IMPERIAL

Biosecurity at the frontier

Wednesday 10 June
London

Foreword

In 1918, on the heels of the First World War, an influenza pandemic began which would go on to kill tens of millions of people around the world. It arrived undetected, spread rapidly, and was, for all practical purposes, untreatable.

A century later, COVID-19 emerged in China, rapidly spread around the world and would again lead to the deaths of tens of millions of people. This time the world was prepared very differently: COVID-19 was rapidly detected, studied and tracked as it travelled across borders and through communities, and medical countermeasures were rapidly deployed against it. In 300 days, an effective vaccine was developed against the deadly virus, critically limiting the damage this new biological hazard could do.

These advances in technologies and approaches to responding to outbreaks we can now cluster under “biosecurity”: our ability to understand biological risks to human, animal and plant health; to detect and track them when they occur; and then to respond to protect populations and eradicate the threat.

These abilities have come on leaps and bounds in recent decades but so too have the risks. Whether it is in the emergence of new viral strains in nature or as an adaptation to antimicrobials; the emergence of biotechnologies allowing the creation of novel organisms; rapid advances in AI allowing those looking to do harm to explore a new and uncharted biological threat landscape; the explosion of data as a new area of international competition; or the ease of access to knowledge required to generate biological threats, the challenge for policymakers is to stay ahead of the curve.

The contributions gathered here reflect that breadth. They span the early signals of an emerging outbreak, the data and infrastructure that lets us see threats as they surface, and the systems that turn scientific possibility into deployable defence. Individually, each marks real ground gained. Together, they map a field maturing fast, and a community determined to close the gap between the threats we face and our ability to meet them.

At today’s conference, we bring together a community of researchers, policymakers, industry leaders and research funders to discuss what comes next. That is the spirit of Biosecurity at the frontier: not to speculate on the problem, but to get to work on it. We are glad you are here to join us.

Professor Hugh Brady

President, Imperial College London

Visit the conference website:

Biosecurity at the frontier

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The full range of biosecurity concerns, from epidemics/pandemics and zoonotic disease, through engineered pathogens, accidental release and biological weapons, to plant health, crops and food systems, have become central issues for policymakers around the world. In each domain, scientific breakthroughs, technological capacities and industrial innovations have combined to present new threats and opportunities.

While acknowledging that every element of biosecurity connects to the others, this invitation-only event will focus on identifying where the latest scientific research and industrial innovations can meet the pressing policy questions being asked about directed and man-made threats to human health.

The gap between emerging threats, the technologies driving these threats, and our ability to detect, attribute and respond, is widening. Closing it will require new approaches and coordination between those with the insights, authority and expertise to act. In response to these challenges, Imperial is hosting this high-level biosecurity conference, convening global leaders to examine these challenges and how, collectively, we can respond: moving beyond analysis to building the frameworks, partnerships and capabilities for better biosecurity.

Conference themes

Threats

The threat landscape is expanding, from weaponised natural pathogens to entirely synthetic threats. We will examine the technologies driving these threats, including AI-enabled threat creation, synthetic organisms, unintentional consequences from frontier biotechnology innovation, evolutionary and infectious disease modelling, and food security challenges.

Surveillance

Work is underway to build the next generation of detection infrastructure, bridging biology, chemistry, and engineering. We will explore integrated platforms for chemical and biological threat detection, water and air surveillance systems, micro forensics, attribution challenges, and governance frameworks for cross-border data sharing and standardised reporting.

Response

Pandemic responses have shown the imperative to develop and deploy rapid response capabilities at scale. We will investigate ‘ever-warm’ production systems, modular therapeutic platforms, resilient supply chains, scalable manufacturing for protein and chemical synthesis of therapeutic countermeasures, and broad-spectrum treatments deployable within weeks, not years.

