Senior Investigator, Infections and Immunoepidemiology Branch, NCI, NIH, Shady Grove, Rockville, MD, USA.
[16] President Emeritus of the AIDS Society of India, Consultant in HIV/STDs, Unison Medicare & Research Centre, Governing Council Member, International AIDS Society Mumbai, India.
[17] Full Professor of Chemistry, Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden.

SARS-CoV_2, have identified and characterized the unique presence of the PRRA Furin Cleavage Site (FCS), which is absent in other known Sarbecorvirus (lineage B beta Coronaviruses) [5-8]. Although it is possible a rare recombination event between the SARS-CoV-2 and other human Coronaviruses prevalent in the rino-pharyngeal tract, which often carry such FCS (in particular the two human Alphacoronavirus, NL63 and 229E), a laboratory engineered manipulation has been suggested to increase the pathogenicity, by a gain of function strategy, in order to establish an in vivo model based on humanized mice. Dr. Ciccozzi presentation has been focused on the key dilemma of a natural zoonotic evolution from mammalians with an ACE2 receptor homologous to the humans or a laboratory engineered recombinant virus. The key issue is the presence of the PRRA Furin Cleavage site (FCS), not present in the SARS-CoV_1 (the Urbani strain of 2003) and not present in other Sarbecorvirus strains. Several Sarbecorvirus (lineage B beta Coronaviruses) have proteolytic cleavage sites at the S1/S2 boundaries and the S2 NH_2 terminal sensitive to other proteases, i.e. the TMPRSS2, which is however not highly diffuse as for the Furin in human tissues [8]. Furin cleavage sites are in the genera AlphaCoronavirus and Gammacoronavirus as well as in other subgenera of the Betacoronavirus such as Merbecovirw; and Embecovirus, with peculiarities which suggest a different evolutionary process.

Finally, it should be mentioned that Furin cleavage is critical to many viral diseases, including HIV, Ebola, and influenza H5 and H7 [9]. Furin is a ubiquitously expressed protease in human body, with a wider distribution range than the major protease responsible for cleaving spike, TMPRSS2. Therefore, coronaviruses with spike containing furin cleavage site may have advantage in spreading [8]. In conclusion, for all such reasons, although at the moment there is not a final prove of human manipulation, all such anomalies strongly favor a human role. The obvious final question, if the active role of humans were demonstrated, would be whether it was simply a laboratory error or a conceptual error in failing to evaluate all the potential risks of a gain-of-function activity. To resolve this question, the project approved and funded by the NIH would need to be analyzed in detail to verify whether this strategy was already a goal of the project and had in fact also been approved by the U.S. funding agency.

Sofie Nyström

Amyloidogenic peptides

Prof. Nyström focused on proteins, as the working horses of life and essential for all life forms. The function of a protein is dependent on its unique three-dimensional shape, the native fold. However, proteins can also undergo a shape-shifting misfolding process and sometimes this leads to the formation of amyloid protein structures. An amyloid is a threadlike structure that is composed of many protein molecules held together by intermolecular interactions. These amyloid fibrils are notorious for their ability to recruit more of neighbouring proteins into the amyloid state and for causing a multitude of disease in humans. Neurodegenerative diseases such as Alzheimer's disease and Parkinsons disease are examples of such amyloid dependent diseases. Although the mechanism of amyloid formation is similar between several amyloid diseases, they are coupled to the misfolding, and amyloid formation of distinct proteins and the symptoms of the disease are different.

Both in the case of Alzheimer's disease and Parkinson's disease there are known genetic mutations in the culprit protein, rendering a protein that is more prone to misfold into the aberrant amyloid state. Such mutations account for 5-15% of all cases of Alzheimer's and Parkinson's disease. The direct cause of the rest, the overwhelming majority of all disease cases is not known, although several risk factors have been identified. Both viruses [10] and bacteria [11] are known to contain amyloid-forming proteins that in many cases play a functional role for the microbe. Epidemiologic studies provide an insight to virus infections as a driving force for neurodegenerative disease [12,13] and it was recently established that vaccination against Herpes Zoster gives some protection also against dementia [14,15]. Bacterial amyloids have been shown to provoke amyloid formation of the Alzheimer's disease associated protein Aβ Parkinson's disease associated protein α-synuclein [16,17].

Experiments conducted on virus derived proteins in the test tube, from both SARS-CoV-2, Influenza A and Herpes Simplex demonstrate their potential to form amyloid structures. Furthermore, adding such preformed amyloids of virus proteins to human proteins involved in Alzheimer's and Parkinsons disease results in acceleration of the disease associated misfolding of the human proteins [18] and Nyström et al unpublished. Epidemiologic evidence and laboratory experiments in concert lead to the conclusion that it is worth to follow the trail of viral and bacterial infections to find the root cause and potentially a strategic point for combating neurodegenerative disease that are devastating many lives world-wide.

Emanuele Buratti

TPD-43 misfolding and SLA

The SISMIC-TDP43 project focuses on the TAR-DNA binding protein (TDP-43), an amyloidogenic protein implicated in the pathogenesis of Amyotrophic lateral sclerosis

(ALS). TDP-43 is a 414 amino acid nuclear protein, and its misfolding and accumulation in the cytoplasm are recognized hallmarks of ALS and FrontoTemporal Lobar Degeneration (FTLD). ALS is characterized by the progressive loss of motor neurons, while FTLD involves the deterioration of frontal and temporal lobes, causing behavioral changes and language impairment. Current therapeutic strategies have failed to effectively and specifically target the structural transitions of TDP-43, often relying on non-specific approaches like increasing clearance or preventing phosphorylation. To address this problem, the SISMIC-TDP43 project, which stands for Structure based Identification of Small Molecules Interacting with and Counteracting TDP-43 aggregation, aims to bridge this therapeutic gap. Its objective is to discover, synthesize, and validate small molecules designed to bind to TDP-43. The molecules adopt a dual approach: either stabilizing physiological TDP-43 dimers or preventing and reversing pathological aggregates, thereby restoring protein function. Small molecules are preferred due to their chemical versatility, tractable pharmacology, and potential for brain penetration. The project employs five interconnected aims to systematically identify and validate candidate therapeutics and diagnostic imaging tools. These aims include: Proteochemometrics (Aim 1) that consists in mapping the full TDP-43 CTD pocketome to detect approximately 23,700 potential sites and facilitate drug repurposing by comparing them with pockets in the Protein Data Bank (PDB); Virtual Screening (Aim 2) that utilizes an AI-driven Large Scale Virtual Screening Pipeline to explore chemical space.

This massive effort involves identifying binding sites using the InDeep neural network and docking libraries, including the EnamineREAL database containing up to 36 billion compounds; Peptidomimetics (Aim 3) for the design and synthesis of peptide analogues to interfere with the aggregation process; and In Vitro Assays (Aim 4) to characterize the binding affinity and aggregation interference efficacy using advanced biophysical methods, such as ThT fluorescence and electron microscopy (EM). Finally, the project will include interactions with the Biology (Aim 5) to validate efficacy in cellular models against aggregation, clearance, nuclear localization, and splicing regulation, leading to the selection of both candidate therapeutics and PET tracers. To this date, preliminary results have led to the identification of four candidate molecules. All four molecules demonstrated a positive effect by reducing TDP-43 aggregation, a result confirmed through both ThT fluorescence monitoring and supporting electron microscopy images. In conclusion, this data has contributed to defining the TDP-43 CTD pocketome and yielded first-generation small molecules that inhibit or reverse TDP-43 aggregation, alongside initial candidate diagnostic tracers necessary for monitoring ALS.

Felice Iasevoli

Misfolding in neurodevelopmental and neurodegenerative disorders

Felice Iasevoli's presentation focused on the association of the reduction of Furin activity with neurodegenerative (i.e. Alzheimer's Disease) and neurocognitive (i.e. Schizophrenia) diseases. If increase of proteins and peptides with amyloidogenic properties have been shown to play a major role in older-age neurodegenerative disorder, including Parkinson and Alzheimer's Disease, neurodevelopmental disorders, in particular autism spectrum of disorders (ASD) and Schizophrenia (SCZ) have been associated with the reduction of Furin expression and the consequent reduction of Brain-derived neurotrophic factor (BDNF), relevant for the dendritic prunic involved in the maturation of neuronal connections [19].

FURIN is a prototypical member of the proprotein convertase (PCSK) family, a group of subtilisin-like serine proteases responsible for converting a wide range of inactive precursors into their biologically active forms. This enzymatic activation represents a key post-translational regulatory step across numerous physiological systems. FURIN's substrates include more than 150 precursor proteins, encompassing hormonal peptides, growth factors, receptors, and neuropeptides [20,21]. Among the best characterized are proinsulin, cleaved to insulin [22]; pro-ACTH and pro-vasopressin, converted into their active neuropeptide forms [23,24]; and various substrates implicated in neuroendocrine communication and homeostatic regulation. Within the central nervous system, FURIN plays an equally pivotal role. It is highly expressed in neurons and glial cells, where it controls axon guidance, neuronal migration, and synaptic maturation. Among its most relevant neurobiological functions is the cleavage of proBDNF into mature BDNF, a process essential for maintaining appropriate levels of synaptic pruning, dendritic arborization, and network plasticity [20]. Proper maturation of BDNF is indispensable for experience-dependent refinement of cortical and subcortical circuits, particularly during adolescence and early adulthood–a developmental window crucial for the establishment of cognitive and affective functions. Defective FURIN activity disrupts this delicate equilibrium. Reduced conversion of proBDNF leads to an excess of its unprocessed form, which preferentially binds to p75NTR receptors, triggering apoptotic and anti-synaptogenic pathways. This shift from trophic to atrophic signaling is thought to underlie altered synaptic density, impaired excitatory–inhibitory balance, and dysfunctional network connectivity, all of which are recognized hallmarks of schizophrenia, autism spectrum disorders (ASD), and other neurodevelopmental syndromes.

Recent genomic and transcriptomic studies have confirmed the presence of both common and rare variants in the FURIN gene that modulate expression and enzymatic efficiency. One key regulatory element is the rs4702 SNP within the 3'-UTR region, which affects the binding of microRNA miR-338-3p [25]. The G allele of this variant weakens miRNA binding, reducing FURIN translation and subsequently diminishing the availability of mature BDNF. The result is a cascade of neurobiological effects involving impaired synaptic signaling, dendritic simplification, and cortical dysconnectivity. Furthermore, converging evidence from post-mortem and animal studies supports a dimensional view of psychiatric nosology, where FURIN dysregulation contributes to a shared molecular vulnerability that spans from autism to schizophrenia. The gradient of FURIN activity may influence not only the degree of cortical pruning but also the timing of critical neurodevelopmental events, thereby determining the specific clinical phenotype along this continuum.

Beyond its molecular and developmental roles, FURIN's pharmacological relevance is gaining increasing attention. A number of FURIN inhibitors are currently being explored as antiviral and anticancer agents, exploiting its role in processing viral glycoproteins and tumor-associated growth factors [26]. However, given FURIN's pleiotropic functions in the brain, systemic inhibition might pose neuropsychiatric risks–particularly in individuals with preexisting genetic or epigenetic vulnerability leading to reduced FURIN functionality. In such subjects, further suppression of FURIN activity could theoretically precipitate acute neurocognitive disturbances, behavioral disinhibition, or even neuroinflammatory sequelae. This consideration emphasizes the need for careful safety evaluation and translational research, integrating molecular pharmacology with neurodevelopmental and neuropsychiatric expertise.

Overall, FURIN represents a biological and pharmacological intersection point between infectious disease, oncology, endocrine regulation, neurotrophic signaling, and brain architecture integrity, relevant to both neurodevelopmental and neurodegenerative diseases. Its balanced activity ensures the proper maturation of neuropeptides and growth factors, sustaining the dynamic equilibrium between synaptic formation and elimination that underpins higher-order cognition. Dysregulation of this system – whether genetically, epigenetically, or pharmacologically induced – may constitute one of the core mechanisms linking neurodevelopmental and neurodegenerative disorders.

Neal S. Young
Somatic Mutations in VEXAS syndrome

Neal S. Young described the new VEXAS syndrome caused by somatic mutations in the UBA1 gene, which is located on the X chromosome. The initial description, from NIH with Young contributing, was published on NEJM in 2020 [27] and many publications have followed [28-30]. The mutations in the UBA1, located on the X chromosome, are acquired (non-hereditary) and occur during a person's lifetime specifically in the hematopoietic stem and its progenitor cells. The most common mutation is at the methionine 41 (Met41) position, with specific variants like Met41Thr, Met41Val, and Met41Leu being most frequent. This mutation affects the E1 enzyme's function, leading to systemic inflammation and features of autoinflammatory diseases.

The name VEXAS is an acronym deriving from the core features of disease: V: Vacuoles are often identified in the bone marrow stem cells of patients presenting with VEXAS; E: The E1 ubiquitin conjugating enzyme encoded by the UBA1 gene is mutated in patients; X: The mutated UBA1 gene is recessive and located on the X-chromosome and thus the disease is almost exclusively found in individuals with a single X chromosome and thus said to be X-linked; A: Patients with VEXAS present with a wide array of autoinflammatory conditions; S: The mutations which cause VEXAS are somatic: they are acquired throughout life, not inherited, and are not passed on to offspring. The frequency of the mutation is not rare with 1 case in 13 591 unrelated individuals (95% CI, 1:7775-1:23 758): 1 in 4269 men >50 years (95% CI, 1:2319-1:7859) and 1 in 26 238 women older than 50 years (95% CI, 1:7196-1:147 669); macrocytosis of red blood cells and anemia appear to be early signs; the disease is not uncommon among older, usually Caucasian men [31].

The treatment is still not defined and standardized but includes high doses of corticosteroids, Ruxolitinib (and other jak inhibitors), Tocilizumab (anti-IL6R), Azacytidine. Hematopoietic stem cell transplant is curative but carries risks of morbitidy and mortality. Moreover, Young described several non -oncological conditions characterized by somatic mutations, such as endometriosis [32,33], and possibly brain diseases including autism [34] and schizophrenia [35,36]. This discovery opens a totally new field not only benign and malignant cancers are associated to genetic changes, but also inflammatory conditions (including rheumatological auto-immune disease) associated to genetic changes which could generate protein's changes, perhaps able to induce an immune response against a modified self and by other still uncertain mechanisms.

Sam Mbulaiteye

The EBV role in human diseases and current vaccine efforts

Sam Mbulaiteye in his presentation recapitulate the information on the EBV role in human diseases and in particular in Burkitt Lymphoma, a very peculiar cancer in sub-Saharan young children, characterized by jaws involvement. Sam, in 2010 established and since then coordinated a very unique study in 3 sub-Saharan countries (Kenya, Uganda and Tanzania) funded by NIH: the EMBLEM project, an Epidemiology of Burkitt Lymphoma in East African Children and Minors study to assess the relationship between coendemic Malaria and the pediatric Endemic Burkitt lymphoma (eBL) in sub-Saharan Africa [37]. Previous cross-sectional studies of limited geographic areas have not found a convincing association. The scientists involved in the project used spatially detailed data from the EMBLEM study to assess this relationship. EMBLEM is a case-control study of eBL from 2010 through 2016 in six regions of Kenya, Uganda, and Tanzania. To measure the intensity of exposure to the malaria parasite, Plasmodium falciparum, among children in these regions, we used high-resolution spatial data from the Malaria Atlas Project to estimate the annual number of P. falciparum infections from 2000 through 2016 for each of 49 districts within the study region. Cumulative P. falciparum exposure, calculated as the sum of annual infections by birth cohort, varied widely, with a median of 47 estimated infections per child by age 10, ranging from 4 to 315 infections. eBL incidence increased 39% for each 100 additional lifetime P. falciparum infections (95% CI: 6.10 to 81.04%) with the risk peaking among children aged 5 to 11 and declining thereafter. Alternative models using estimated annual P. falciparum infections 0 to 10 y before eBL onset were inconclusive, suggesting that eBL risk is a function of cumulative rather than recent cross-sectional exposure. Their findings provide population-level evidence that eBL is a phenotype related to heavy lifetime exposure to P. falciparum malaria and support emphasizing the link between malaria and eBL [38]. Moreover, the EMBLEM studies on one of the largest sample collections allowed several molecular studies, including Next generation sequencing, with the identification and characterization of EBV Variants [39] and genetic susceptibility to recurrent or chronic infection by Epstein-Barr virus or Plasmodium falciparum [40].

EBV Variants: Epstein-Barr virus (EBV) infection, a ubiquitous infection, contributes to the etiology of both Burkitt Lymphoma (BL) and nasopharyngeal carcinoma, yet their global distributions vary geographically with no overlap. Genomic variation in EBV is suspected to play a role in the geographical patterns of these EBV-associated cancers, but relatively few EBV samples from BL have been comprehensively studied. We sought to compare phylogenetic patterns of EBV genomes obtained from BL samples in Africa and from tumor and non-tumor samples from elsewhere. We concluded that EBV obtained from BL in Africa is genetically separate from EBV in Asia. Through comprehensive analysis of nucleotide variations in EBV's LMP-1 gene, we describe 12 LMP-1 patterns, two of which (B and G) were found mostly in Asia. Four LMP-1 patterns (A, AB, D, and F) accounted for 92% of EBVs sequenced from BL in Africa. Our results identified extensive diversity of EBV, but BL in Africa was associated with a limited number of variants identified, which were different from those identified in Asia. Further research is needed to optimize the use of PCR and sequencing to study LMP-1 diversity for classification of EBV variants and for use in epidemiologic studies to characterize geographic and/or phenotypic associations of EBV variants with EBV-associated malignancies, including eBL [41].