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Establishing a blueprint for safe biosecurity research

Professor Wendy Barclay, Regius Professor of Infectious Disease, Imperial College London

Most viruses that make humans ill used to infect animals only. But spillover events that can lead to outbreaks and pandemics are becoming more frequent. Climate change and human activities such as deforestation and high-intensity animal agriculture increase the risk of animal diseases jumping into humans.

Pandemic preparedness hinges on predicting which pathogens are most likely to become a problem. This requires a broad biosecurity framework that combines surveillance, modelling and public health preparedness with laboratory science.

However, studying viruses with pandemic potential in the laboratory – which sometimes involves genetically engineering dangerous viruses in the laboratory to understand how they might evolve in the natural world – comes with security risks of its own.

Funders, regulators and researchers from around the world need to communicate existing safety mechanisms to the public and agree on global guardrails for this research. The UK, with its cautious yet open approach, could offer a blueprint for how to manage these risks.

> "The UK, with its cautious yet open approach, could offer a blueprint for how to manage these risks."

Above: Professor Wendy Barclay works alongside a colleague in the laboratory. Credit: Thomas Angus, Imperial College London
Right: Cell cultures in Professor Wendy Barclay's laboratory. Credit: Dave Guttridge, The Photo Unit

When animal viruses acquire mutations that can make them transmissible among humans, they can cause global pandemics, threatening lives and the global economy. Some viruses might already be poised to jump, and outbreaks occur when humans encroach into new territories, which is what happened with the Ebola virus in the Democratic Republic of the Congo.

For other viruses, there are many evolutionary steps before they could make this leap. By tracing the biological route and intermediate steps by which this emergence could happen, we can empower authorities and health systems to thwart it.

In 2024, an H5N1 avian influenza strain was discovered for the first time in dairy cows.

The highly pathogenic virus had already killed millions of wild and domestic birds around the world, and even infected some mammals. This new development showed that the virus had managed to jump to a new host species with which humans have extensive contact, making it more likely that it could target humans in the future.

Recent research[1] by academics at Imperial College London showed how the H5N1 strain had evolved to replicate in mammalian cells, moving it closer to humans. But at the same time, they found that the virus' recent adaptations – which optimise its existence in the cattle's mammary glands – make it less likely to become airborne and easily transmissible between humans[2].

Such information is vital to understand and monitor threats, and there are many precautionary approaches embedded within the scientific and regulatory community to ensure that this type of research does not itself become a danger.

For example, researchers will genetically manipulate similar, but less dangerous, viruses to understand how a deadly virus works and evolves. This step reduces the risk of accidents and unexpected outcomes. It also means that when researchers work on the highly pathogenic form of a virus, they have a lot more information about how it could respond and can take appropriate containment measures.

All projects have to submit risk assessments to local and national regulators. These assessments state not only what researchers will do when genetically engineering a virus, but also what they will not do, and what steps they will take if something unexpected occurs.

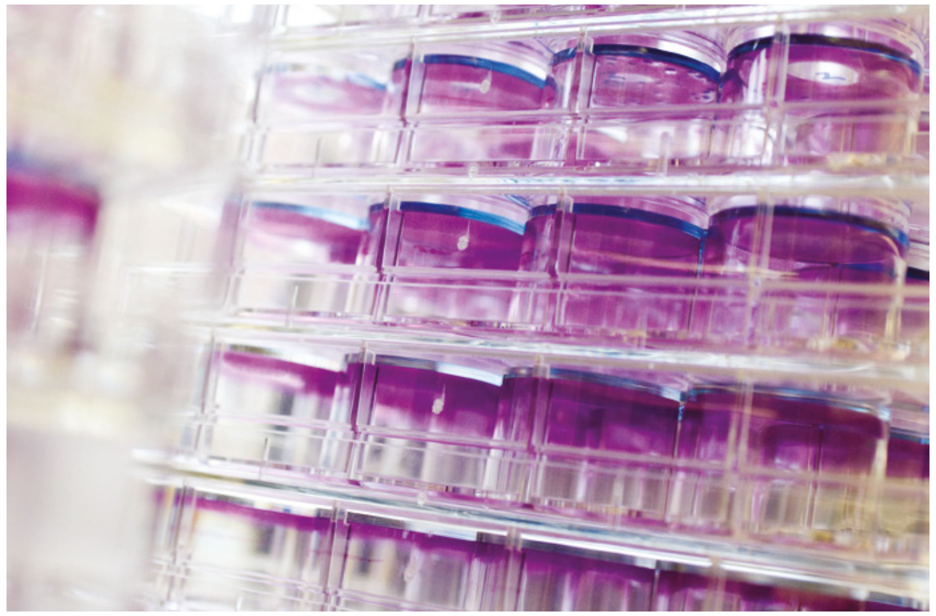
However, there is no global agreement on how to manage these risks.