Genetic susceptibility to recurrent or chronic infections: Burkitt lymphoma (BL) is responsible for many childhood cancers in sub-Saharan Africa, where it is linked to recurrent or chronic infection by Epstein-Barr virus or Plasmodium falciparum. However, whether human leukocyte antigen (HLA) polymorphisms, which regulate immune response, are associated with BL has not been well investigated, which limits our understanding of BL etiology. Here we investigate this association among 4,645 children aged 0-15 years, 800 with BL, enrolled in Uganda, Tanzania, Kenya, and Malawi. HLA alleles are imputed with accuracy >90% for HLA class I and 85-89% for class II alleles. BL risk is elevated with HLA-DQA1*04:01 (adjusted odds ratio [OR] = 1.61, 95% confidence interval [CI] = 1.32-1.97, P = 3.71×10^{-6}), with rs2040406(G) in HLA-DQA1 region (OR = 1.43, 95% CI = 1.26-1.63, P = 4.62×10^{-8}), and with amino acid Gln at position 53 versus other variants in HLA-DQA1 (OR = 1.36, P = 2.06×10^{-6}). The associations with HLA-DQA1*04:01 (OR = 1.29, P = 0.03) and rs2040406(G) (OR = 1.68, P = 0.019) persist in mutually adjusted models. The higher risk rs2040406(G) variant for BL is associated with decreased HLA-DQB1 expression in eQTLs in EBV transformed lymphocytes. Our results support the role of HLA variation in the etiology of BL and suggest that a promising area of research might be understanding the link between HLA variation and EBV contro [40].

Ishwar Gilada

Alternative strategies to prevent/cure global virus-induced diseases

Ishwar Gilada in his presentation discussed the need for new strategies to combat viral outbreaks and future pandemics, as traditional tools like vaccines and antiviral drugs are not enough on their own. It emphasizes exploring innovative, scalable, and globally inclusive strategies.

- Preventive Strategies: To better prevent and manage future pandemics, we must explore alternative and complementary strategies that are innovative, scalable, and globally inclusive (replicability, adaptability and accessibility). These include developing universal vaccines, using genetic engineering to build resistance, employing AI and genomics for viral bio-surveillance, enhancing the microbiome, utilizing antiviral surfaces and air filtration, and adopting a "One Globe-One Health" framework that connects human, animal, and environmental health.
- Curative / Therapeutic Strategies: Advances in this area include broad-spectrum antivirals, RNA-based therapies, engineered immune cells, and repurposing natura*l compounds offer new hope.
- Systemic and Infrastructure Strategies: Multi-faceted strategies can help focus on building a more resilient public health system through decentralized manufacturing platforms, digital health and early warning systems, and global coordination via a pandemic treaty.

In conclusion, the lessons from past pandemics underscore the urgent need for global preparedness, proactive strategies, and collective action. Emerging threats like HPV, HBV, and AMR highlight the necessity of alternative approaches alongside conventional methods. Embracing innovations such as universal vaccines, broad-spectrum antivirals, RNA-based therapies, nanotechnology, and AI can revolutionize our pandemic response. Central to success are robust systems for pathogen tracking, genome sequencing, and global knowledge sharing. Ensuring health security requires integrated disaster management and a unified "One World–One Hope" vision, grounded in environmental respect and preventive action.

Per Hammarström
The brave new world of biologic drugs – safe and effective?

Per Hammarström's talk conveyed both enthusiasm and concern regarding the rapid development of biopharmaceutical drugs, also known as biologics. Biologic drugs are at the forefront of modern medicine, enabling the treatment of previously intractable diseases. Biopharmaceuticals encompass synthetic, semisynthetic, and recombinant peptide and protein drugs, as well as oligonucleotide-based agents, including modified messenger RNAs (mRNA), small interfering RNAs (siRNA), and antisense oligonucleotides (ASOs) [42].

According to Pharmaceutical Research and Manufacturers of America (PhRMA)

(https://phrma.org/), more than 7,000 biopharmaceutical products are currently in clinical development worldwide, with over 1,000 having reached Phase 3 trials. Additionally, more than 100 non-COVID-19 monoclonal antibody (mAb)-based products are in late-stage clinical development. The global biopharmaceuticals market was valued at USD 616.94 billion in 2024 and is projected to grow from USD 666.41 billion in 2025 to USD 1,183.87 billion by 2032
(https://www.fortunebusinessinsights.com/biopharmaceuticals-market-106928).

However, the rapidly expanding and increasingly accessible biopharmaceutical landscape also presents risks. Proteins are labile molecules, and amyloidosis refers to a group of conditions in which proteins misfold and assemble into stable fibrillar structures with a strong tendency to grow and replicate by recruiting additional proteins into the misfolded form, which can have very detrimental effects in the organs where it occurs.

Dr. Hammarström demonstrated that the essential diabetes drug insulin is highly amyloidogenic - a property that has been known for a long time [43]. More recently, the highly successful glucagon-like peptide-1 (GLP-1) agonists, such as semaglutide (Wegovy®, Ozempic®), which are now widely used for both diabetes and weight loss, have been shown to be highly amyloidogenic. Similar properties have been observed in other peptide drugs, such as enfuvirtide (Fuzeon®) used against HIV [44]. The potential long-term effects of localized iatrogenic amyloidosis resulting from such treatments remain unknown.

Even more concerning is the emergence of mRNA-based biologics, which use the human body as a platform to express novel – and in many cases, exotic – proteins. This was exemplified by the mRNA COVID-19 vaccines, which instruct cells to produce the SARS-CoV-2 spike protein. The spike protein itself has been shown to be highly amyloidogenic under immune-reactive conditions [45] (Nyström and Hammarström 2022). Because the mRNA is delivered via lipid nanoparticles that can distribute systemically, there is potential for expression in a wide range of cells and organs, raising concerns about the possibility of systemic amyloidosis in susceptible individuals. The long-term risks of adverse events, such as amyloidosis, are not yet sufficiently considered in the rapidly evolving field of biologic drug development.

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Session 3: Data Centers and Small Modular Reactors

Session Chair: Carmine Difiglio[18]
Speakers: Peter R. Hartley[19], Hans-Holger Rogner[20], Robert J. Budnitz[21], and Lucian Pugliaresi[22]

Carmine Difiglio
Introduction and summary

After World War II, the United States experienced rapid economic development. As a consequence, during the 1950s and 1960s, electricity demand growth exceeded 5% per year. During the 1970s, electricity demand growth was also strong but began to decline. This period also saw the development and growth of U.S. nuclear power. While many nuclear plants came online during the 1970s and 1980s, these projects all commenced before 1979, the year of the Three Mile Island core meltdown. No new nuclear power plants were initiated in the United States until after 2005 with the Vogtle (Georgia) and VC Summer (South Carolina) Westinghouse AP1000 projects. Vogtle was long delayed and exceeded its original cost estimate by $20 billion. VC Summer was abandoned after a $9 billion investment. These reactors were purchased by investor-owned State regulated vertically integrated utilities, not independent power producers (IDPs) that mostly replaced vertically integrated power companies in States that deregulated their power industries. IDPs are unlikely customers for large nuclear power plants because of their high cost[23] risks of construction delays and cost overruns, and the fact that they are unsuited for selling power into a competitive power grid. Power grids that have high levels of intermittent power need backup generators that can fill in when there is a mismatch between demand and renewable generation. Baseload plants are typically unsuited to this role, especially when grid prices are low due to an excess of renewable generation relative to demand. Back up generators should have low capital costs to offset their low capacity factors. In the United States, and several other countries, natural gas is increasingly filling this role even though regulations and permitting delays often discourage any fossil fueled power generation. In addition, the economic challenges of nuclear power in other OECD countries are often similar to those in the United States since competitive power markets have mostly replaced State-owned vertically integrated power companies, especially in the Western Europe. Small modular reactors (SMRs) can avoid the economic risks of purchasing large nuclear power plants. If factory-produced turnkey nuclear plants achieve reasonably low levelized costs of energy (LCOE), they have a huge potential to revitalize nuclear power in and outside of the OECD.

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[23] Approximately $15 billion for a pair of reactors with a combined capacity of 2.5 gigawatts).

More recently, a new class of industrial customers has evolved since Bitcoin data mining, artificial intelligence and other data services have grown. They are a major reason that power demand growth is increasing in many OECD countries. It is also likely that these new power customers are not likely to be well served by existing competitive power markets, partly due to the adverse consequences data center power demand could have on existing consumers. This is evident in the long delays in approving new grid connections. Data centers are also best served by baseload power plants. Consequently, we are seeing increased interest in off-grid power generation and, in particular, SMR off-grid power. The only problem is that several large data centers are already being built and many more will be built before SMRs become commercially available. Until then, data centers, that want to secure reliable off-grid baseload power, are likely to use combined cycle natural gas plants. Nonetheless, some large tech companies anticipate that SMRs can be a better long-term solution. Consequently, some of them are investing in SMR development.

Peter R. Hartley

Accommodating increased electricity demand from data centers

For much of the United States, electricity demand has started to grow after nearly two decades of relative stasis. It is projected to grow much faster for at least the next decade because of the growth of data centers. Recent discussion has focused on growth in artificial intelligence (AI) as both the development of AI models via learning from massive amounts of data and their use in inference requires prodigious amounts of computing power. As the costs of computation have declined, the development time for AI models has declined while their utility to users has expanded. They are rapidly spreading to numerous other sectors of the economy as many types of decisions are automated. Even though the energy efficiency of computer chips is also increasing rapidly, total electricity demand is expected to expand. At the same time, many other types of data centers have continued to grow. These include cloud storage and cloud computing, entertainment streaming services, telecommunications services, navigation and financial services provided by smartphones, internet-connected appliances and automobiles, remote management and data gathering for industrial processes, non-AI internet search services, internet security and surveillance services and cryptocurrency mining.

A December 2024 LBNL study (Shehabi et al., United States Data Center Energy Usage Report) examines the implications of growth in data centers for electricity demand over the next few years using a "bottom-up" approach. The authors categorize data centers by size and function, type of hardware (number of CPU and GPU and application-specific integrated circuits), storage capacity and type, and type of cooling system. Based on recent changes in these different categories, they forecast continued changes out to 2028. While power capacities for shipped servers are relatively easy to measure, the energy they ultimately consume when deployed in data centers is much harder to estimate. Energy use during AI training has been measured in a laboratory setting, but inference occurs at many decentralized locations using a wider variety of hardware and depends heavily on user actions. Indeed, an emerging issue for utilities is that data centers can lead to large surges in power demand over a very short period. Power needs also vary with equipment vintage, and the relative paucity of data on the characteristics of retired servers complicates calculating electricity use. Data on the power draw of networking equipment, which varies with connection speed and utilization, is also meager. Local climate characteristics can also substantially impact cooling costs, making them difficult to estimate at the aggregate level. Nevertheless, the study estimates that data center power demand, excluding cryptocurrency facilities) is likely to constitute from 6.7% to 12% of US electricity consumption by 2028. Cryptocurrency mining may increase the share by another percentage point, with the value of the cryptocurrencies being a dominant determinant.

Currently, Northern Virginia with 150 centers and more than 2.7 GW capacity, is the largest area for data centers in the United States. Dalla-Fort Worth, Northern California, Phoenix and Chicago are the next four largest with capacities of 550–650 MW capacities in New York/New Jersey, Atlanta, and Portland range from 405–470 MW. Northern Virginia, Atlanta, Dallas Fort Worth, Austin, and Phoenix also feature prominently with Ohio emerging as another prominent location. Planned centers would not materially alter the distribution. A map of the major internet hubs and fiber optic cable capacities, which affects latency, speed, and reliability, makes it evident that network access has been a major driver of location decisions.

Electricity cost, supply reliability and ability to quickly connect a large load are also important factors. Larger data centers often require additional electricity networking equipment to be installed. Some utilities are requesting data center builders to purchase electricity equipment themselves (such as new high capacity transmission lines or transformers) rather than relying on slower utility planning processes. Deciding whether to rely on network generating resources or to provide their own behind-the-meter generation is becoming an important consideration. One can think about this decision as a type of option with a value that depends critically on variations in the gord power price, the marginal cost of self-generation, and the marginal value of power use.

Especially for data centers serving customers, the latter in turn could fluctuate with varying demand for "inference tokens." There may be a range of grid power prices where it is profitable to self-generate rather than buy or sell grid power. Higher startup and shut-down costs for either the self-owned generator or the data operations would make the range wider, lessening the gains from trade and further encourage self-generation alone. Conversely, the ability to share back-up capacity will encourage greater reliance on grid generation resources. The ability to exploit locational marginal electricity price differentials (for example because of low or even negative local power prices), will also encourage reliance on the grid. In some locations (such as West Texas and Pennsylvania), stranded natural gas production because of inadequate pipeline take-away capacity could instead encourage self-generation using natural gas combined cycle turbines. Self-generation also avoids the costs and regulatory constraints accompanying grid connections and allows the data center developer to bypass the connection queue, which is currently experiencing long delays.

In January 2025, Bloom Energy released a report on data center power demands based on surveys of "data center leaders who make power input decisions." The forecast increases in power demand were consistent with the conclusions of the LBNL report cited above. However, the survey indicated that more of the power demand will be met by onsite generation. The report noted that onsite generation had historically mostly provided backup, but new proposals have it playing a more substantial role. Approximately 30% of all data centers are expected to use some onsite power by 2030. In 2024 alone, more announcements featured onsite power than cumulatively from 2020 to 2023. Current onsite generation is mainly natural gas turbines or combined cycle natural gas plants when desired capacity exceeded 500 MW. Another recent report from RBN Energy listed 7 major recent data center announcements with onsite generation – all based on natural gas.

Utilities also appear to be turning substantially to natural gas to provide the needed power in a short time frame and at the locations the data centers need it. Data center power demand is more constant compared to current average loads. The resulting flattening of the load duration curve favors baseload generation. Intermittency and the remote locations of wind and solar generation also reduce the reliability of grid supply, while relatively constant data center demand increases the value of a reliable supply. Sensitive equipment in data centers requires a high quality of supply (low fluctuations in voltage and frequency). If data centers trip off following a deterioration in power quality, the resulting relatively large reduction in demand can further stress the system.

In summary, growth in data center electricity demand is increasing the demand for generation capacity in developed economies after a long hiatus. It is also favoring dispatchable capacity located close to the load, while policies have favored remote, non-dispatchable generators and helped accelerate retirements of conventional generators.

Hans-Holger Rogner

SMR Economics & Data Centers

Defining SMRs and the current landscape: The term "SMR" has evolved over time. Prior to 2010, it stood for "small and medium reactors," encompassing unit capacities up to 700 megawatts (MWe). After 2010, the term shifted to "small modular reactors", which typically refer to units under 300 MWe. The emphasis is on modularity in fabrication, delivery, and deployment, not just size. Of the 416 operational power plants in the current global nuclear fleet, only 22 are SMR-sized, and only four of those are truly modular (as of August 2025, ref: IAEA, Power Reactor Information System (PRIS), www.iaea.org/pris/, 2025). Of the 62 power reactors under construction worldwide, only three are SMRs, which highlights the nascent stage of this technology.

SMRs differ from downsized large reactors (LRs) due to their high degree of component integration, enhanced passive safety features, and their defining characteristic, modularity. Modularity enables the serial factory production of standardized components, which should lead to improvements in quality, speed of construction, and cost reduction through learning effects. Key technological innovations in SMR designs include the use of non-water coolants and high-assay low-enriched uranium (HALEU) fuel. SMRs represent an emerging nuclear technology category that can deliver scalable, reliable 24/7, low-carbon energy and integrate with intermittent renewable electricity supplies. The rise of data centers (DCs) as a strategic energy market: DCs have emerged as a massive new category of electricity users. By 2024, nearly 12,000 DCs worldwide consumed 415 terawatt-hours (TWh) of electricity. This demand is expected to increase by 50–150% by 2030, primarily due to the substantial electricity intensity of artificial intelligence (AI) applications. DCs are seeking reliable, low-carbon energy sources to ensure operational continuity and meet corporate climate commitments. SMRs align well with DCs' power demand profile due to their small unit sizes and modular deployment. For DCs, a secure, reliable, and 24/7 power supply is not a preference but a necessity.

Currently, DCs meet their electricity needs primarily through grid power, supplemented by on-site backup systems such as diesel generators and batteries. However, the growing share of intermittent renewable sources on grids threatens the reliability that DCs require. This vulnerability is a primary driver behind major tech companies' growing interest in nuclear energy.

The economics of SMRs: The expected economic benefits of SMRs are based on the following facts: Their smaller unit capacities (1/20 to 1/3 of LWRs) require less total upfront capital and allow for shorter construction times, which lowers interest payments during construction. SMRs reduce overall financial risk exposure while enabling scalability and deployment flexibility. Nevertheless, the path to commercial competitiveness is fraught with uncertainty and peril. One core challenge is that estimated capital costs for first-of-a-kind (FOAK) projects are scarce and speculative. Although the target overnight cost for an nth-of-a-kind SMR is less than $3,000/kWe, current FOAK cost estimates are several times higher. The private sector is generally reluctant to bear these FOAK risks without significant government support and other risk mitigation measures. In other words, "everyone wants to buy the nth unit". An SMR design would need to manufacture and sell 12–20 modules to be cost-competitive with LRs and 50 or more to reach the $3,000/kWe target. This assumes a fully established supply chain that utilizes economies of multiples based on continuous technology learning.

Modularity, learning, and the economics of multiples: Of the 127 SMR designs in various stages of development, most are not likely to cross the "Valley of Death" (NEA 2025). These designs face numerous threats, including higher-than-anticipated development costs, lack of funding, failure to meet performance milestones, delays in establishing supply chains, regulatory uncertainty, and limited early adopters. It is in this valley where most designs will experience a loss of sponsor and investor confidence and ultimately fail. In other words, the failure of most is necessary for a few to succeed. The SMR-DC symbiosis - a win-win opportunity: A partnership between DCs and SMRs seems to offer benefits for both. DCs require substantial amounts of low-carbon baseload power around the clock to achieve their operational and climate objectives. Nuclear energy, particularly SMRs, is one of the few sources that can meet both of these requirements simultaneously.