Above: In 2024, an avian influenza strain was discovered for the first time in dairy cows. Credit: John Cairns

It is essential that good practice is international and universal, and the UK, with its open and facilitating biomedical research system, could be a world leader in this area.

Alongside this scientific capability, institutions such as Imperial also benefit from extensive high-containment laboratory infrastructure, enabling work on hazardous pathogens to be carried out safely, securely and under tightly controlled conditions.

With the risk of zoonotic spillover increasing, the more researchers know about how viruses evolve, the better prepared everyone will be for the next pandemic.



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Building a global knowledge base for future threats

Dr Anne Cori, Associate Professor in Infectious Disease Modelling, Imperial College London

A rapid and effective pandemic response hinges on understanding how a pathogen behaves and spreads through populations – and what actions will help stop the contagion. That knowledge buys critical time to contain its spread and allocate resources where they are most needed.

We have the knowledge to be better prepared for the next pandemic, but it is scattered through the scientific literature, World Health Organisation (WHO) reports, and other documents.

There have, for example, been 40 documented outbreaks of Ebola in central Africa, 17 of which have been in the Democratic Republic of the Congo. And yet when the 2014 West African Ebola epidemic began, we had to collate that information about the virus and previous outbreaks while trying to analyse the epidemiology of the outbreak. The information already existed, but not in an easy-to-access standardised format.

For almost a decade, researchers from the Pathogen Epidemiology Review Group at Imperial College London have been developing a database called epireview that compiles known information about dangerous viruses, so that researchers can analyse outbreaks and support authorities to understand what is happening on the ground in real time.

Left: Imperial researcher. Credit: Thomas Angus, Imperial College London
Right: Sampling for COVID-19 on the Transport for London (TFL) Network. Credit: Thomas Angus, Imperial College London

Since 2019, the group has worked to populate the database with information about nine pathogens that the WHO has identified as most likely to cause a future epidemic or pandemic. These pathogens include Zika, SARS, Lassa Fever, Ebola virus disease, Marburg virus disease, and others.

The team identified the parameters that researchers and authorities want to know at the beginning of a disease outbreak, such as the severity of the disease and transmissibility of the virus, the duration of time before symptoms appear, and how long people are usually hospitalised for. They also included information about potential existing immunity in populations and contextual information such as population demographics. This data is standardised and easily extracted.

When the ongoing Ebola outbreak, caused by the Bundibugyo virus, was declared, we drew on the database and were able to provide epidemiological information and estimates to health authorities within hours instead of a week[1] .

The next global biosecurity threat could come from an existing pathogen, but it could also be something new. Yet, it is likely to be related to viruses or other microorganisms that have caused disease in the past.

For example, the SARS-CoV-2 virus was novel, but it was closely related to pathogens that have been closely studied, specifically Severe Acute Respiratory Syndrome and Middle East Respiratory Syndrome.

When the COVID-19 pandemic struck, we were able to analyse its epidemiology because there was extensive literature available on coronaviruses, which described their natural history parameters. That helped us in our initial assessment of the COVID-19 pandemic and is a recurring need that I've seen in every epidemic I've been involved in.

Unfortunately, analytics infrastructure, such as disease literature databases and software packages to perform epidemiological analyses, often falls between research and response funding. To date, researchers within the Pathogen Epidemiology Review Group have been populating epireview alongside their own research, with no dedicated funding.

If we want to be prepared for the next pandemic, all biosecurity stakeholders need to come together to evaluate the pathogens that are most likely to cause an epidemic or pandemic, not just the viruses. And then they need to fund preparedness infrastructure, so that when the warning signals of an outbreak begin to emerge, we can respond as quickly as possible and save lives.

> "Understanding how a pathogen behaves and spreads buys critical time to contain its spread and allocate resources where they are most needed."

Reference

1 McCabe, R. *et al.* (2026) 'Estimation of the size of the Ebola outbreak caused by Bundibugyo virus in the Democratic Republic of the Congo: May 20, 2026 update,' *Imperial College Research Computing Service Data Repository*

The emerging risk of manmade pathogens

Professor Neil Ferguson, Director of the School of Public Health, Imperial College London

Being able to identify a manmade pathogen and attribute it to a source is a powerful deterrent that will become increasingly important in the global biosecurity arms race.

Rapid developments in artificial intelligence (AI), the widespread availability of gene editing tools, and a better scientific understanding of gene function have made developing novel organisms easier than it has ever been. While a boon for researchers, that also makes it much easier for malicious actors to create and release dangerous organisms into the environment or expose humans to them.

Natural biosecurity hazards remain more likely than manmade threats, but the threat from intentionally released pathogens is rising. Today, there is a risk that a technically competent individual with a benchtop synthesiser and enough computing power could bioengineer an organism that could wreak havoc on agricultural systems, the environment, or human health.

The risk of pandemics has long been identified as one of the most serious risks facing the UK. The COVID-19 pandemic reinforced pandemics' catastrophic toll on nations' socio-economic landscape and human life, and governments around the world have bolstered their surveillance and outbreak analytics.

The MRC Centre for Global Infectious Disease Analysis at Imperial College London provides one example of the expertise that will become increasingly critical in the years ahead. With a focus on outbreak analytics, it uses mathematical modelling and statistics to characterise emerging threats and help policymakers determine how best to contain them and save lives.

Health systems deal with naturally occurring outbreaks on a regular basis, with the Hantavirus outbreak on a cruise ship being one recent example. Stakeholders need to be aware that the next outbreak they face could be caused by a genetically modified agent. Universities, governments, and companies can harness existing technologies and infrastructure to respond to intentional threats: both mitigating its consequences and discouraging bad actors from creating and releasing biological organisms in the first place.

> "Coordination and cooperation are vital if we want to ensure the world's biosecurity machinery is ready to meet the next manmade threat."

Their day-to-day capabilities can be generalised for a broader range of threats and rapidly applied to any new threat that might emerge.

For example, associate professor Dr Anne Cori from the MRC Centre founded the Pathogen Epidemiology Review group, which includes more than 30 researchers who have undertaken systematic reviews of key factors that indicate how a pathogen would spread through populations, such as its transmissibility, how long it incubates in a host, and how fatal it is.

Such research is a fundamental aspect of pandemic and outbreak preparedness, but can also inform understanding of a novel virus that fits into a specific family or clade.

While AI and technological developments are increasing potential threats, they are also boosting research that can respond to them. Imperial researchers Dr Oliver Watson and Professor Samir Bhatt are integrating generative AI models into epidemiological models and genomic analysis. This is revolutionising the types of analysis we can do to track and ultimately identify threats. With such tools, researchers can rapidly develop statistical mathematical simulations and produce new models quickly so authorities can respond to emerging pathogens swiftly – and save lives.