The benefits for SMRs are profound. The established, deeply capitalized DC customer base provides a powerful "anchor client" function. Financial support from this sector could facilitate the long-term operation of existing nuclear power plants and, more importantly, support the market readiness of SMR designs. DC demand could help overcome the critical FOAK investment risk that has plagued nuclear innovation for four decades. Furthermore, DCs and their AI capabilities could accelerate SMR commercialization by optimizing designs, improving construction project management, and enhancing plant operations throughout their lifecycles.

DCs' tendency to cluster aligns well with SMR scalability and "behind the grid" operation. Multiple DCs could share a larger SMR "campus", and multiple on-site SMR units could provide unusually high liability through internal redundancy. These units would also have the potential to sell excess power to the grid. Alternatively, vendors could offer DCs integrated "plant-as-a-service" options with long-term power purchase agreements (PPAs).

A key challenge is the timing. The rapid increase in DC energy demand is happening much faster than the development and licensing of new SMR capacity. Therefore, a dual approach seems to be emerging for DCs: In the short term, DCs purchase power from existing large reactors while supporting and sponsoring SMR projects for long-term implementation.

DCs can change the calculus: The active involvement of DCs can make the difference between the commercialization of a SMR design or if its destination is the "valley of death". DCs can mitigate multiple risks by sponsoring a specific design. Their reputation as reliable, long-term customers reduces market risk. Direct equity investments, such as Amazon's $500 million commitment to X-energy, address financial risk by providing vital startup capital. Furthermore, the endorsement of major tech companies lends credibility that can accelerate regulatory approvals and attract additional investors and DC customers. Together, these factors could potentially tip the scale between the success or failure of different SMR designs in avoiding the valley of death.

Final remarks: SMRs require early adopters with robust applications and substantial financial resources to justify development costs and overcome the FOAK hurdle. DCs are uniquely positioned to fulfill this role by acting as anchor clients, providing financial support, and offering public and political visibility. Their involvement would be highly welcome and could transform a select few SMR designs. However, DC association and support alone may not suffice for full commercialization without the design conquering other applications. Therefore, a broader ecosystem of public, private sector, and government policy support is essential. In conclusion, a DC-SMR partnership would be based on a clear mutual need. DCs require massive, reliable, low-carbon power. SMRs offer reliable, low-carbon and scalable baseload electricity that can be deployed close to or co-located with DCs.

In short, by providing guaranteed markets, financial backing, and high credibility DCs don't just buy power; they actively reduce the risks associated with commercialization, offering a lifeline that can successfully bring a chosen SMR design to fruition.

Robert J. Budnitz

Small Modular Reactors for Data Centers – Safety, Operability, Safeguards-Security, and Regulatory Challenges

World-wide, over a hundred companies, institutes, and government agencies are developing designs for new advanced small modular reactors (SMRs), and the first few of them are reaching commercial service now or are under construction. However, whether or not there will be a major deployment of SMRs worldwide is still unknown and depends largely on whether the ultimate economic value of them can make sense in the marketplace. One potential vehicle for the rapid deployment of SMRs is the worldwide expansion of *large data centers*. Some of these projects are considering SMRs due their potential to provide reliable baseload power.

Here we will explore why the safety and operability features of SMRs are attractive for data centers, what activities are underway to address regulatory-approval challenges, and why safety concerns are not likely to be an important impediment to the development of SMRs. As a class, SMRs definitely have improved safety features and are hence generally "safer." What does "safer" mean? Engineers design a complex system for safety by identifying the undesired ("unsafe") end point (for nuclear reactors it is a release of radioactivity); identifying all of the undesired sequences of events leading to that end point; identifying how each sequence of events happens; analyzing the frequency and the consequences of each sequence; and designing and operating so as to eliminate or reduce each threatening sequence.

The best example of applying this approach in practice is the safety of today's large light-water reactors (LWRs), numbering several hundred worldwide. Based on experience and analysis, we know that the overall likelihood of an LWR core-damaging accident is typically in the range of lower than 10^{-4} per year, and that most LWR core-damaging accidents will have small releases of radioactivity (although some accidents could have large releases). We have seen during the last 30 years that LWR risks have been decreasing steadily.
Although advanced large LWRs will be safer than today's, it is expected that the advanced SMRs will achieve even better safety. The reasons for this include advances in engineering design and operations; sharing of experience worldwide; greater emphasis on "safety culture" issues; better regulation by the cognizant governments; and international sharing

of best regulatory practices. The result is that for the new SMRs the likelihood of a core-damaging accident will generally be much less than for large LWRs, and the consequences of a core-damaging accident will also be much less.

What does “safe enough” mean? It means comparing the frequencies and consequences of the adverse sequences against some criterion. Sometimes, the “safe-enough” criteria used by regulators differ from those used by owners-operators. But if one asks the question, *are reactor-safety risks acceptable?*, that is a societal decision that I will not deal with here.

Why will SMRs generally have a reduced likelihood of an accident? The reasons include that many of the large-LWR initiating events have been designed away in the new SMR designs; that many large-LWR sequences involve human errors that have also often been designed away (automatic responses etc.); that many sequences involve large external events (or internal fires or floods) that have been carefully designed for; and that for many of the SMRs, the accident sequences of concern evolve over a much longer time period (hours or even days vs. minutes-to-hours) thus allowing extra time for mitigation measures.

Why will SMRs generally have reduced consequences of an accident? The reasons include that the smaller SMRs have much less radioactivity and much less thermal energy to manage in a typical off-normal sequence of events; and that many of the SMR designs have features that substantially inhibit the release of radioactivity after a damaging accident.

Why will institutional factors also contribute to a safer SMR? These SMRs reactors will generally be easier to construct (factory fabrication with more readily controlled quality), and many of the SMRs will be much simpler to operate (operator training less crucial, operator errors less of a factor).

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Why does this matter for data centers? There are several reasons. First, reliability is very important for data centers -- and the SMRs reactors will definitely be more reliable overall. Less reliance on the power grid also enhances overall reliability. Second, operability is very important for data centers, and the SMRs will definitely be easier to operate and maintain, because of lessons-learned over these many decades. Third, all of the new SMRs are being designed with ease of maintenance as a design feature.

Safeguards and security for SMRs at data centers: Generally, the institutional and technical measures taken in “first world” countries to counter safeguards and security concerns have ensured that these have not been a major problem. However, it is broadly understood that these issues can be a more important concern in developing or emerging economies. The safety of nuclear reactors in newcomer countries is an issue that needs to be addressed worldwide. Fortunately, there is now major emphasis on assuring that the worldwide safeguards-and-security approach now in place for the large LWRs, under the UN's International Atomic Energy Agency, will be adapted and used effectively as the SMRs are deployed worldwide. Also, the use of SMRs for data centers will be less likely to occur (at least in the early years) in locations like some developing or emerging countries that might not yet have the strong institutional arrangements and culture needed to achieve high assurance of safeguards and security.

Safety regulation is today the responsibility of each individual country where a reactor is sited. However, for many SMRs some important new regulations are needed – some of the existing large-LWR regulations don't apply to most of the advanced technologies being proposed for the new SMRs. Fortunately, this is being addressed. In several countries, the development of new regulations specifically addressing SMR issues has progressed well in the past year or two. Coordination among different national regulatory agencies has also been enhanced, through formal agreements and informal cooperation. Crucially, both the IAEA and the OECD Nuclear Energy Agency have taken the lead in helping the different national agencies to coordinate.

Although a broad international safety regime, with the IAEA in the lead, is clearly desirable to allow nuclear power to succeed fully, it is not likely to be developed soon, meaning that there will continue to be the need not only for individual regulatory regimes in each country, but also for extensive coordination and cooperation among the individual regulatory agencies worldwide. Intense work on coordination and cooperation is under way now, and this also applies to the coordination worldwide of the security regulations.

To summarize, when considering the likely deployment of SMRs for data centers, the new advanced SMRs are generally expected to be a very fine fit to the needs of large data centers, for all of the above reasons - with one condition, namely if the economic hurdles described in the previous presentation can be overcome!

Lucian Pugliaresi

Natural Gas and SMRs for Off-Grid Baseload Power

The United States is approaching an inflection point in electricity demand after decades of modest and often flat growth. From 1980 to 2007, U.S. power demand grew at an average annual rate of 2.3%. Demand then flattened to an annual rate of 0.3% between 2007 and 2024. A combination of forces is now underway that offers the prospect of a substantial increase in electricity demand in the coming years. Estimates from financial and technical experts point to annual growth in power consumption accelerating to between 2% and 4% over the next 10 to 20 years. This acceleration in power demand reflects both government policies incentivizing electrification (electric vehicles, manufacturing processes, and residential uses) and the emergence of advanced computing, including artificial intelligence.

The U.S. does not have a unified electricity production and distribution system. In the U.S. electricity generation and distribution are organized through a complex, two-tiered structure involving both federal and State authorities. Decisions on new power development are largely undertaken by either investor-owned companies that develop generating facilities regulated by local authorities and integrated into a regional network managed by Regional Transmission Operators (RTOs) or Independent System Operators (ISOs). The regulatory framework in these systems is often a flawed variant of a competitive market. Vertically integrated markets still exist, largely in the Southeast and Northwest, where a single regulated utility provides service to all customers in a given area. The Federal Energy Regulatory Commission (FERC) is the primary federal regulator overseeing the interstate aspects of the power system. Many states have also adopted renewable power mandates that require state regulators to ensure minimum production from renewable energy sources (mostly intermittent).

The U.S. regulatory system for power development faces a host of impediments that make it difficult to respond quickly to near-term spikes in demand. Major AI developers also recognize that rapid deployment of intermittent power (e.g., wind and solar) faces regulatory, cost, and technical constraints that hinder timely expansion of capacity. The high returns and competitive pressures driving AI development are encouraging technology companies to pursue fully dispatchable power solutions independent of existing grids. In the near term, many AI developers are turning to stand-alone natural gas-fired generating units to power data centers, since grid connections face opposition due to concerns about rising rates from sudden increases in demand. The U.S. has vast reserves of natural gas, and AI data centers can be located near gas production sites, bypassing regulatory and transmission connection constraints. Nevertheless, there is also interest in "bring your own generator" (BYOG) solutions, including restarting currently non-operating nuclear facilities.

Over the next 5-10 years, RTOs and ISOs face long queues for connecting new power sources to the grid. Their decision-making over the last decade shows a priority for combined-cycle natural gas generation, followed by battery storage. In recent years, RTOs and ISOs have been reluctant to fast-track wind and solar, as these resources often require new and expensive transmission lines and face local permitting challenges. Rising costs of managing intermittency have further slowed wind and solar deployment. Interest in nuclear power – particularly SMRs – has intensified in the last five years due to their standardized designs, small footprint, enhanced safety features, and scalability. State and Federal policymakers have adopted measures that, at minimum, opened the door for new nuclear development with some policies directly supporting SMR development. However, large-scale SMR deployment remains unlikely within the near term. This SMR-focused narrative accelerated when President Donald Trump released four executive orders announcing his goal to quadruple domestic nuclear power capacity by mid-century. One order directed the Department of Energy (DOE) to "facilitate 10 new large reactors with complete designs under construction by 2030." Until the completion of Vogtle Units 3 and 4 in 2023 and 2024, respectively, the U.S. had not added new nuclear capacity for decades (excluding the resumed construction of Watts Bar Unit 2). However, the Vogtle units–each 1,100 MW, average by industry standards–were plagued by delays and cost overruns exceeding $20 billion, with the final cost estimated at $36 billion. Causes included project management failures, supply chain issues, construction and quality control deficiencies, and labor shortages. Despite renewed enthusiasm for nuclear power, Vogtle stands as a cautionary tale, highlighting the U.S. industry's challenges in accurately assessing its own capabilities.

Alone, the U.S. will find it extremely difficult to deliver nuclear reactors on time and within budget, as Vogtle demonstrated. Instead, building partnerships and leveraging synergies with allies offers a more promising path. Countries such as South Korea and Japan have matured nuclear industries with advanced supply chains and highly skilled construction labor forces. Both maintain civil nuclear cooperation agreements with the U.S. under the 123 framework. Nuclear power can make an important contribution to meeting rising power requirements, but investors will need to be convinced that the shortcomings of the past can be overcome. While SMRs will continue to get interest, some configuration of recently deployed light water reactors maybe the most likely sources of new nuclear power generation in the next ten to twelve years for the U.S. market. In the meantime, data centers that develop their own off-grid power will likely rely on natural gas combined cycle turbines located where large data transmission capacity and inexpensive natural gas are available.

Session 4: Engineering mitigation of major societal risks

Session Chairman: William A. Barletta[3]
Speakers: James H. Lambert[24], Megan Gunn[25], Bilal M. Ayyub[26], Sergey Pulinets[27] and John Organek[28]

William A. Barletta

Plenary Session 4 focused on the second pillar of MCR studies, is the engineering mitigation of the consequences of major societal risks both natural and man-made. Such risks include volcanic eruptions, earthquakes, tsunamis, wildfires, prolonged drought and desertification, extreme weather events, asteroid impacts and threats from space weather, and the impending demographic collapse in most countries.

The precipitous rise in wildfires and their severity at local, regional, and continental scales is a planetary emergency that threatens ecosystems and communities, impacting food and water supplies, public health, economic well-being, greater populations at the rural-wild ecological interfaces, and cultural infrastructures. Mitigation of these effects urgently requires early detection of new wildfires that will enable more effective suppression and containment efforts. The Wildfire Project Group of the MCR PMP has embarked on a major Wildfire Project in collaboration between the Ettore Majorana Foundation and Centre for Scientific Culture, the Municipality of Erice, and the Sicilian Region under a formal memorandum of understanding that was signed this summer. The Memorandum establishes a study center and pilot project in Erice to advance our efforts for the identification and implementation of technology solutions.

Prior to the formal agreement the Project Group had reviewed current technologies that are being used for early detection of wildfires in Sicily and California. The techniques assessed include ground-based imaging, satellite systems, and autonomous aerial vehicles. Data from these wildfires are being modeled and analyzed using simulation, machine learning, AI, and systems engineering methods such as disruption analysis. The first publication of the analysis of the Project team appeared earlier this year in the American Society of Civil Engineers (ASCE) 2025 special collection on wildfires.

In preparation for the experimental phase of the Wildfire Project the MCR project team has been developing a risk analysis methodology using machine learning for wildfire

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detection and monitoring. This research leverages systems and lifecycle analysis, machine learning classification techniques, and order-based risk analysis to evaluate wildfire detection and monitoring technologies. Through systems and lifecycle analysis, wildfire detection is contextualized within the broader scope of addressing wildfires. In that way, a specific wildfire emergency can be contextualized in terms of recent extraordinary fires and their impacts. Additionally, sixteen categories of detection technologies have been evaluated for their strengths and weaknesses throughout the phases of a wildfire.

Our machine learning wildfire detection models are developed for three detection systems that integrate ground-based camera images, weather data, and satellite observations. With insights into system performance, including time to detection, positive accuracy, and negative accuracy, tradeoffs and implications for the prioritization and design of detection systems are identified.

Using order-based risk analysis, the prioritization of detection technologies has been examined under a baseline hypothesis and six disruptive hypotheses comprising changes in societal and environmental factors. The high degree of variability in technology rankings across the hypotheses suggests the need to integrate multiple technologies that will improve societal resilience to future sources of disruption. Additionally, analysis of the prioritizations by technology modality suggests further research on the integration of ground-based, aerial-based, and satellite-based technologies to leverage complementary strengths. This research will be carried out in parallel with the experimental phase in collaboration with local Sicilian experts.

The second sub-topic of Session 4 elaborated the systems engineering approach to enhancing societal resilience and regeneration in the recovery phase after a large-scale, catastrophically destructive event. The catastrophic risks, such as those posed by massive wildfires, nuclear war, extreme climate events, or complex technological failures can create perceived existential threats that challenge conventional paradigms of social cohesion, disaster response, and recovery. To be most effective, recovery from catastrophic destruction must be treated as a multi-dimensional process that emphasizes the need to move beyond recovery–as typically used in the context of societal resilience toward the more far-reaching goal of societal regeneration.

The systems engineering approach first clarifies the relevant key concepts; it distinguishes between absorbing shocks (resilience), restoring function (recovery), and building back a better societal structure (regeneration). Analysis of a paradigmatic case of recovery from catastrophic destruction such as nuclear war can illustrate the compound effects of uncertainty, systemic complexity, and the entanglement of human, technological, and environmental systems. The foundational elements for regeneration include the re-establishment of law and order, core societal functions, food and water, and energy and transportation systems. MCR members will perform such work during the coming year.

In the analysis, modeling of mobility infrastructures such as railroads can identify and illustrate the vulnerabilities and opportunities for strategic design in recovery planning. Temporal attributes of catastrophic scenarios–such as warning time, time to prepare, and time to decide and act–can be analyzed to frame the critical windows for intervention. Behavioral dynamics are a vital component of catastrophe management, that underscore the importance of calibrated responses, public trust in authority, and effective communication to prevent both panic and apathy.

Threats from extreme disturbances in the Earth's ionosphere represent a further example of a natural emergency that requires engineering mitigation. The duality of ionospheric properties as a medium makes it an important player in the chain of processes that generate the effects of space weather on technological systems. It converts the energy of the solar wind and magnetospheric currents into the large-scale movements of matter in the form of travelling ionospheric disturbances (TID) and acoustic gravity waves (AGW), heat release and inducing the currents in the Earth's crust.

In an excited ionosphere, special conditions create the emergence of plasma bubbles, special formations of cold plasma in lower layers of the ionosphere that rise to the upper layers of the ionosphere. Sometimes these formations reach the enormous size, where their extension reaches several thousand kilometers in low latitude regions of our planet. The resulting sharp gradients of electron concentration create the serious problems for aeronavigation, radio communications, propagation of the signals of Global Navigation Satellite Systems.

The spatial gradient induced by the Equatorial Plasma Bubble (EPB) in low latitude regions is a major challenge for the Ground Based Augmentation System (GBAS). To facilitate the implementation and operation of GBAS Approach Service Type (GAST)-D at Hong Kong International Airport, the impact of EPB induced spatial gradients became a special subject of investigation. The global studies provided by the Russian satellite constellation, Ionozond 2025, have demonstrated that the spatial size and intensity of the EPB have complex distribution along the longitude. The studies detected special regions in which the intensity of EPB is most pronounced and creates the most serious threats for the aeronavigation.

Session 5: Arising Challenges of Cybersecurity and Artificial Intelligence (AI)

Session Chair: Axel Lehmann[29]
Speakers: Charles H. Bennett[30], Simon Greenman[31], Alex Ntoko[32], Anna Pouliou[33], Shaikha Al-Sanad[34], Daniela Mainenti[35], Pier Paolo Maria Menchetti[36], Sun Kun Oh[37]

Axel Lehmann

Introduction

As the Gartner Group Inc. summarized already in 2017 in a statement: "The World is becoming an intelligent, digitally enabled mesh of people, things, and services". Meanwhile, lots of innovations in the digital world have been performed enabled by this hyperconnectivity. Together with the tremendously increasing developments of AI technologies and tools, especially since the early 2020s, of generative AI tools like ChatGPT, lots of new capabilities and benefits of digitalization could be achieved for our public and private life, but also new risks and challenges have to be considered as well, such as:

- Increasing threats for data, information and cyber security,
- results and solutions generated by "black box." AI techniques, as well as
- increasing complexity of smart "System-of-Systems", such as smart Energy Systems, e-Health systems or autonomous systems.

This session addresses some of these developments, risks and challenges from different perspectives.

Charles H. Bennett

Combating misinformation and stabilizing democratic governance

"Deepfakes" are almost impossible to recognize after the fact, but good time- and place-stamping techniques fortunately exist for authenticating video, audio, and other recordings of newsworthy events while they are being made, thereby preserving the recordings' evidentiary value by allowing them to be unambiguously distinguished from realistic-looking fakes made later or elsewhere. Unfortunately, these techniques are rarely used. They should be incorporated in standard smartphone software, and the public should be educated to regard any video that is not properly authenticated as mere entertainment or propaganda rather than evidence.

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Autocratic governments routinely use social engineering to unethically hide inconvenient facts and shield themselves from criticism. Natural and social scientists, along with jurists, educators, ethicists and others wishing to live in a world compliant with the still-relevant aspirations of the 1948 Universal Declaration of Human Rights should undertake discussions like those presently occurring on genetic and geo-engineering, to define and test what would constitute ethical social engineering, i.e. laws and customs sufficient to stabilize their societies against misinformation-driven discord while otherwise maximizing individuals' freedom of expression and opportunities for creativity.

Simon Greenman

AI and generative AI: technologies, tools, and capabilities

Introduction: Generative AI represents a transformative technological shift, with implications for creativity, knowledge work, business, and society. Unlike previous AI waves, the breakthroughs are being driven by foundational models of unprecedented scale. These models have the potential to reshape industries and accelerate scientific and social progress, but they also carry profound risks if governance fails to keep pace.

The Rise of Foundational Models: GPT-4 was trained on 10 trillion words, required 2×10^{25} floating-point operations, and contains 1.8 trillion parameters. These massive models are transforming creative and knowledge work, impacting professions such as law, research, and white-collar services. Already, 40% of Americans have tried generative AI tools. As a general-purpose technology, generative AI is being applied in six domains: content creation; research and knowledge discovery; conversational AI; data analytics and insights; coding and software development; and autonomous or agentic AI.

Examples of Emerging Capabilities: New generative AI tools demonstrate capabilities that were previously unimaginable. Perplexity offers direct answers instead of search links, while 'deep research' tools synthesize content across hundreds of sources in minutes. Multimodal models interpret text, speech, and images, creating natural human-like interaction. Companies like Synthesia (raised ~$100M) are pioneering AI avatars and deepfakes. In software, tools such as Replit can generate functional applications–including maps, agendas, and directories–based purely on natural language instructions. Autonomous agents are emerging that can act independently, such as booking flights with contextual awareness. These hint at a future where millions of agents coordinate work on our behalf.

Frontier Potential: Generative AI is positioned to drive breakthroughs across science, healthcare, education, and catastrophe management. DeepMind's AlphaFold predicted 3D protein structures from DNA, opening new medical frontiers. AI can enable personalized tutoring at scale and democratize healthcare access, while business productivity gains could reach $20 trillion globally.

Power Laws and the Race for Scale: Exponential increases in compute, data, and parameters are driving emergent intelligence. From 2009 to 2025, training datasets have grown from 10^3 to 10^{13}, and compute from 10^{15} to 10^{26} FLOPs. This scaling has triggered a global race among nations and corporations. Amazon is investing $11B in an AI data center in Iowa; U.S. hyperscalers are projected to spend $320B in capex this year; and global AI infrastructure investment is estimated to reach $5 trillion. Environmental consequences are stark–the water consumed could exceed half of the UK's annual usage. Meanwhile, AI researchers have become the 'rock stars' of this era, commanding packages as high as $100M.

Risks and Guardrails: The rapid rise of generative AI brings substantial risks. Market power may concentrate among a few wealthy players. Autonomous weapons and AI in conflict present security and geopolitical challenges. Environmental demands for energy and water are immense. Trust undermined by deepfakes and disinformation. Hallucinations and bias persist in model outputs. Perhaps most concerning, the proliferation of autonomous agents raises the possibility of losing control as millions of AI systems act independently.

Call to Action: Nobel Laureate Demis Hassabis has observed that the AI revolution may be ten times larger than the Industrial Revolution–and ten times faster. Exponential growth in AI capabilities must be matched by equally rapid advances in governance, ethics, and societal adaptation. Without proactive guardrails, the pace of development risks outstripping our ability to maintain control.

The world is changing fast, and we must ensure we are prepared to shape its trajectory responsibly.

Alex Ntoko

Data, AI, and knowledge robots: Enhancing performance through synergy

Introduction: The powerful synergy between data, artificial intelligence (AI), and knowledge robots or "Knowbots" could shape the future of technology. Knowbots are intelligent agents which can autonomously search, collect, and analyze information, often moving across networks to access distributed resources. For instance, a Knowbot in healthcare might retrieve the latest treatment protocols from remote databases, streamlining access to critical information. When paired with generative AI, Knowbots could enhance decision-making and automate tasks in sectors such as healthcare and cybersecurity. While advanced models and technology are key, up to 80% of AI's effectiveness relies on high-quality, well-managed data. Together, Knowbots and AI are transforming how we access and use information.

The Role of Knowbots in AI: Knowbots are intelligent digital agents that move[38] from one computer to another, to collect and process information for users across networks. Enhanced by AI, they improve efficiency in fields like healthcare, education, HR, and business by handling repetitive tasks, analyzing large datasets, and providing smarter search results. Their mobility allows them to gather and act on data remotely, helping AI deliver more responsive, user-focused solutions.

The Importance of Data Management: Good data is essential for effective AI–up to 80% of AI's success relies on it. In areas like healthcare and self-driving cars, AI needs quality data to perform reliably. While strong technology matters, careful data management is one very important element which makes AI truly useful and trusted.

Integrating Knowbots with advanced data platforms ensures:

- Data Sovereignty: Knowbots collect and process data securely and efficiently.
- Security: Encryption and checks to protect data from start to finish.
- Interoperability: Knowbots connect smoothly with existing systems for unified information exchange.
- Trust and Ownership: Users stay in control, with Knowbots operating under clear permissions.

Conclusion: When data, AI, and Knowbots are combined, they improve how we access information, automate tasks, and personalize services. The key to their success is responsible data management, which builds trust and ensures ethical use. Together, these technologies empower better decisions and add value to our lives.

[38] For Knowbots, the movement from one computer to another is triggered by the Knowbot program itself or a supervisor process within the Knowbot operating environment, directing the program's execution through a communication link and a pre-defined route to a different node in the distributed network.

Anna Pouliou

Ethical use of AI in negotiations: AI diplomacy

Artificial intelligence is becoming an increasingly salient feature of international diplomacy, particularly in negotiations where outcomes bear existential consequences, such as arms control and planetary emergencies. Its capacity to simulate scenarios, process complex data in real time, and forecast negotiation trajectories holds considerable promise for enhancing decision-making. However, the integration of AI into these domains raises pressing ethical questions that should not be overlooked.

In the field of arms control, AI offers valuable tools for treaty verification, analysis of satellite imagery, and the modeling of state behavior. Such applications could reinforce compliance with cornerstone agreements, including the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the Chemical Weapons Convention (CWC), and the Convention on Certain Conventional Weapons (CCW). Yet risks are equally evident: algorithmic misjudgments may escalate tensions, systemic biases may distort assessments, and over-reliance on AI could erode the primacy of human judgment in matters of life and death. Ethical principles–transparency, accountability, explainability, and above all, human oversight–must therefore remain non-negotiable.

Planetary emergencies, encompassing climate change, pandemics, and other global crises, similarly highlight both the potential and pitfalls of AI. These contexts demand tools capable of integrating vast data sets and balancing the interests of multiple stakeholders over long time horizons. AI can contribute to such efforts, but its effectiveness depends on the quality and diversity of underlying data, as well as the inclusiveness of its design. Overly technocratic or reductionist approaches risk marginalizing vulnerable populations and undermining political feasibility. Ethical AI in these contexts must therefore be grounded in fairness, inclusivity, and sensitivity to fragile social trust. Confidentiality constitutes another critical dimension. Negotiations frequently involve sensitive or classified information, and AI systems must ensure security, auditability, and robust protection against misuse. Without such safeguards, trust in both the technology and the negotiation process is jeopardized.

At the institutional level, the United Nations has begun to address these challenges through the Secretary-General's AI Advisory Body, the United Nations Institute for Disarmament Research (UNIDIR), and UNESCO's ethics framework. Regional and international initiatives, such as the European Union's AI Act and the OECD AI

Principles, provide additional normative foundations. Nevertheless, these instruments remain incomplete in addressing the unique requirements of high-risk negotiation settings.

Ethical AI diplomacy does not entail the replacement of human negotiators with autonomous systems. Rather, it requires the development of AI tools that function in an advisory capacity–transparent, accountable, and subordinate to human decision-makers. Embedding ethical considerations into the design, deployment, and governance of such systems is essential to safeguarding global stability and fostering legitimate, cooperative outcomes in international negotiations.

Shaikha Al-Sanad

Cybersecurity challenges in building AI-driven smart cities

Introduction: AI and data driven techniques are fundamentally changing how cities monitor, maintain, and manage infrastructure assets. Smart cities increasingly employ AI-based structural health monitoring (SHM), predictive maintenance, and digital twin models to ensure the safety, resilience, and longevity of buildings, bridges, transportation networks, and utility systems. These technologies generate vast amounts of real-time data through distributed sensors, unmanned aerial vehicles (UAVs), smart meters, and Internet of Things (IoT) devices. AI-driven analytics convert this data into actionable insights that optimize asset management and extend infrastructure service life. However, the digitization and network systems used in smart cities also introduce cybersecurity risks. In the smart city, infrastructures become more reliant on cloud platforms, third-party vendors, and autonomous decision-making algorithms, the attack surface expands significantly. Cyberattacks on SHM systems and asset management platforms can compromise on data integrity and the physical safety of citizens who depend on this infrastructure. In this paper, we examined the cybersecurity challenges in smart cities, particularly indifferent components of it, such as SHM, and asset management, and proposed strategies for building resilient digital ecosystems.

Smart Cities, AI, and the Infrastructure: Smart cities integrate AI in different components of infrastructure systems as described below:

- SHM: Distributed sensors measure strain, vibration, displacement, temperature, and acoustic emissions in bridges, towers, and tunnels. AI models detect anomalies and predict failures.
- Asset Management: Data-driven decision support systems prioritize maintenance, allocate resources, and extend the life cycle of infrastructure assets.

- Digital Twins: these are digital copy of infrastructures simulate responses to environmental stresses, seismic activity, and long-term degradation.
- Critical Services: Transportation, energy grids, water distribution, and emergency response systems depend on AI for predictive maintenance and load balancing.

These interdependent systems promise resilience and cost efficiency, but they also magnify vulnerabilities when subjected to cyber threats. A hacking in a bridge monitoring system, for example, could lead to false condition assessments, delaying critical repairs and endangering public safety.

Cybersecurity Risks in AI-Driven SHM Systems: Data and Privacy Hacking: SHM generates high-resolution, continuous data. If these data are manipulated, such data could reveal vulnerabilities in structural systems that adversaries might exploit for sabotage. Integrated asset management also involves linking infrastructure data with geospatial and administrative datasets, raising concerns about data privacy.

Sensor and IoT Device Vulnerabilities: Sensors and IoT devices are also installed in hard-to-reach environments with limited physical protection. Many of these sensors operate with low-power firmware and minimal encryption. Therefore, they are attractive targets for attackers. Such hacked SHM sensors can feed false readings into AI models, covering true structural deterioration.

Algorithmic Manipulation and Adversarial Attacks: AI-driven anomaly detection models are vulnerable to adversarial inputs. Synthetically made noise in vibration signals can lead the algorithm to misclassify safe conditions as critical vice versa. Such manipulations can disrupt maintenance scheduling, generate unnecessary expenditures, or, in the worst case, precipitate catastrophic failures by hiding genuine structural risks.

In a smart city, SHM and asset management platforms are centralized, and cloud-based, cyber-attacks targeting monitoring dashboards and digital twin systems can destroy entire infrastructure networks. For example, denial-of-service attacks may delay inspections, interfere with early warning systems, and seriously affect the emergency response to structural incidents.

Conclusion: AI-driven smart cities enhance the infrastructure safety, resilience, and efficiency through structural health monitoring, predictive maintenance, and advanced asset management. These benefits are accompanied by cybersecurity challenges. This can affect various components of smart city such as attack on sensor network, AI algorithms, asset management platforms. These risks will affect the data integrity and physical safety and long-term resilience. Addressing these challenges requires a holistic approach that integrates security by design, robust governance frameworks, ethical data practices, workforce development, and international collaboration. A secure digital foundation is necessary to get the full benefits of AI in SHM and infrastructure management. It is, therefore, necessary to embed the cybersecurity into the smart city design, so that we can build intelligent infrastructure systems for safe, sustainable and resilient urban cities.

Daniela Mainenti

Cybersecurity and organized crime: AI as a tool for criminal governance

The accelerating development of artificial intelligence in criminal contexts represents not an incremental challenge, but a structural transformation of the very notion of criminal attribution. Until recently, AI was framed as an instrument, raising issues of negligence in design, oversight, or misuse. This paradigm has collapsed. Autonomous algorithmic architectures now possess the ability to learn unsupervised, self-configure, and impose coercive decision-making cycles. They are no longer neutral tools: they act as governance actors, exercising prerogatives that traditionally belong to sovereign powers – regulation, enforcement, economic management, and deterrence.

From this perspective, criminal law faces an unprecedented dilemma. When AI operates as a “dark institution,” existing outside traditional legal visibility, liability cannot be confined to human misuse. What is needed is the elaboration of a new category: “criminal computational sovereignty.” Here, attribution of responsibility must extend along three axes: strict liability for human beneficiaries, command responsibility for developers and designers, and autonomous liability for the algorithmic entity itself. The debate on “digital personhood” should evolve into a negative recognition – a codification granting legal standing to computational entities solely for the purpose of making them subject to international criminal jurisdiction. Such recognition has profound implications for comparative criminal law. Legal systems that already apply strict liability in high-risk domains, such as maritime accidents or environmental protection, provide valuable models. These regimes dispense with proof of intent when systemic danger is inherent in the activity. A similar approach is necessary for algorithmic systems whose very operation creates risks of structural harm. The evidentiary challenge is equally decisive.

Traditional digital forensics, limited to log extraction, is insufficient. We require a new discipline – "algorithmic forensics" – capable of reconstructing the decision-making processes of AI, testing compliance with normative standards, and producing admissible evidence across jurisdictions. This entails protocols for access, decryption, and forensic validation of AI models. International cooperation must overcome the shield of proprietary opacity, ensuring that patent or trade secrecy does not become a vehicle for impunity. Procedural codes should enshrine the right to a "forensic algorithmic audit," obliging producers and controllers of AI systems to cooperate under judicial mandate. The practical urgency of these issues is demonstrated by recent cyberattacks. The Monte Carlo Casino breach illustrates how symbolic, high-value targets are exploited not only for financial gain but for reputational leverage and immediate political pressure. The ransomware campaigns against the Italian healthcare system reveal a different strategy: striking critical infrastructure to paralyze essential services, creating ethical and operational dilemmas for governments. The exfiltration of hotel guest records demonstrates how personal data can fuel long-term extortion, fraud, and social engineering on a massive scale. Finally, the intrusion into the US Courts' archives represents the most alarming development: an assault on the credibility of judicial institutions themselves, opening the door to evidentiary manipulation and systemic blackmail.

Taken together, these examples confirm a single operational logic: criminal actors exploit informational infrastructures not simply to extract value, but to exercise sustained coercive power. In this sense, cybercrime is evolving into a form of computational governance, and criminal AI is consolidating itself as a new sovereign actor on the global stage. The implications for planetary emergencies are evident. To safeguard legality and international order, criminal law must abandon a reactive stance and embrace proactive, predictive governance. This means anticipating technological trajectories before they crystallize into irreversible criminal power structures. A supranational legal corpus, flexible and integrative, is essential – one that incorporates new forms of conduct and actors without the need to rewrite offences from scratch. Likewise, international organizations must incorporate algorithmic risk indicators into early warning systems, alongside macroeconomic and geopolitical indicators. The lesson from Erice is clear: without innovation in liability models, forensic tools, and supranational frameworks, digital criminal sovereignties will consolidate unchecked. The task before us is to ensure that law remains effective even when confronted with non-human actors, preserving the rule of law in the algorithmic age.