New tools and algorithms should take both scenarios – natural hazards and manmade threats – into account. Such developments would have the dual benefit of identifying emerging pathogens sooner while also bolstering the ability of authorities to attribute new pathogens to a specific source.

Now is the time for intensive dialogue between universities, companies, governments and the defence sector to design systems that respond to a multitude of threats. Coordination and cooperation are vital if we want to ensure that the world's biosecurity machinery is ready to meet the next manmade threat – or deter it from happening at all.

Left: Professor Neil Ferguson
Credit: Thomas Angus, Imperial College London
Above: Workshop on AI and Future of Work.
Credit: Jo Mieszkowski

Developing the biosecurity capabilities of tomorrow

Left: Researcher and microplate.
Credit: Thomas Angus, Imperial College London

Professor Azra Ghani, Chair in Infectious Disease Epidemiology, Imperial College London

Biosecurity threats are increasing globally, and our capacity to detect and respond to them is not keeping pace with the risks we face.

Whether they arise naturally or are deliberately created, the likelihood and impact of biological threats is increasing. Environmental disruption, changing patterns of human and animal contact, technological advances, and microbial evolution are all potential risk factors that need to be mitigated. Preparing for these risks requires us to invest now in the tools, expertise and systems that help us spot threats early, track them and respond quickly.

Biological risk is being shaped by several interrelated drivers. Climate change is altering where infectious diseases can spread, while habitat loss, urbanisation and conflict are increasing the chances that diseases will pass from animals to humans. At the same time, advances in artificial intelligence and synthetic biology are making it easier to design and potentially produce harmful biological agents. Meanwhile, antimicrobial resistance leaves us in a continual race against evolution, as pathogens adapt and existing treatments become less effective.

> "Academia, government and industry need to develop tomorrow's capability today to meet mounting biosecurity risks."

Science and technology are a major part of this changing landscape. They can increase the scale and speed of potential threats, while also providing new tools to detect, characterise and mitigate them. The task now is to ensure that these tools for detection, assessment and response are developed and connected in ways that allow them to be deployed rapidly and effectively when needed.

This work is already under way. One important example is the Coalition for Epidemic Preparedness Innovations' (CEPI) 100 Days Mission[1], which aims to develop safe, effective and accessible vaccines within 100 days of identifying a new pandemic threat. The policy reflects a critical principle: preparedness cannot begin once a crisis is already unfolding.

But rapid response depends on more than vaccine platforms alone. It relies first on recognising a threat early, understanding its likely consequences, and generating evidence that decision-makers can act on with confidence. Research underpins the innovations needed to detect emerging threats and develop effective countermeasures. It also shifts away from passive data collection towards diagnostic and surveillance systems capable of identifying threats in real time. Modelling and analytics are equally important in helping to assess risk, identify priorities, and guide the timing and scale of intervention.

Imperial College London contributes to these efforts through expertise spanning infectious disease modelling, analytics, synthetic biology and biotechnology development, including collaborations with organisations such as CEPI. Interdisciplinary capability like this is essential if scientific advances are to translate into operational preparedness.

Scientific knowledge alone, however, is not sufficient. Preparedness depends on how effectively research, surveillance, policy and industrial capability are connected. Scientists can generate tools, data and evidence, but industry is essential in turning these into diagnostics, vaccines and treatments that can be deployed rapidly. At the same time, these scientific advances need to be embedded in systems that support policy- and decision-makers in real-world settings.

Coordination becomes even more important in a geopolitical environment increasingly shaped by regionalisation. While there may be pressure to focus inward, biological threats do not respect borders. Effective biosecurity cannot be maintained without sustained collaboration across countries, sectors and institutions, including support for capacity strengthening in lower-resourced settings.

A more fragmented world does not lessen the case for international cooperation on biosecurity; it strengthens it. Biological threats are shared risks, and preparedness will depend on whether countries are willing to invest in shared capability before the next crisis emerges.