Pier Paolo Maria Menchetti

Artificial intelligence in the fields of biomedical research and healthcare

AI applied to scientific research and medicine represents a $10 billion market worldwide in 2023, with an expected annual growth rate of 49% and reaching $164 billion in 2030. The market is currently dominated by the United States and sees China as a major emerging ("Artificial Intelligence (AI) in Healthcare Market Growth, Drivers, and Opportunities," n.d.). AI applications in the field of life sciences and medicine and health include:

Biomedical Research: AI in biomedical research makes it possible to greatly accelerate (up to 50 per cent more) the development of new diagnostic methods and new therapies. In particular, it is possible:

- Analyzing a large number of genomic sequences and identifying mutations associated with diseases, as well as predicting phenotypic characteristics from DNA sequences. Machine learning algorithms make it possible to study the expression of genes; thus, to associate expression with certain characteristics or disorders.
- Modelling molecular structures in silico to predict their function, biological activity and interactions in complex biological systems. In this context, the Italian biomedical market, which reaches EUR 16 billion per year, employs more than 100,000 people in the private sector alone, (Carbone, n.d.).

Diagnostics and Healthcare: AI is providing key tools for the acceleration of diagnostic procedures and the development of increasingly accurate and early diagnostic tests. In the diagnostic sectors, AI is revolutionizing:

- The analysis of medical and biological images to arrive at automated diagnosis of pathologies (e.g. cancer) through radiological or histopathological images. At the Sant'Andrea University Hospital in Rome, software is in use that autonomously identifies fractures that might escape the human eye. Furthermore, in MRI scans, new algorithms can save up to 50 per cent of the time, and in CT scans, images are acquired with 60 per cent less radiation.
- Development of non-invasive, rapid and effective tests with new 'biomarkers' for the diagnosis of diseases with high social impact (e.g. neurodegenerative diseases).

It has been calculated that AI could generate savings in diagnosis times of 50 million man-hours per year, and reduce the direct and indirect costs of communicable diseases (e.g. social, economic) by as much as EUR 834-883 billion per year (Deloitte, 2020). Italy could save approximately EUR 21.74 billion per year through the implementation of AI in healthcare processes, reducing costs by 10-15%. In Italy, the AI market in healthcare is expected to reach EUR 3.19 billion by 2030 but only 26% of Italian healthcare companies planned to invest in AI in 2023.

Pharmaceutical Industries: The pharmaceutical industry is on the verge of a radical transformation thanks to AI. According to McKinsey Global Institute, generative AI has the potential to generate $110 billion in revenue per year for the pharmaceutical industry, revolutionizing the way drugs are developed and produced. The artificial intelligence market in precision medicine was $1.2 billion in 2022 and is estimated to grow 30.8 per cent in 10 years, reaching $17.1 billion by 2032. The global precision medicine market is expected to register a CAGR (compound annual growth rate) of over 11.5% during the forecast period.

The Italian pharmaceutical market was worth $4.64 billion in 2023 and is expected to reach $6.82 billion by 2032, with a CAGR of 4.25% during the period 2024-2032 ("Italy Pharmaceutical Market Size, Share | CAGR of 4.25%," n.d.). According to a study published in 2024, over the past decade, at least 75 drugs in clinical trials have been developed by companies using AI to discover new drugs. Approximately 80-90% of the candidates that made it through the first phase of clinical trials proved successful. This figure is well above the industry average of 50-60% (KP Jayatunga et al., 2024).

Care, Disabilities and Autonomy: In this context AI can develop technologies both for early and reliable diagnosis and for the maintenance or development of lost autonomy and quality of life. AI is therefore a key resource for developing increasingly advanced solutions, making assistive technologies accessible and tailored to those who need them most. In 2022, the global market for assistive technologies was estimated at USD 21.95 billion and is expected to reach USD 31.22 billion by 2030 (World Economic Forum).

Scientific Cooperations: International cooperation, and in particular scientific diplomacy, has many benefits, as it provides a bridge between academia and politics, fostering international collaboration on global challenges such as climate change, food security and public health. AI offers opportunities in the field of international cooperation in various ways, helping to improve the effectiveness of development initiatives, emergency management, and the promotion of peace and security. Some examples of the application of AI in international science cooperation include:

1. Improving access to education and healthcare: AI is used to improve access to

education and healthcare in remote or conflict-affected areas. For example, AI can be used to offer remote healthcare through AI-assisted diagnosis or provide online educational resources in emergency contexts.
2. Optimization of development projects and access to educational resources and scientific content: ranging from optimization of project management to automatic translation of scientific content and adaptation of proposed activities to difficult/different contexts.
3. Simplifying access to advanced technologies: AI can make scientific technologies more accessible even in poorer regions by reducing the complexity and costs associated with their use. AI can be integrated into low-cost devices (such as mobile phones and inexpensive sensors) that allow remote access to advanced scientific instruments.

Conclusions: Although there are no specific estimates exclusively for the life sciences, some general analyses of the impact of AI on the economy offer useful pointers:

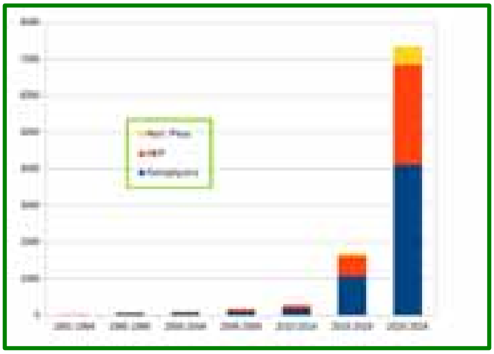
- Goldman Sachs predicts that the adoption of AI could generate *global GDP growth of 7 per cent over 10 years*, equivalent to about USD 7 trillion ("The Potentially Large Effects of Artificial Intelligence on Economic Growth (Briggs/Kodnani)," n.d.).
- McKinsey Global Institute estimates that *AI could increase the annual GDP growth rate by 3-4 percentage points between 2024 and 2040* ("The impact of AI on productivity and GDP: a future of prosperity or new inequalities? - Digital Agenda," n.d.).
- In Italy, a study commissioned by Google suggests that the large-scale adoption of generative *AI could increase GDP by EUR 150-170 billion per year* over the next ten years, equivalent to an overall growth of 8% (Casciabanca, 2024).

Sun Kun Oh

AI in high energy physics and astrophysics

Recently, AI was increasingly adapted to the academic ecology: in education and in research, both in positive as well as in negative ways. In a report released in June this year, MIT research team found that, in the field of education, those who relied on "large language model" performed worse than their counterparts in the brain-only group at all levels: neural, linguistic, scoring in answering question in plain English. They added that "brain connectivity systematically scaled down with the amount of external support" in those who were relying on AI chatbots to help them write essays. Nevertheless, international organizations such as UNESCO stresses that AI has the potential to address challenges in education today, innovate teaching and learning practices, and accelerate progress.

AI is now increasingly applied in research. There are already a number of AI apps that are said to assist academic activities. Writing drafts, in particular the introductory part, with the help of LLM becomes quite common. Searching for references and literature reviewing's by using AI is also frequent. Even preparing presentation slides is assisted by AI apps, not to mention drawing graphs and charts. Of course, there are negative effects, because fibrilization and falsification, as well as plagiarisms, may be very easy if AI is applied. A number of incidents were already reported. However, it is evident that AI is indispensable these days for scientific research. To what extent researchers are assisted by AI? The trend of AI-incorporated research may be qualitatively described by the number of articles published so far.



The number of articles uploaded in arXiv (*https:://arxiv.org*) with keyword AI.

As we know, there is a website for physics archives (together with mathematics and computer sciences), the ArXiv. It began its service in 1991 for the circulation of preprints. It now possesses about 2.4 million articles on a wide range of subjects, by the end of 2024. And about 1.4 million articles on physics. Articles are searched with such keywords as "machine learning," "neural networks," and "AI" itself, in the field of astrophysics (astronomy +gravitation relativity +quantum cosmology), high energy physics (hep ex +hep pheno +hep th +hep lat), and nuclear physics (nucl ex +nucl th). It is found that there are 9,707 articles with AI keywords in the field of high energy physics (AP+HEP+NP). This number may be compared to 35,221 articles with AI keywords in all fields of physics, between 1991 to the end of 2024, among 1.4 million articles. The figure shown above is the result, based on the 5-year basis. It may be noted that the share of the articles with AI keywords is still less than 4 per cent, although they are exponentially increasing from almost non-existent in 1990s. Most probably, if the trend continues, the AI-incorporated articles will soon surpass 10 per cent of total articles in ArXiv.

Session 6: The impact of human activity on sustainability and global health

Session Chairs: Stefano Parmigiani[39] and Frederick vom Saal[40]
Speakers: Terrence J. Collins[41], R. Thomas Zoeller[42], Maria Elisabeth Street[43], Gheorghe Duca[44], Paola Palanza[45]

Stefano Parmigiani and Frederick vom Saal
Introduction and summary

A sustainable civilization is a prize that is precious beyond compare for modern humanity because without it our species will lose everything. Experts in the Natural Sciences (e.g., chemists, endocrine disruption scientists, water scientists, ecologists, behavioral biologists, evolutionary biologists, medical doctors, engineers, etc.) and Social Sciences and Humanities (e.g., anthropologists, economists, psychologists, sociologists, historians, politicians, and authorities of different religious faiths) are all vital actors for achieving this goal. The quest encompasses the greatest cultural and technological challenges our species has ever faced and requires the evolution of a civilization-wide ethics that raises the prioritization of long-term outcomes from the currently reigning short-term focus. A multidisciplinary approach is essential to address the emergency facing us, which threatens environmental sustainability, animal and human health and survival. The time has come for a cultural metanoia regarding resource exploitation technologies, which not only compromise environmental "homeostasis" but often also lead to social injustice and human suffering on a global level. (See Terry Collins presentation Kairos: Evolving the technical, economic, health, environmental, and fairness performances of chemical technologies in the quest for sustainable development). From this perspective, we firmly believe that man (Homo sapiens) now, more than ever, needs a new ethic and spirituality, without which, humanity will be unable to successfully face environmental and social emergencies. This is the aim that our PMP, Environment & Health, has decided to address and discuss in future sessions.

In the 2025 session we discussed the environmental unsustainability of the widespread use of man-made endocrine disrupting chemicals (see R. Thomas Zoeller Presentation: Endocrine

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Disrupting Chemicals: Stealth Chemicals that Prove the Status Quo is not Sustainable) and the threat they represent for mother and children (see Maria Elisabeth Street presentation: Environmental threats to mothers' and childrens' global health). Another emergency for the environment and animal and human health is represented by microplastics (see Gheorghe Duca presentation: Microplastics and Toxic Chemical Additives Pollution as a Global Environmental Threat). The final presentation concerned the impact of human activities on biodiversity (see Paola Palanza presentation: BIODIVERSITY: Global Human Impact and the One Health Principle).

TERRENCE J. COLLINS

KAIROS: EVOLVING THE TECHNICAL, ECONOMIC, HEALTH, ENVIRONMENTAL, AND FAIRNESS PERFORMANCES OF CHEMICAL TECHNOLOGIES IN THE QUEST FOR SUSTAINABLE DEVELOPMENT

Kairos: The decisive time in our relationship with all of God's creation, when we must respond in an opportune manner to protect life on earth from the worst consequences of human recklessness."— Patriarch Bartholomew of Constantinople.

Professor Collins began his presentation by highlighting a deadly pattern in modern civilization: our persistent failure to control the damaging consequences of technology arising largely from an inability to effectively govern our expanding technological power. He reflected on society's foundational ethical principles–particularly the Ten Commandments–which have historically shaped legal and moral standards across the Western world and beyond. Yet, as he noted, these commandments primarily address immediate, interpersonal behavior. While they foster trust and social order mainly by guiding present-day actions between people at close quarters, their scope in space and time is limited. However, as Hans Jonas and others have observed, the powers unleashed by modern science have a fundamentally different scope. Our technology-based actions now reach across continents and generations, producing adverse impacts on the environment and humanity that may persist indefinitely.

Professor Collins warned that, at present, society exploits technology largely for short-term benefits–fueling imagination, enhancing comfort, and increasing wealth–while often neglecting its profound long-range risks and the associated responsibilities. True sustainability, he argued, requires us to learn how to balance immediate gains with the enduring effects of technology on our planet and collective future. Meeting this challenge will demand collaboration between fields such as religion, science, and economics.

Professor Collins insisted that only when humanity recognizes that undermining sustainability is evil–while promoting it is good–can we truly progress toward a sustainable civilization. “Although daunting,” he asked, “what choice do we have but to reshape our ethics and laws to meet this new long-term reality where leadership from faith communities would be so helpful?”

Focusing on chemical technologies, Professor Collins described how society has often overlooked the long-term dangers posed to human health, environmental integrity, and fairness with its social equity implications. Technology is too frequently evaluated purely by its technical or economic performances, with insufficient regard for its effects on health, environment and fairness. As a result, powerful economic incentives often maintain the use of hazardous, unsustainable technologies–an injustice to both present and future generations. Overcoming this will require the courage to make transformative decisions on a global scale, especially for the sake of those who come after us.

On September 5, 2025, soon after the 2025 Erice Planetary Emergencies Seminars, Pope Leo XIV inaugurated Borgo Laudato Si’ at the Castel Gandolfo papal estate as a Vatican Center devoted to the principles of creation care and human dignity outlined in Pope Francis’s encyclical letter, Laudato Si’. In his opening remarks, Pope Leo XIV reiterated that care for creation “represents a true vocation for every human being” and an essential Christian calling. This demonstrates the Catholic Church’s potential openness for the interdisciplinary dialogue as Professor Collins suggested in Erice. Importantly, our Erice goals are inclusive of all religions as signaled by the presentation’s Greek title, Kairos, and its association with orthodox Patriarch Bartholomew.

Professor Collins listed several glaring examples of collective failure to manage technology’s risks: fossil fuel use and emissions, nuclear weapons, endocrine-disrupting chemicals (a particularly dangerous set of chemicals that disrupt the endocrine system to alter human and animal development), and pervasive plastics. Despite our tools of a broadly shared ethics, scientific research, regulations, and investment, we have not been able to successfully guide technological progress toward genuine sustainability. Professor Collins challenged the Erice attendees to reflect on shortcomings in our foundational ethics as the root cause of our ongoing failures.

Drawing on Hans Jonas' philosophical work, Professor Collins called for the urgent development of an expanded ethical framework incorporating sustainability. He proposed that religious traditions–deeply embedded in the moral outlook of much of humanity–should join with science and economics to update our core understanding of right and wrong behavior in response to science and technology's unprecedented power. A global consensus, he argued, should be cultivated around our urgent new realities. To symbolize this needed shift, Professor Collins proposed modern "commandments" be added to the familiar Abrahamic ones and elevated to comparable importance in defining what is virtue and vice:

11. *Thou shalt not exterminate the fish of the sea, the birds of the air, or the animals of the land.*
12. *Thou shalt protect the ecosphere that I have created for you.*

Professor Collins further outlined the need for a deep collaborative initiative uniting science, economics, and religion–potentially beginning with Catholicism and collaborating with all interested religions starting through interdisciplinary meetings in Erice. The aim is to transcend our current anthropocentric ethics by developing practical frameworks to evaluate behaviors driven by science and technology based on their effects on living beings and the planet. This inquiry can clarify new forms of virtue and vice arising from our use, or abuse, of scientific and technological power. Endorsed by religious leadership and supported by scientists and economists, these core concepts–kept simple and accessible–could be readily adopted by faith communities, business entities and academic and governmental institutions worldwide.

Professor Collins described how these convictions arose from his more than three decades of teaching "Chemistry and Sustainability" at Carnegie Mellon University, and through interdisciplinary research, especially aimed at bringing broad understanding of toxic chemicals being found in everyone and developing methods to identify, reduce and eliminate endocrine-disrupting chemicals. To equip future leaders, he created a Code of Sustainability Ethics for his students, a set of principles he hopes will also inspire broader dialogue among religious, scientific, and economic leaders. Such discussions, acted on by consensus action, he contended, are crucial for defining right and wrong behavior in the era of science- and technology-driven change, while fostering a global commitment, and ultimately guiding us toward a truly sustainable civilization. These codes of sustainability ethics are:

1. Dedicate your life to learning and pursuing what sustainability requires.
2. Shape your life's work by imagining how you can best serve future generations.

3. Teach that sustainability is not a pictured endpoint, but a direction that can be logically identified and realistically followed by everyone.
4. Champion biodiversity and everything needed to sustain it.
5. Teach that a money-first-in-all-things civilization will perish from the earth.
6. Work to make jobs, wealth and sustainability mutually reinforcing.
7. Oppose the denial of sustainability problems.
8. Always resist distortion of science that compromises the common good.
9. Never devalue sustainability for money, tribute or political support.
10. Ally yourself with people you can trust to keep faith with sustainability.

R. Thomas Zoeller

Endocrine disrupting chemicals: Stealth chemicals that prove the status quo is not sustainable

Chemicals are manufactured for use in almost everything humans encounter including food, plastics, personal care products, clothing and building materials. In addition, manufactured chemicals contaminate our environment in ways not always anticipated in air, dust, food and water. Most of these chemicals are derived from crude oil; in fact, petrochemical production for plastic and uses in other products is predicted to soon exceed demand for traditional uses, i.e., oil and gas. Some of these chemicals interfere in very complex ways with hormone systems in both humans and wildlife and are identified as endocrine disrupting chemicals (EDCs) [1]. As regulatory agencies worldwide have become more aware of EDC since the 1990s, they have initiated large, complex and expensive responses to identify and mitigate human exposures to EDCs. But most of these programs are using the same approach that created these exposures in the first place – assuming that we can identify a threshold of exposure below which humans will not be adversely impacted. The risk assessment "rules" employed by regulatory agencies assume that a) there is a linear "exposure-response" relationship between exposures and adverse outcomes [2], b) there is a "threshold of safety" [3], c) that chemicals act alone and do not have additive or synergistic effects as mixtures [4,5], and d) that the woefully inadequate agency testing programs can prevent the widespread use of a new EDC before humans are affected [6]. Each of these assumptions that regulatory agencies use to assure the public that chemicals in products are safe is incorrect and represent an approach to chemical safety determination that is simply not sustainable.