Reference

1 https://cepi.net/100-days-mission

Surveillance

Scaling wastewater surveillance for global biosecurity

Professor Leon Barron, Professor of Analytical and Environmental Sciences, Imperial College London

Fingerprints of the next disease outbreak could be detected in wastewater before people start showing symptoms – buying critical days to prepare for a major outbreak.

Wastewater monitoring is an integral part of biosecurity surveillance, and countries around the world are using this scalable and relatively low-cost methodology to detect pathogens, chemicals, and antimicrobial resistance, among other concerns, in their populations.

Pathogens and chemicals in people's bodily waste enter the sewerage system, where they can be detected by their genetic material or chemical signatures. Wastewater samples mirror trends within a given community and also show what materials could be introduced to the environment when they leave the facility.

Historically, this method was used to detect polio and antimicrobial resistance, but it emerged as a crucial surveillance approach during the COVID-19 pandemic. If there was a surge in SARS-CoV-2 infections within a community, authorities could detect the hotspot in wastewater and rally a response before people started showing symptoms. Dozens of countries now have wastewater surveillance[1] programmes and are harnessing them to detect emerging pathogens.

Last year, the UK Health Security Agency launched a £1.3 million programme[2] to expand the country's ability to detect and identify the genetic material of several dangerous viruses, such as Mpox and Crimean Congo Haemorrhagic Fever.

"The diversity of biological threats is increasing globally, and it's crucial that we stay at the cutting edge of new technology to detect them," Imperial College London researcher Professor Steven Riley, who is also the UK Health Security Agency's Chief Data Officer, said at the launch.

But emerging diseases are not the only threats wastewater can identify. Sewage also contains the fingerprints of other dangers to human and environmental health.

Left: Professor Leon Barron and Juditha Gurumurthy testing WaterBlitz samples in the lab.
Above right: Juditha Gurumurthy testing WaterBlitz samples in the lab.
Credits: Jo Mieszkowski

> Countries around the world are harnessing wastewater surveillance to detect emerging pathogens and strengthen biosecurity."

In 2011, we began tracking illicit drug and pharmaceutical usage in London, which was then rolled out across England. It has been a national capability since 2021. Over the course of a year, we analysed more than 1,700 water samples from 15 wastewater treatment sites across the country. It was an indirect way to quantify illicit drug consumption behaviours and the size of the market in near real-time, identify where consumption of drugs was concentrated, and show which interventions worked to reduce drug use on the ground.

A major drug bust in March 2022, for example, resulted in a significant decrease in concentrations of cocaine in samples across several major cities. We have also since expanded the capability to track other target chemicals. We now monitor chemicals that affect critical ecosystem services, such as those critical for crop production and those driving antimicrobial resistance. This capability also empowers us to identify more immediate threats from malign actors.

These chemical surveillance methods are now being picked up by groups and authorities around the world. Imperial is part of an international network called the Sewage Analysis Core Group (SCORE), which connects more than 40 laboratories in 30 countries and shares data, methodologies and best practices. Multiple governments are now implementing programmes based on Imperial's work since the inception of SCORE in 2011.

Once wastewater leaves the treatment plants, it finds its way into rivers, and communities also want to know if there are threats hiding in their water. These pollutants affect the environmental systems that people rely on and interact with, creating a slow-burning biosecurity threat.

Imperial researchers have developed follow-on passive sampler technology that members of the public, as well as environmental authorities, can use to identify and monitor new contaminants in river water at scale – and potentially pick up emerging biosecurity threats. We worked with over 2,000 people across the UK to test their local waterways for chemicals, such as pesticides, antimicrobials and pharmaceuticals. This has resulted in major governmental reviews of the safety and regulation of some chemicals that are known to impact biodiversity and biosecurity and can be linked back to wastewater.