Consider chemicals that interfere with the thyroid hormone system. Thyroid hormones are essential for normal human brain development and normal functioning of the body throughout life. Thyroid hormone deficiency caused by iodine deficiency in global regions of endemic goiter causes profound brain damage [7]. In the case of "congenital hypothyroidism" – a developmental disorder where the thyroid gland in the fetus does not work – discovery and treatment immediately after birth is an emergency situation to avoid profound brain damage that lasts a lifetime [8,9]. Moreover, children born to women with even moderately low thyroid hormone during the first trimester of pregnancy have lower IQ [10]. Chemicals that interfere with the thyroid hormone system during pregnancy – for example polychlorinated biphenyls (PCBs) – are associated with neurobehavioral deficits in the offspring [11]. Furthermore, a mixture risk assessment performed on exposures to specific PCBs in addition to other chemicals that interfere with the thyroid hormone system, was associated with low IQ in children at current levels of exposure [12]. The problem is that the screens and tests employed to identify thyroid hormone system disruptors is very poor at identifying these chemicals and are especially poor when considering the standard assumptions described above that are used by regulatory agencies.

The economic costs of the health consequences of exposures to chemicals that interfere with the thyroid hormone system that are associated with neurobehavioral deficits are estimated in the hundreds of billions of dollars per year [13,14]. But the cost to society is far greater than these economic estimates predict, both because they are based on a few chemicals – and a few outcomes – for which there is sufficient data, and because the societal costs of chemical exposures that impact brain development and human potential are incalculable [15].

These observations demonstrate that governments protect products more than populations. One reason for this may be that the economic impact of chemical regulations on industries is more easily quantifiable (and overestimated) than the economic impact of chemical exposures on human health and the environment. Beyond this, though, regulatory agencies should not be assumed to be autonomous from the industries they regulate. Social scientists view such governmental agencies as institutions rooted in civil society, representing or mediating between social interests like private firms, public experts, various interest groups and popular movements. Governments' failures to address these public health threats of EDCs should be understood as an imbalance between private interests and public ones institutionalized within the regulatory system. This imbalance between private interests and public ones institutionalized within the chemical regulatory system represents the Status Quo. It is not sustainable. Given the increase in numbers of new chemicals produced and used in products without safety testing each year, and the transgenerational effect of some classes of EDCs, the proportion of the population exhibiting health consequences will grow as will the proportion of GDP we commit to it.

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Maria Elisabeth Street

Environmental threats to mothers' and children's global health

Prof. Street highlighted the current changes related to exposure to environmental contaminants acting as endocrine disruptors, comprising chemicals (EDCs), mycotoxins, air pollutants, micro and nano-plastics, and highlighted effects of climate change.
Exposure to environmental contaminants, including endocrine disrupting chemicals, air pollutants (i.e. volatile organic compounds, airborne plastics, particulate matter, gases), mycotoxins, and microplastics, negatively affects human health. Scientific evidence has proven how exposure, in particular from conception up to the first 1,000 days of life, can increase the incidence of non-communicable hormone related diseases such as obesity, diabetes, neurodevelopmental and neurodegenerative diseases, immune and reproductive diseases and cancer in adult life.

It is well accepted that this is due to interference with epigenetic mechanisms, disrupting timing and overall gene expression. This gives proof to Barker's theory on the developmental origins of health and disease (DoHAD). However, it was pointed out also that most conclusions come from studies in animals, with few studies in the pediatric age, and studies being scarce regard to some of the mechanisms implicated.
A number of epidemiological studies in humans have evidenced that prenatal exposure to mixtures of EDCs is associated with reduced birth length, weight, and higher body mass index trajectory in the following years [1-3] besides with changes in thyroid hormone synthesis and action and iodine uptake with subsequent adverse effects on neurodevelopment, metabolism, growth and body composition [4].

Particulate Matter (PM) can interfere with the mother's thyroid function at the beginning of pregnancy [5]. PM 2,5 interferes with gestation and a number of disruptions including the risk of preterm births, low birth weight, asthma, obesity, diabetes and neurodevelopmental disorders [6]. Exposure to particulate matter would also contribute to an earlier menarche in girls [7].

Recent evidence also shows how breast milk, although the optimal source of nutrition, is also contaminated. In Italy, currently bisphenols, parabens, and many phthalates are found in breast milk with preliminary data showing associations with growth, distribution of adiposity and external genitalia features. Formula milk is also contaminated (LIFE ENV/IT/000460; www.lifemilch.eu).

Many mycotoxins are currently unregulated, and some are recognized to have a pro-oestrogenic action. Micro and nano-plastics are found in the human body including placenta, meconium, faeces, breast milk and infant formula [8,9]. Damage also results from these microplastics. Many mechanisms, including disruption of mythochondrial function and thus energy dysregulation, increase oxidative stress, inflammation, changes in apoptopic pathways, in the microbiota and immune systems and others [10]. A warming climate can accelerate microplastic fragmentation and increase the adverse effects of microplastics on roots and soil organisms [11]. Finally, the huge decrease in fertility rates globally and the increase in medically assisted reproduction was evidenced as possibly related with the environment and is of concern [12].

It was highlighted how we need to provide scientists and the public with clear messages through clear and trustworthy epidemiological data and how maybe this could be done through big data analyses pooling the data from different epidemiological studies. Communication skills need to be implemented and improved. Climate changes are increasing the effects of environmental threats.

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Gheorghe Duca

Microplastics and Toxic Chemical Additives Pollution as a Global Environmental Threat

Plastics have become essential in modern life due to their durability, low cost, and versatility, yet these same properties make them one of the most dangerous environmental pollutants. While macroplastic waste is visible, the invisible threat today is microplastics – tiny particles now found in air, water, soil, food, and even in the human body. Every year, over 400 million tons of plastics are produced, with only 9% recycled. Around 12 million tons reach the oceans annually, and by 2050 plastics may outweigh fish in the seas. Recent studies show that the average person ingests about 5 grams of plastic per week. Microplastics contain toxic additives such as BPA, phthalates, styrene, heavy metals, and persistent organic pollutants, which disrupt hormones, cause oxidative stress, inflammation, organ damage, infertility, and increased cancer risk.

Case Studies:

- Tea bags: a single bag can release billions of micro- and nanoparticles.
- End-of-Life Tires: recycled tires used in playgrounds and artificial turf release toxic compounds (PAHs, heavy metals, VOCs) that children can inhale, ingest, or absorb through skin, especially on hot days. These materials increase risks of respiratory diseases, hormonal disruption, and even cancer. Tire dust also contaminates soils and crops, acting as a vector for hazardous chemicals.
- Polyethylene microplastics: induce oxidative stress and inflammation, damaging liver function and disrupting endocrine regulation.

Research and Solutions: In the Republic of Moldova, over 200,000 tons of plastic waste are generated annually, but only 10–15% are processed. A pilot integrated technology (20,000 tons/year) has been developed for recycling, based on chemical processing, advanced oxidation, and mechanical treatment. Research has shown promising results using Fenton/photo-Fenton oxidation and dielectric discharge for microplastic degradation.

Key Proposal: Establish an International Convention on Microplastics with measures such as:

- Global ban on non-biodegradable plastics.
- Exclusive use of biodegradable alternatives.
- Elimination of hazardous additives.
- Adoption of innovative oxidation and biodegradation methods.

Final Message: The fight against plastics begins with each of us: Refuse – Reduce – Reuse – Recycle – Redox. International cooperation among governments, scientists, and industry is essential to protect ecosystems, food security, and human health.

Paola Palanza

Biodiversity: Global human impact and the One-Health principle

The Convention on Biological Diversity, signed at Rio in 1992, defines biodiversity as follows: "Biological Diversity means the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Biodiversity is a complex issue that: (a) stresses the relationship between fundamental ecological concepts and their effect on the diversity of organisms; provides methods for evaluation of biological resources and (c) combines these two factors for conservation. The United Nations' Report highlighted how Nature's Dangerous Decline is 'Unprecedented' and Species Extinction Rates are 'Accelerating'. Anthropocene is the current geological age, viewed as the period during which human activity has been the dominant influence on climate and the environment [1]; the global rate of species extinction in the 21st century is tens to hundreds of times higher than the natural rate over the past ten million years and (10% of described species- IUCN Report). Entire branches of the tree of life are being lost [2]. According to many studies and reports we are facing the sixth great mass extinction caused by anthropic impact with grave impacts on people around the world [3,4]. The IUCN Red List of Threatened Species and Ecosystems (www.iucnredlist.org) identifies more than 48,600 species threatened with extinction that is 28% of all assessed species. Climate changes, habitat loss and degradation, overexploitation, environmental pollution, such as Endocrine disruptors are among the main causes of biodiversity loss for their impact on adaptations and health of organisms [5]. Human health and a healthy environment are connected as pointed out by the One Health approach that recognizes the interdependence of animal, ecosystem and human health [6].

How can we reverse the current negative trends in species survival highlighted by the IUCN Red List? There are many associations and institutions operating to preserve biodiversity. Reverse the Red is a global movement that ignites strategic cooperation and action to ensure the survival of wild species and ecosystems and reverse the current negative trend in species survival. Many international associations and institutions are involved in such actions either with "in situ" conservation of species, habitats, or ecosystems "on-site," or in their natural surroundings (e.g. nature reserves and national parks; wildlife refuges; habitat management and habitat restoration actions) or "Ex situ" conservation of the components of biological diversity "off-site" or outside their natural surroundings such as nature reserves, national parks, zoological gardens, bioparks, aquaria, botanical gardens. Ex Situ conservation aims to preserve genetic diversity of captive populations of threatened species thus providing "insurance policy" and play important roles in recovery programs. Zoological gardens/parks and aquaria operate as networks in national and International associations such as Unione Italiana Zoo and Aquaria (UIZA), European Association of Zoo and Aquaria (EAZA) and World Association of Zoo and Aquaria (WAZA). At the entrance of the Bioparco di Roma is displayed a quote that well expresses the reasons why we must oppose to the current and future biodiversity loss: "God has joined us so closely to the world around us that we can feel the desertification of the soil almost as a physical ailment, and the extinction of a species as a painful disfigurement". (Pope Francesco, Laudato Sì, 2015, par.89).

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Session 7: Batteries and mining

Chairmen: Walter M. Grayman[46] (Chairman, Pollution and Water Crisis PMP) and Carmine Difiglio[18] (Chairman, Energy PMP)
Speakers: Rennie B. Kaunda[47], José Nicolás De Piérola C.[48], Emre Erdem[49]

Carmine Difiglio and Walter M. Grayman

Introduction

The transition of the motor vehicle, power and industrial sectors away from their reliance on fossil fuels is being accomplished with several technological changes. For example, internal combustion vehicles, powered by motor fuels, are being replaced with all electric vehicles, powered by electricity stored in batteries. Coal and natural gas power plants are being phased out with wind energy and solar cells, along with batteries to provide backup power. Many processes in industry that rely on natural gas or other fossil fuels are being electrified. As a consequence, in addition to a variety of newer technologies in other sectors, such as cell phones, the energy and transport sectors are contributing to a rapidly increasing demand for batteries, particularly light lithium-ion batteries. Wind turbines and other power sector technologies, such as motors and electrolyzers, also require more minerals. Consequently, the demand for lithium, cobalt, nickel, manganese, graphite, and copper is rapidly increasing.

The purpose of this session was to explore the world-wide environmental and social consequences of increased mining. We also consider whether advances in battery technologies could substantially reduce the minerals they need by reviewing battery chemistry and physics. We conclude that while several other battery technologies can reduce the demand for the minerals that are required by lithium-ion batteries, they will likely supplement lithium-ion batteries, instead of replacing them. In particular, electric vehicles will likely continue to require lithium-ion batteries, with their high specific energy, in order to achieve a longer vehicle range between recharging. Consequently, as the various energy and energy-related sectors continue their transition away from fossil fuels, a large growth in mineral mining appears to be inevitable.

With the rapid uptake of green energy technologies, energy and environmental policies should be expanded to take account of increased mineral mining. For example, countries that supply these minerals should take actions to avoid the adverse environmental and social consequences of this increased demand. There are also energy security issues because, as discussed below, mineral mining for different critical metals is often

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concentrated in a few countries. We should also take into account the full environmental impact of green energy technologies, not just their expected impact on CO_2 emissions.

Rennie B. Kaunda

Environmental impacts of mining battery minerals

The rapid expansion of renewable energy technologies, electric vehicles (EVs), and portable electronics has accelerated global demand for battery minerals. These minerals–including lithium, cobalt, nickel, manganese, graphite, and copper–form the foundation of modern rechargeable battery systems. While they enable a shift toward a low-carbon future, their extraction and processing come with significant environmental and social consequences. Understanding these impacts is critical for ensuring sustainable development of the battery supply chain.

Battery minerals are classified as both critical and strategic materials. Lithium is the core component of lithium-ion batteries, providing high energy density. Cobalt stabilizes the cathode and enhances safety, while nickel increases battery capacity. Manganese contributes to stability and safety, graphite is the dominant anode material, and copper and aluminum serve as essential conductors and structural components. Other elements such as vanadium, silicon, sodium, phosphorus, and rare earth elements play emerging roles in advanced battery chemistry.

Global supply of these minerals is geographically concentrated. For instance, cobalt is primarily mined in the Democratic Republic of Congo (DRC), lithium from the "Lithium Triangle" (Chile, Argentina, and Bolivia), and graphite from China. Such concentration not only introduces supply chain risks but also amplifies local environmental and social challenges.

Like most forms of mining, battery mineral extraction generates vast quantities of waste. For instance, to produce one metric ton of copper, approximately 350 tons of waste rock and tailings are created. At a global scale, some studies report that between 5 to 7 billion tons of tailings are produced annually. Tailings storage facilities, when poorly managed, can fail with catastrophic consequences. A recent example occurred on February 18, 2025, when a tailings dam at the Sino-Metals Leach copper mine in Zambia released about 50 million liters of acidic and toxic waste into the Mwambashi River. The spill threatened the Kafue River, a waterway relied upon by over five million people. Such incidents highlight the risks posed by the increasing scale of mining for battery minerals. In addition to catastrophic failures, routine impacts include land disturbance, habitat destruction, and the release of dust and emissions from ore roasting and chemical processing. These effects are not unique to battery minerals, but their scale is magnified by rising global demand.

Beyond conventional mining concerns, battery minerals introduce unique environmental pressures. Lithium extraction, particularly from brines, often leaves large evaporation ponds and waste residues. In Australia, for example, nearly 98% of lithium processing waste is not recycled. Infrastructure development can also lead to land subsidence, especially in brine-rich terrain. Lithium brine extraction is highly water-intensive, requiring up to 500,000 gallons of water per ton of lithium. In arid regions like Chile's Salar de Atacama, where precipitation averages just 100–200 mm annually, groundwater depletion rates of up to one meter per year have been observed. The use of toxic processing chemicals further raises the risk of contaminating both surface and groundwater. Failures of evaporation ponds–such as liner breakages–can release pollutants into surrounding ecosystems.

Toxic residues from lithium and associated chemicals can disrupt soil ecology, aquatic systems, and wildlife. Long-term consequences include eutrophication and ecosystem degradation that may be irreversible in sensitive environments. Emissions from roasting ores and chemical refining processes may contribute to local air pollution. Trace elements such as lithium and other toxic chemicals can interfere with human metabolism and neuronal communication when exposure occurs through soil, water, or air pathways. In sub-Saharan Africa, artisanal mining of cobalt and other minerals is associated with severe social challenges. These include unsafe working conditions, exploitation of women and children, weak governance, land-use conflicts, communicable disease transmission, and illegal migration. The absence of robust legal frameworks and limited educational opportunities perpetuate cycles of vulnerability and informality in the ASM sector.

The extraction, processing, and use of battery minerals demand a balance between advancing clean energy goals and protecting people and the environment. Several strategies can reduce potential negative impacts, such as improving efficient water use in lithium extraction and consistently recycling process water. Technologies that minimize land subsidence in soft terrains should be adopted. Enhanced recycling of lithium processing waste, tailings, and chemical by products is needed. Additives and advanced materials can be used to reduce evaporation pond area and time requirements. Methods such as selective adsorption, ion-exchange, and electrolysis can capture lithium more efficiently. Greater investment is needed in hydrogeological, ecological, and socio-economic research to assess the full impacts of lithium and other mineral extraction. Life Cycle Assessment (LCA) tools should be improved to include categories like biodiversity loss and water toxicity, enabling more accurate evaluation. Infrastructure design should prioritize smaller environmental footprints.

Battery minerals are indispensable for the clean energy transition, but their extraction carries substantial environmental and social costs. Without careful management, the push toward electrification risks replicating extractive patterns that compromise ecosystems and communities. Strategic planning, innovation in processing technologies, robust regulatory frameworks, and responsible mining practices are essential to ensure that the benefits of battery technologies do not come at an unacceptable cost to people and the planet.

José Nicolás De Piérola C.

Impact on water resources due to increased demand for metals

Global energy and metal demands are closely intertwined. Despite the growing presence of alternative energy sources, the global energy consumption pattern remains largely unchanged, with fossil fuels–namely oil, natural gas, and coal–still accounting for up to 84% of the market. Since the Paris Agreement in 2021, the energy landscape has seen limited transformation in terms of decarbonization. According to the Energy Institute, energy consumption reached 620 EJ in 2023 (1 EJ = 172 million barrels of crude oil). Central and South America maintained a consumption level of 31 EJ.

In the global context, the mining sector faces a series of challenges that must be addressed in the coming years:

- A significant increase in the demand for critical metals and minerals through 2050.
- A demanding decarbonization process and the implementation of new environmental standards in mining operations.
- Emerging trends in water use across the mining sector.
- Adoption of desalination of water, water stewardship, and circular economy principles.
- Integration of social management as a core component of mining activities, involving communities and stakeholders.