Scalable wastewater surveillance systems give researchers and governments a critical head start to understand trends over time, and empower authorities to act on threats before they become crises. ■

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2 UK Health Security Agency. (2025) UKHSA launches development programme for wastewater monitoring techniques which could catch pandemic threats early. *GOV.UK*, 26 August. https://www.gov.uk/government/news/ukhsa-launches-development-programme-for-wastewater-monitoring-techniques-which-could-catch-pandemic-threats-early

Building the next generation of biosurveillance with Lab-on-Chip technology

Left: Dragonfly, a point-of-care molecular diagnostic platform, in use.
Below: A Dragonfly results card in hand.
Credits: ProtonDx

Professor Pantelis Georgiou, Professor of Biomedical Electronics, Imperial College London

The COVID-19 pandemic demonstrated the power of having diagnostic capacity outside of hospitals.

During the crisis, countries including the UK, the US, and several European countries ran mass testing campaigns, with rapid testing in ports, airports, and even in homes. This near-real-time information fed into national surveillance systems and allowed authorities to pinpoint COVID-19 hotspots, rally resources in those areas, and ultimately save lives.

This challenge will only become more important in the coming years. Disease surveillance among humans and animals is a critical component of biosecurity, but at the moment there are few portable technologies that can give high-quality diagnostic information similar to the output of a PCR machine. As the world faces an increasing number of biosecurity hazards and threats, it is vitally important that governments and health systems improve their biosurveillance.

In well-resourced countries, it can take days or weeks to transport and process human samples in government laboratories. It can be even longer for animal samples. The situation is more acute in developing countries, where health ministries struggle with capacity and resources. And at each stage of this process, the samples come into contact with more people, increasing the risk of something going wrong and pathogens potentially infecting people or escaping into the environment. By the time results are available, the disease could have spread and the opportunity for early containment may have passed.

Poor diagnostic capacity is also contributing to the rise of antimicrobial resistance (AMR). When confronted with a critically ill patient who displays the symptoms of an infection that could be bacterial or viral, doctors often choose to prescribe antibiotics. This is contributing to pathogen evolution and resistance.

In response to this global diagnostic gap, I, along with my colleagues from Imperial College London, Dr. Jesus Rodriguez Manzano and Dr. Nicolas Moser, spun out ProtonDx: a life sciences company that develops diagnostics and sample-processing technologies.

Its portable Lacewing diagnostic test is a ‘lab on a chip’, that enables highly sensitive and highly specific infection detection, delivering laboratory-quality results virtually anywhere. The system comprises a cartridge and an electronic reader. ProtonDx’s sample extraction technology within the cartridge is able to extract nucleic acids from several sample types such as blood, tissue and nasal swabs, without the need for large, expensive equipment.

> Health systems need to improve their surveillance so that they can identify and neutralise outbreaks before they turn into pandemics. Point-of-care diagnostics are a crucial element of this biosurveillance.”

The resulting fluid is channelled towards the cartridge’s microchip, which contains several primers. Each primer targets a different pathogen, meaning that Lacewing can screen for multiple diseases simultaneously. ProtonDx produces a variety of diagnostic panels, each of which targets a different symptom cluster, such as respiratory infections, common fevers, and tropical infections. The test, from sample to diagnosis, takes about 30 minutes.

In healthcare settings, such information can assist healthcare professionals to determine the best course of treatment. In developing countries, for example, fevers in children are a common and often fatal problem in areas with a high number of disease-causing agents. An immediate diagnosis, which identifies or rules out pathogens, could save lives.

The diagnosis can also be communicated in real-time to a surveillance network. The system can transmit its findings to a smartphone via Bluetooth, which can sync to the cloud for population-wide monitoring.

Importantly, it is also possible to design bespoke cartridges for new emergent pathogens. For years, Imperial has been building up its expertise in this area and can develop these chemistries and deposit them on the chip within weeks. Deploying and validating the cartridges would be a matter of months.