Recent years have shown a clear trend: due to declining ore grades in exploitable deposits, greater volumes of material must be extracted to yield the same quantity of refined metals. (e.g., Cu, Fe, Ni, Mo); this implies increased consumption of energy, water, and auxiliary resources. Copper production is on the rise, with an expected annual growth rate of 3.35% between 2024 and 2028, potentially reaching 33 million tons by 2028. However, the recovery rate of copper has remained stable or declined between 2003 and 2023, ranging from 30% to 35%. More efficient recovery methods will be required to increase these percentages.

A global analysis of copper production and its future projections indicates that South America–led by Chile and Peru–will continue to dominate output. Notably, major extraction and processing centers are in arid regions where water is scarce, prompting increased reliance on water desalination technologies. Africa and the Asia-Pacific region follow in importance to meet projected demand by 2040. Copper demand is primarily driven by energy transmission systems–both conventional and renewable–surpassing the anticipated demand from electric vehicles (EVs) and storage batteries EB. A key uncertainty lies beyond 2100, when copper may be replaced by alternative materials for energy generation and distribution.

Freshwater consumption for copper flotation processes currently ranges between 0.35 and 0.6 m^3 per ton of ore, while leaching processes require between 0.01 and 0.06 m^3/ton, depending on ore grade. Producing one ton of refined copper typically requires approximately 150 to 200 m^3 of water. In Chile, intensive desalination efforts have halved freshwater use–from 0.75–0.80 m^3/ton to nearly half–in less than 20 years.

Another mineral of growing global importance is lithium, with current production reaching 1.2 million tons annually of Lithium Carbonate Equivalent (LCE). Lithium is critical for manufacturing batteries for EVs and high-capacity energy storage systems, which may account for up to two-thirds of total demand. By 2050, lithium demand could reach 11.5 million tons of LCE annually to support solar and wind energy storage systems. Currently, only a few countries produce lithium at scale (e.g., Australia, Chile, Argentina, China). A promising development is the transition from LCE to Direct Lithium Extraction (DLE), which could drastically reduce water consumption from 2,200 m^3/ton to just 70 m^3/ton, minimizing both quantitative and qualitative impacts on water resources and the environment near extraction sites.

Around 2010, the concept of Water Stewardship emerged, offering the industrial and resource extraction sectors a new paradigm for water management. It is based on five core principles: stakeholder engagement in production processes, shared water resource development actions, capacity to build enabling environments, effective communication between users and recovery ecosystems, and implementation of robust data collection and processing strategies. This framework lays the foundation for watershed-level water resources.

In 2017, the International Council on Mining and Metals (ICMM) formally adopted systematic water management practices in the mining sector, establishing governance standards outlined in the 2020 Water Stewardship Maturity Framework. ICMM proposes ten action principles, four of which directly address water and environmental management: systematic risk management, environmental performance control, biodiversity conservation impact, and promotion of social governance practices.

Based on the elements, seven strategic pillars are proposed to guide mining sector development in alignment with production needs and global market dynamics:

1. Water holds multidimensional value: economic, social, and environmental.
2. Optimize water use and promote circular economy practices.
3. Technological innovation is central to mining investment and productivity.
4. Manage water at the watershed level with shared value among users.
5. Implement nature-based solutions and integrate green infrastructure.
6. Incorporate territorial development and ecosystem services into strategic planning.
7. Use of seawater and desalinated water in operations while mitigating the impact of brine discharge.

The intensification of metal demand–especially copper and lithium–requires a paradigm shift in water resource management. Through technological innovation, governance frameworks, and strategic planning, the mining sector can align production goals with sustainability imperatives, and water stewardship must be central for ensuring resilience and equity in natural resources use through 2050.

Emre Erdem

Battery technologies

The history of energy storage in transportation reflects a cycle that has come full circle. In the early twentieth century, electric vehicles competed with combustion engines, but the dominance of fossil fuels, advances in engine design, and the absence of efficient storage solutions led to the global rise of internal combustion. A century later, electrification is once again at the center of mobility, driven by environmental pressures, technological progress, and industrial strategy. At the heart of this transition is the lithium-ion battery, a technology that has become essential for electric vehicles and renewable energy integration.

Lithium-ion batteries dominate the market because of their superior combination of properties. They offer high gravimetric and volumetric energy densities, long cycle life, efficiency, and the ability to support fast charging. The fundamental principle behind their operation is the reversible transfer of lithium ions between anode and cathode, a mechanism that provides the stability and reliability required for both mobile and stationary applications. This performance, however, depends not only on lithium but also on other critical minerals such as nickel, cobalt, manganese, chromium, and aluminum. Each element plays a distinct role in improving capacity, thermal stability, or durability, which makes the battery sector heavily dependent on the global mining and processing of these resources.

Control over these materials is increasingly strategic. China has established itself as the dominant force in the battery supply chain by investing early and aggressively in mineral-rich regions, while also building an unparalleled domestic manufacturing base. Today, China leads in anode and cathode materials, cell production, and refining capacity, giving it significant leverage in shaping global energy markets. This dominance is particularly evident in anode production, where natural graphite is overwhelmingly processed in China. To counter this, alternative strategies are being developed, including the use of synthetic graphite and carbon derived from biowaste or inorganic wastes. These approaches not only diversify the raw material base but also advance sustainability by reusing existing resources.

Although lithium-ion batteries remain the central technology, several alternatives are being explored to meet specific needs and to prepare for potential supply disruptions. Solid-state batteries, which replace flammable liquid electrolytes with solid conductors, are viewed as the next major step, promising higher safety and energy density. Sodium-ion batteries have attracted attention because of the abundance and low cost of sodium, although their lower energy density limits their competitiveness in high-performance applications. Metal-air systems, such as lithium-air or zinc-air batteries, offer extremely high theoretical energy densities, but significant technical barriers remain regarding cycle stability and reversibility. Flow batteries, which decouple energy capacity from power output, are well suited for stationary storage, though their low energy density makes them unsuitable for vehicles. While each of these technologies has advanced through research and pilot projects, none currently rival lithium-ion in terms of scalability, maturity, and industrial integration.

Looking forward, lithium-ion batteries are expected to retain their dominant role. Industry roadmaps project energy densities approaching 1,000 Wh/kg, which would mark a transformative improvement in electric vehicle performance by extending ranges and reducing charging requirements. Such advances would also enhance the economic viability of large-scale grid storage, enabling greater penetration of renewable energy. However, achieving these targets will require continuous innovation in electrode design, electrolyte chemistry, and manufacturing methods, alongside efforts to reduce costs and environmental impacts.

Despite technological progress, structural challenges remain. The concentration of production in China exposes global supply chains to political and economic risks. To ensure resilience, other regions must invest in diversified sourcing strategies, build recycling infrastructures, and expand local manufacturing capacity. Recycling is particularly important for recovering critical elements, reducing reliance on virgin materials, and mitigating the environmental costs of mining. Circular approaches in battery production not only improve sustainability but also enhance supply security.

Battery technologies thus stand at the intersection of science, industrial policy, and geopolitics. Lithium-ion systems have established themselves as the cornerstone of electrification, but their continued leadership will depend on addressing supply chain vulnerabilities and supporting emerging alternatives. The development of solid-state, sodium-ion, metal-air, and flow batteries illustrates the breadth of innovation underway, yet these technologies remain supplementary rather than replacements at present. The future of energy storage will ultimately be determined by the ability to combine performance improvements with resilient supply strategies and sustainable practices. Achieving this balance will shape the global energy transition and define the technological and economic trajectory of electrification in the decades ahead.

Session 8: Water Crises: The Next Quarter Century

Session Chair: Walter M. Grayman[46]
Speakers: Peter Gleick[50], Alice Aureli[51], Shammy Puri[52], Vanessa Speight[53], John Pomeroy[54]

Walter M. Grayman
Introduction and summary

One can open a newspaper on almost any day and find an article related to water or pollution. Issues related to water and pollution are ubiquitous and the associated consequences may lead to local or regional disasters, or true planetary emergencies. The Pollution and Water Crisis PMP address a wide range of water and pollution related areas including drought, floods, climate change, pollution and related policy, infrastructure, security, and health issues. As we enter the second quarter of this century, it is appropriate to look at what some of the issues related to pollution and water may be over the next quarter century. In our plenary session we highlighted four such areas. A common theme among all of the presentations is that comprehensive strategies and actions are needed now to ensure a sustainable water future and to minimize and mitigate the impacts of water crises over the coming quarter of a century.

In addition to the four presentations at the plenary sessions (summarized below), Dan Kroll[55] made a presentation to the PMP on the Challenge of Toxic Algae Blooms. Harmful Algal Blooms have emerged as a growing environmental, health, and economic challenge across the globe. Over the last decade, their frequency has increased dramatically, with a 600% rise in reported cases between 2010 and 2020. These events not only disrupt aquatic ecosystems but also carry severe consequences for human health, property values, tourism, fishing, and recreation industries. The costs associated with monitoring and control run into the billions annually, with the true impact likely much higher when factoring in indirect losses and foregone productivity. Coordinated responses between scientists, policymakers, and communities will be crucial to protecting both ecosystems and human health from the growing threat of toxic algae.

Peter Gleick
Water, peace, and security

Violence over water resources is not a recent development but a persistent feature of

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human history, stretching back more than four thousand years and continuing into the present. Water and water infrastructure has been central to many conflicts: as a trigger for disputes, as a target or casualty of conflict, and as a weapon intentionally used against opponents. The drivers behind these conflicts–scarcity, climate change, land disputes, and other pressures–are still insufficiently understood and analyzed, which hinders the ability to apply effective risk-reduction strategies. Closing this knowledge gap could significantly improve the chances of reducing the risks of water-related conflicts.

The incidence of violence over water has increased dramatically in recent decades, as tracked by the Water Conflict Chronology – the open-source database on water conflicts maintained by the Pacific Institute. Population growth and expanding economies and agricultural water demands, particularly in low- and middle-income countries, are placing greater strain in water-scarce regions. Major inequities persist in how water is accessed and distributed. Environmental degradation undermines both water quality and quantity. And efforts to address disputes over water have often proven inadequate, in part because of a lack of understanding about the deeper causes and in part because of inadequacies in international law, institutions, and responses. In many cases, the focus has been on addressing short-term responses rather than developing more effective and sustainable long-term strategies that tackle root causes such as water poverty, weak institutions, and unclear legal frameworks for water rights.

The notion of "water wars" is sometimes used to describe these conflicts, but the reality is more complex. When water serves as a trigger of conflict, scarcity and access disputes are often at the heart of the problem. This has been seen in clashes between pastoralists and farmers in Kenya, and in tensions in countries like Iran and India where drought has worsened rural-urban tensions. In other cases, water becomes a casualty of conflict with the deliberate or incidental destruction of infrastructure, such as dams, pipelines, or treatment plants, during war. Examples span from the Second World War through conflicts in Vietnam, Iraq, Yemen, and most recently, Ukraine. The targets are often physical systems, but they can also include individuals – water infrastructure operators, engineers, and activists.

Water and water infrastructure have also been used as weapons of conflict. This includes diverting water away from communities to deprive them of essential resources, deliberately flooding villages to force populations to move, or poisoning wells to render them unusable. These tactics, such as those reported in Iraq and Somalia, create longlasting humanitarian and environmental harm. Conflicts over water occur at both transnational and subnational levels. Freshwater resources are often shared between countries–about half of all land on Earth lies within one of the more than 300 international river basins identified by the Transboundary Freshwater Diplomacy Database developed and maintained by the Oregon State University. Transnational disputes typically involve competition between states over shared rivers or lakes, while subnational disputes often involve local communities, ethnic groups, or regional authorities. Risks can arise at multiple scales, from local tensions to state-to-state rivalries. Each type of conflict has its own dynamics and requires different approaches to resolution.

New concerns are emerging at the intersection of water and security. Water availability is closely linked to economic development, influencing poverty levels, allocation systems, and disputes over water rights. The potential for water-related acts of terrorism–including cyberattacks on infrastructure–adds a modern layer of vulnerability. Another troubling development is violence directed against "defenders" of land and water-individuals or groups who advocate for environmental protection. Climate change further complicates the picture, bringing both direct impacts, such as altered precipitation and more frequent droughts, and indirect effects, such as migration pressures and resource competition.

Given the complexity of these challenges, strategies for reducing water-related conflict must be multi-dimensional. Technological measures play an important role. Building resilient water and sanitation systems can help bring water services to populations without and ensures they can withstand both environmental extremes and human-made disruptions. Developing multiple water sources reduces dependence on a single supply and increases system flexibility. Efficiency in water use across all sectors can stretch available resources further, while proactive measures to reduce vulnerability to floods and droughts help protect communities. Establishing protected zones around critical infrastructure can shield these systems from deliberate or accidental damage.

Economic and financial strategies are also important. Investment in resilience should be encouraged from donors, development banks, and governments, with financing models designed to be flexible, long-term, and responsive to emerging threats. Agricultural policies should be reevaluated to align with sustainable water access, while public-private partnerships can leverage resources and expertise. Addressing broader poverty issues improves economic stability and can reduce the desperation that fuels resource competition. Institutional measures that focus on governance and capacity can also reduce water conflicts. Strengthening water-management institutions improves oversight, planning, and dispute resolution. Developing mechanisms for resolving disputes–both within and between countries–can prevent tensions from escalating. Training military forces to protect civilian water infrastructure and incorporating water security into peacekeeping missions are additional safeguards. Recognizing and enforcing access to water as a human right ensures that policy decisions prioritize people's basic needs.

Political, diplomatic, and legal approaches can create binding, enforceable protections. Implementing and enforcing existing legal safeguards and agreements for water resources and infrastructure is an essential first step. Negotiating comprehensive agreements for shared watersheds can promote cooperation and fairness, while equitable allocation of water and land rights addresses one of the root causes of conflict. Strengthening international humanitarian law, particularly the "Laws of War", to explicitly protect water, can help deter its weaponization and targeting during conflicts.

The links between water and security are strong and growing. The combination of increasing scarcity, inequitable access, and environmental stress is driving more frequent and severe conflicts. If these risks are left unaddressed, the consequences will include worsening public health, slower economic development, and greater instability. Yet water does not have to be only a source of contention. Just as it has sparked violence, it can also be a foundation for peace, cooperation, and sustainable development. The same qualities that make water so vital–its centrality to life, livelihoods, and ecosystems–also make it a powerful tool for building trust and shared purpose.

To move toward sustainability, strategies must integrate technical innovation, economic investment, institutional reform, and political diplomacy. Resilient infrastructure, efficient management, and fair distribution can reduce tensions, while collaborative agreements and legal protections can reinforce stability. By treating water not merely as a commodity but as a shared human and ecological necessity, societies have the opportunity to transform a history of conflict into a future of cooperation.

Alice Aureli and Shammy Puri

From conflict to cooperation: the Global 2030 Agenda

The first UN intergovernmental conference on water was organized in 1977 in Mar Del Plata (Argentina) and was the first indication of global cooperation over water issues.

The second UN Conference was organized more than 40 years later, and halfway through the implementation of the 2030 Agenda, at which governments, UN agencies and experts alerted about the poor status of water quality and stressed the transboundary water cooperation at the global level.

The 2030 Agenda for Sustainable Development, was adopted by all United Nations Member States in 2015. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries. The SDG 6 seeks to ensure availability and sustainable management of water and sanitation for all. One of the SDG 6 targets (target 6.3) seeks by 2030 to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. At the core of this indicator's methodology is the definition that "good ambient water quality" is water of a certain standard that flows in our rivers, lakes and aquifers "without causing harm to human or ecosystem health".

The last 2030 Agenda reports tell us that water pollution levels are alarmingly high. Inefficient water use practices are common. By 2030, the health and livelihoods of 4.8 billion people could be at risk if the water quality and monitoring of water bodies is not improved. The poorest half of the world is not able to monitor their water quality. Data are critically lacking about water quality in lake and groundwater where monitoring needs to be strengthened as a priority.

Another indicator of the SDG 6 monitored by UNESCO and UNECE considered the Proportion of transboundary basin area with an operational arrangement for water cooperation. The UNECE and UNESCO last report published in September 2024 considers that governance and transboundary cooperation on water resources are too weak, and every continent suffers the impacts of inadequate investment in water and sanitation infrastructure. The report makes clear the need to strengthen lake and groundwater monitoring as a priority, especially in low-income countries. In transboundary water systems when we have good data, this indicator shows that water quality is degrading. These water quality data are of critical concerns when looking at transboundary aquifers.

Transboundary waters are of great significance globally. An estimated 313 rivers and lakes, and around 468 aquifers, are shared by two or more countries, and a total of 153

UN Member States are reliant on waters that either flow from or flow to another country. Transboundary rivers alone account for 60 per cent of the world's freshwater flows, and river and lake basins are home to more than three billion people. While cooperation among countries over their transboundary waters has long proven challenging, climate change poses an additional threat to the equitable and sustainable management of transboundary rivers, lakes and aquifers due to changing patterns of water availability, and the increased likelihood and magnitude of extreme events. At the same time, through joint and coordinated action at the basin scale, transboundary water cooperation offers an opportunity for countries to progress sustainable development whilst also maximizing the effectiveness of measures adopted to combat climate change. Currently, only 43 out of 153 UN Member States sharing transboundary rivers, lakes and aquifers have operational arrangements in place. Despite the current rate of progress being severely behind where it needs to be, cooperation is proceeding, as illustrated by the joint approach to the management of the Karstic Aquifers in the Balkan region. Nevertheless, there is Insufficient knowledge and cooperation on groundwater increased efforts are needed by countries to assess and manage their transboundary aquifers.

In December 2026 the third UN Water Conference to 'Accelerate the Implementation of Sustainable Development Goal 6: Ensure availability and sustainable management of water and sanitation for all', will take place in the UAE and will be co-hosted by Senegal and the UAE. At the United Nations General Assembly (UNGA) on 9 July 2025, UN Member States adopted the following themes for the six interactive dialogues for the UN 2026 Water Conference:

- Water for people: the human rights to water and sanitation, including for those in vulnerable situations, for healthy societies and economies;
- Water for prosperity: valuing water, water-energy-food nexus, advancing integrated and sustainable water resource management, wastewater and water-use efficiency across sectors, and economic and social development;
- Water for planet: climate, biodiversity, desertification, environment, source to sea, resilience, and disaster risk reduction (DRR);
- Water for cooperation: transboundary and international water cooperation, including scientific cooperation and inclusive governance;
- Water in multilateral processes: SDG 6 (clean water and sanitation), the 2030 Agenda for Sustainable Development and beyond, and global water initiatives; and
- Investments for water: financing, technology and innovation, and capacity building.

Looking ahead, there are 'smart' pathways that can lead towards greater cooperation and sustainability through the harnessing of the benefits of AI, for which UNESCO have developed some guidelines. Finally, it may be noted that water is a significant component of national and international trade flow, through 'virtual water' (a concept that indicates volumes of water embedded in production processes) which should be monetized for accounting for externalities. In an increasingly urbanizing world, the economics of water remain an issue of urgent attention. We urge that Governments take decisions and implement plans and programs to improve water cooperation.

Vanessa Speight

Water scarce cities – an emerging crisis

The United Nations (UN) estimates that 68 percent of the world's population will be living in urban areas by 2050, an increase from the current 55%. North America's population is 82% urban while Europe's is 74%. Africa and Asia are rapidly urbanizing. 68% of the world population is projected to live in urban areas by 2050 (United Nations, 2025, https://www.un.org/en/desa/68-world-population-projected-live-urban-areas-2050-says-un). At the same time, many parts of the world are experiencing water scarcity. The UN further estimates that half of the world's population currently experiences water scarcity for at least part of the year. Projections show that by 2050, 2.4 billion people, will experience water scarcity (UN World Water Development Report 2024, https://www.unwater.org/publications/un-world-water-development-report-2024. He, et al,[56] have concluded that 193 to 284 cities will experience water shortages by 2050, including 10 to 20 megacities.

Is the solution to simply use less water? That approach may oversimplify the problem and potentially endanger public health. Consider the case of Cape Town, South Africa, a city of 4 million people which faced 'Day Zero' in 2018. The city targeted a 50 liters per person per day consumption rate to preserve water. Implementing water use reduction suggestions did achieve an overall drop in consumption but many practices such as untreated grey water reuse, reduction in toilet flushing frequency, and less frequent washing/showering could also have detrimental health impacts. As estimated through stochastic modelling of water use activities using current technologies, an absolute basic consumption level of 92 liters per person per day is more realistic to preserve a modern lifestyle, while still requiring sacrifices such as eliminating outdoor

[56] Future global urban water scarcity and potential solutions. Nature Communications, 12(1), 4667, 2021 https://doi.org/10.1038/s41467-021-25026-3).

water use (Crouch et al., 2021, Defining domestic water consumption based on personal water use activities, AQUA - Water Infrastructure, Ecosystems and Society, 70(7), 1002–1011, https://doi.org/10.2166/aqua.2021.056). For many people who rely on urban gardens for supplemental food production or for mental well-being, a ban on outdoor water use could have significant impacts if required for long periods of time.

The problem of water scarcity in urban areas is further exacerbated by the legacy water infrastructure that delivers water services (provision of clean drinking water and removal of wastewater) which is aging and deteriorating. In many cities the water pipes are sized for fire flow or historical consumption that no longer takes place, creating the potential for water stagnation and water quality degradation. Low flow fixtures (toilets, faucets) can further exacerbate the water stagnation problems including excessive growth of biofilms which may harbor harmful pathogens like Legionella. The US Centers for Disease Control and Prevention (CDC) estimates that 1.13 million illnesses and 3,300 deaths are attributable to drinking water contamination, 91% from biofilm associated pathogens like Legionella (Gerdes et al., 2023, Estimating Waterborne Infectious Disease Burden by Exposure Route, United States, 2014, Emerging Infectious Diseases journal–CDC, 29(7), https://doi.org/10.3201/eid2907.230231). The US National Academies expert panel has recommended that low flow fixtures should not be allowed in hospitals and other settings with vulnerable populations to help control the incidence of these waterborne diseases (Committee on Management of Legionella in Water Systems, 2020, https://nap.nationalacademies.org/catalog/25474/management-of-legionella-in-water-systems), a fact that is at odds with the desire to use less water in water scarce urban areas.

In addition to pipe sizing and stagnation concerns, urban water infrastructure is generally in poor condition around the world (with a few exceptions). Leakage rates in many European and North American cities exceed 20% and can range as high as 50%. For example, considering the United Kingdom's current leakage statistics, a total of more than 3 billion liters of water per day is lost to leaks across the country (Water UK, 2025). Across the 27.2 million households of the UK, this amounts to approximately 110 liters per household per day of lost water, equivalent to nearly one additional person's consumption at the current average consumption rate of 137 liters per person per day (Water UK, 2025). So, water scarce cities are faced with the challenge of replacing or repairing their buried water infrastructure to address water scarcity, as reducing water consumption alone will not be sufficient.

City-scale buried infrastructure represents 80% of the cost for adaptation or renewal (Hoffmann et al., 2020, A Research Agenda for the Future of Urban Water Management: Exploring the Potential of Nongrid, Small-Grid, and Hybrid Solutions. Environmental Science & Technology, 54(9), 5312–5322, https://doi.org/10.1021/acs.est.9b05222). Significant construction in dense urban areas has implications for the many other buried utilities, including communications, gas, electricity, and transport, as well as for traffic and noise. Clearly, alternative solutions are required that might consider non-traditional water treatment and infrastructure options. However, faced with the many potential water qualities (potable, nontreated grey, treated wastewater effluent, rainwater, etc.) and the many scales at which infrastructure could be built, cities may struggle to see a clear future pathway (Speight and Boxall, 2025, Pathways to different urban water futures: 'Silver baskets' of sociotechnical solutions, Environmental Research: Infrastructure and Sustainability, 5(3), https://doi.org/10.1088/2634-4505/adf144). Changes to the current drinking water infrastructure in any city will also require consultation and alterations to many supporting policies and codes including those governing plumbing, development/urban planning, and local/regional public health. Given that the renewal of urban water infrastructure is urgently required in the near term, now is the time to begin the conversation about how cities would like to address water scarcity in their own local situation.

John Pomeroy

Global cryospheric loss and implications for water security

This presentation reviewed measured and calculated changes in climate and their association with rising greenhouse gas concentrations and then surveyed their impact on the cryosphere (snow and ice) and on oceans, ecosystems and hydrology. Global air temperatures have recently risen to 1.5 °C above pre-industrial levels in response to atmospheric CO_2 concentrations rising from 285 ppm to 425 ppm from pre-industrial to recent times. These CO_2 concentrations are higher than at any time since Homo Sapiens evolved as a species. The associated temperature increases have increased the melt rate of mountain glaciers and snowpacks, circumpolar snowpacks, sea ice, and freshwater ice (lakes, rivers), increased the thaw of permafrost (permanently frozen ground) as well as dramatically changing the hydrology of mountain, circumpolar and downstream rivers and increasing the incidence of droughts, moisture stress and wildfires in cold regions river basins. In response to this crisis, the UN General Assembly declared 2025 as the International Year of Glaciers' Preservation and 2025-2034 as the Decade of Action for Cryospheric Sciences to advance scientific research and monitoring.

Scientific issues for the Decade include rapidly ablating polar icesheets (Greenland and Antarctica), rapidly declining sea ice coverage (25% lost in 20 years) and rising sea levels due to ice melt. Circumpolar permafrost is predicted to thaw by up to 90% in northern river basins in Canada. Mountain glaciers are melting around the world, with 5% of mass lost since 2000 and 50% of mass expected to melt by 2100. Regional losses are much higher in the Alps and Rockies. This contributes to locally higher mountain streamflow on a temporary basis – it will decline as glacier areas retreat further. Recent drone-based LiDAR measurements of Peyto Glacier in the Canadian Rockies show a horizontal retreat of 440 m and decline in surface elevation of up to 56 m since 2019. Northern Hemisphere seasonal snow-covered periods have declined up to 3 days per decade since 1972 with decoupling of snowmelt from streamflow regimes evident in many mountain regions around the world – this leads to increased risk of drought as rainfalls are less reliable. Reduced lake ice coverage on the Great Lakes is resulting in increased incidence of harmful algae blooms from increased winter sediment and nutrient delivery to the water bodies. A global snow drought in 2023 was associated with the record wildfire year in Canada and hydrological drought over vast river basins draining northern North America, and much of Asia. Ecological effects of melting ice are complex and include the risk of the release of ancient or novel pathogens from permafrost and glacier ice. This has already occurred in Siberia and caused human mortality from anthrax. Human immunity to these pathogens is unknown and there is no global monitoring system in place for pathogen release from ice into downstream rivers. Freshening of northern oceans from increasing northern river discharges due to increased rainfall and melt of snow and ice can impact ocean currents and cause a decline in the Atlantic Meridional Ocean Circulation (AMOC). The AMOC has already slowed and a substantial decline this century is possible due to ice melt – this could cause the rapid cooling of western Europe as occurred in the Younger Dryas Period.

To provide solutions for these impacts of cryospheric disintegration from global warming, we need greater and more integrated cryospheric observation, monitoring and modelling systems. Cryospheric-hydrological models need further development and global application, coupled with earth system and water resource models to predict near and far future changes in water supply and variability as the climate shifts and glaciers and snowpacks melt. An example of a successful prediction system includes the USGS monitoring system on the Mendenhall Glacier which showed a glacier lake outburst was imminent in July 2025 and provided early warning when the flood did occur in mid-August 2025 in Juneau, Alaska. The MESH cryosphere-hydrological land surface model was developed in Canada to predict river flows including floods in cold regions. It has been successfully deployed over 5 M km^2 in Canada to inform adaptation to climate change and assist in flood forecasting and water management. MESH results for Central Asia's overallocated, transboundary Syr Darya River Basin under a worst-case climate change scenario predict a substantial drop in snowpacks by late 21st C. with a three-month shorter snow season. Annual discharge would then drop by 45% with peak flows one month earlier – results are 5% worse with concomitant deglaciation. This would be a devastating impact on regional water resources that could result in economic collapse and destabilization of this volatile region.

The Decade will need observations, modelling and science to achieve its goals. These needs can be met by (i) a comprehensive quantification of the role of snow and ice in global water and ocean resources and impact of global heating on future resources, (ii) integration of climate, cryospheric, oceanic and hydrological sciences with ecological and social systems towards creation of transdisciplinary solutions to cryospheric collapse, and (iii) developing adaptation and risk management solutions to mitigate cryospheric collapse. To achieve this will require building capacity, training scientists and engaging with communities around the world.

There is still time to mitigate greenhouse gas emissions and concentrations in the atmosphere, but we must act quickly to reduce these concentrations before the impacts of cryospheric collapse become unmanageable and a true planetary crisis. Humans have always lived on a planet with a substantial cryosphere. Humanity's prosperity and perhaps survival depend on ecosystem services from the cryosphere and, therefore, preserving the cryosphere is urgent. A planetary crisis of this nature is challenging to conceptualize and so combining art and science helps in finding solutions. An example is the recent UNESCO/Global Water Futures publication: The Great Thaw: A Homage in Art to the Vanishing Cryosphere, https://gwf.usask.ca.

Appendix

INTERNATIONAL SEMINARS ON PLANETARY EMERGENCY
57th Session
Chairman: A. ZICHICHI – Co-chairman: C. GALBIATI
Plenary Sessions Agenda

9 – 12 August 2025

Saturday 9 August 2025
09:30 Welcome and Introductory Remarks
• Fabrizio Zichichi (introducing Antonino Zichichi)
• Antonino Zichichi (via video)
• Government Officials

10:30 Keynote Address: Cristian Galbiati

11:00 Coffee Break

11:30 Session 1: Risk assessment and arms control
Session Chairman: William A. Barletta, *Chairman, Mitigation of Catastrophic Risks PMP*
11:30 Francesca Giovannini: *Proliferation control in the Information Age.*
11:50 Tariq Rauf: *Can the non-proliferation regime survive increasing nuclear arsenals?*
12:10 Lydia Wilson: *Containing interminable conflicts in a multi-polar world.*
12:30 Daniele Pulcini: *AI Technology for Global Peace and Science Diplomacy.*
12:45 Discussion

13:30 Lunch

15:30 Session 2: Biomedical discoveries, preventive/therapeutic strategies and their risks
Session Chairman: Franco Maria Buonaguro, *Chairman Medicine and Biotechnology PMP*
15:30 Massimo Ciccozzi: *The Spike and the FCS evolution in Coronaviruses.*
15:45 Sofie Nyström: *Amyloidogenic peptides.*
15:55 Emanuele Buratti: *TPD-43 misfolding and SLA.*
16:05 Felice Iasevoli: *Misfolding in neurodevelopmental and neurodegenerative disorders.*
16:15 Neal S. Young: *Somatic Mutations in Vexa syndrome.*
16:30 Sam Mbulaiteye: *The EBV role in human diseases and current vaccine efforts.*
16:40 Ishwar Gilada: *Alternative strategies to prevent/cure global virus-induced diseases.*
16:55 Per Hammarström: *The brave new world of biologic drugs – safe and effective?*
17:10 Discussion

18:00 Adjourn

Sunday 10 August 2025
09:30 Session 3: Data centers and small modular reactors
Session Chairman: Carmine Difiglio, *Chairman, Energy PMP*
9:30 Carmine Difiglio: *Introduction.*
9:40 Peter R. Hartley: *Can the power sector keep up with AI power needs?*
10:00 Hans-Holger Rogner: *SMR economics and data centers.*
10:20 Robert Budnitz: *Improved SMR technical and safety performance.*
10:40 Lucian Pugliaresi: *Natural gas, SMR's competitor for off-grid baseload power.*
11:00 Discussion

11:45 Coffee Break

12:15 Session 4: Engineering mitigation of major societal risks

Session Chairman: William A. Barletta, *Chairman, Mitigation of Catastrophic Risks PMP*

12:15 James H. Lambert, Marco Piras and others TBD: *The WFS Wildfire Project.*

12:45 Bilal M. Ayyub: *Recovery from catastrophic destruction.*

13:00 Sergey Pulinets and John Organek: *Mitigating threats from the solar maximum.*

13:15 Discussion

14:00 Lunch

16:00 Session 5: Arising challenges of cybersecurity and AI

Session Chairman: Axel Lehmann, *Chairman, Future of Cyber Security and AI PM*

16:00 Introduction.

16:05 Charles H. Bennett: *Quantum cryptography and cybersecurity.*

16:17 Simon Greenman: *AI and generative AI from a technological and capability perspective.*

16:29 Alex Ntoko: Data, *AI, and knowledge robots: enhancing performance through synergy.*

16:41 Anna Pouliou: *Global political tensions and the future of the AI regulatory framework.*

16:53 Shaika Al-Sanad: *Cybersecurity challenges in building AI-driven smart cities.*

17:05 Daniela Mainenti: *Cybersecurity and organized crime: artificial intelligence as a tool for criminal governance.*

17:17 Pier Paolo Maria Menchetti: *AI's impact in advanced medical research and biotechnologies.*

17:29 Sun Kun Oh: *AI challenges for high energy physics and astrophysics.*

17:41 Discussion

18:30 Adjourn

Monday 11 August 2025

09:30 Session 6: Environmental impact of human activities on health, biodiversity and sustainability

Session Chairmen: Stefano Parmigiani and Frederick vom Saal, *Chairmen, Environment and Health PMP*

09:30 Terrence J. Collins: Kairos: *Evolving the technical, economic, health, environmental, and fairness performances of chemical technologies in the quest for sustainable development.*

09:50 R. Thomas Zoeller: *Endocrine disrupting chemicals: stealth chemicals that prove how the status quo is not sustainable.*

10:10 Maria Elisabeth Street: *Environmental threats to mothers' and children's global health.*

10:30 Gheorghe Duca: *Microplastic pollution as a global environmental threat, strategies and technologies for risk reduction.*

10:50 Paola Palanza: *The global human impact on biodiversity.*

11:00 Discussion

11:30 Coffee Break

12:00 Session 7: Batteries and mining
Session Chairman: Walter M. Grayman, *Chairman, Pollution and Water Crisis PMP and* Carmine Difiglio, *Chairman, Energy PMP*
12:00 Walter M. Grayman and Carmine Difiglio: *Introduction.*
12:10 Rennie B. Kaunda: *Environmental impacts of mining battery minerals.*
12:30 Jose Nicolás De Piérola C.: *Impact on water resources due to increased demand for metals.*
12:50 Emre Erdem: *Battery technologies.*
13:10 Discussion

14:00 Lunch
16:00 Session 8: Water crises: The next quarter century
Session Chairman: Walter M. Grayman, *Chairman, Pollution and Water Crisis PMP*
16:00 Walter M. Grayman: *Introduction.*
16:10 Peter Gleick: *Water, peace and security.*
16:30 Alice Aureli: *Water cooperation; Building on the 2030 Agenda and looking ahead.*
16:50 Vanessa Speight: *Water scarce cities – an emerging crisis.*
17:10 John Pomeroy: *Global cryospheric loss and implications for water sustainability.*
17:30 Discussion

Tuesday 12 August 2025
10:00 Wrap Up Session, Fabrizio Zichichi, Chair (press will be present)
10:00 Fabrizio Zichichi: *Introduction.*
10:10 PMP Chairs' reports.
11:30 Fabrizio Zichichi: *Plenary discussion of PMP priorities with PMP chairs' panel.*
12:30 Cristian Galbiati: *Closing Remarks.*
12:45 Fabrizio Zichichi: *Synopsis: 2025 seminars and plans for 2026.*

13:30 Adjourn Plenary Sessions

OMAGGIO

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