Biosecurity threats are increasing. Health systems need to improve their surveillance, so that they can identify and neutralise outbreaks before they turn into pandemics. Point-of-care diagnostics are a crucial element of this biosurveillance. ■

Closing the diagnostic gap with portable technology

Dr Jesus Rodriguez-Manzano, Associate Professor in Diagnostic Technologies, Imperial College London

Being able to diagnose disease quickly and accurately is vital in any health response. Yet almost half of the world's population lacks access to diagnostic technology. This scarcity is costing lives today, and is only going to get worse in the future as global biosecurity threats and hazards continue to grow[1].

Health systems rely on diagnostic capabilities to support surveillance networks, detect disease outbreaks, and guide the efficient deployment of resources. The same applies in agriculture, where large-scale animal farming can act as a breeding ground for infectious disease, antimicrobial resistance (AMR), and possible spillover events.

The gap is most pronounced in low-resource settings, particularly in low and middle-income countries, where both the infectious disease burden and AMR are highest.

Each year, more than 10 million people die from infectious diseases[2], and, at the same time, pathogens are becoming resistant to the medications used to treat illnesses. AMR has been described as a "silent pandemic" that threatens the wellbeing of billions[3]. These two challenges are also mutually intertwined: misdiagnosis, inappropriate prescribing, and incorrect dosing not only fail to control the spread of infectious diseases but also accelerate the development and spread of resistance.

Recognising this, the World Health Assembly in 2023 urged countries to establish national diagnostics strategies and routine data collection systems to rapidly identify disease outbreaks[4]. However, the reality is that many countries lack the resources and infrastructure to supply diagnostics where they are most needed: at the point-of-care.

> "Without timely and reliable diagnostic data, public health authorities risk misjudging the disease landscape, leading to delayed or misdirected responses."

Without timely and reliable diagnostic data, public health authorities risk misjudging the disease landscape, leading to delayed or misdirected responses.

Even in well-resourced settings, there remains a need for more accessible and accurate diagnostics. From GP offices to large farms and research laboratories looking to test the efficacy of newly developed vaccines, better diagnostic tools can improve patient care, speed up diagnosis, reduce the need for antibiotics, and facilitate pharmaceutical innovation.

Imperial College London researchers have been at the forefront of developing portable, accurate diagnostics that can be deployed in a wide range of settings. In 2020, I, along with my colleagues from Imperial College London, Professor Pantelis Georgiou and Dr Nicolas

Moser, co-founded ProtonDx, a life sciences company spun-out from Imperial that focuses on point-of-care diagnostics and sample processing technologies.

One of the key innovations is Dragonfly, a point-of-care molecular diagnostic platform already on the market and being used around the world.

It incorporates ProtonDx's SmartLid technology, which enables nucleic acid extraction directly from samples without the need for specialised laboratory equipment. The Dragonfly platform can detect a wide range of pathogens, including SARS-CoV-2, mpox viruses[5], and malaria parasites.

A 2025 study[6] conducted in the Gambia and Burkina Faso, published in *Nature Communications*, evaluated the Dragonfly system using 672 whole blood samples for malaria diagnosis. The platform delivered PCR-grade results directly from fingerprick capillary blood in under 45 minutes, processed multiple samples simultaneously, and outperformed both expert microscopy and other existing rapid diagnostic tests. Notably, it detected 95% of asymptomatic cases.

Dragonfly can also be configured to detect respiratory viruses, such as SARS-CoV-2 and respiratory syncytial virus, as well as skin-tropic viruses including mpox, herpes simplex, and varicella-zoster5. The Dragonfly Respiratory Test Panel was even deployed by Team GB at the 2022 Winter Olympic Games in Beijing, China.

More recently, ProtonDx has been awarded PACE-AMR funding to adapt Dragonfly for the diagnosis of urinary tract infections, including the identification of AMR markers.

Infectious diseases and AMR are interrelated, complex biosecurity threats that need multiple innovative approaches. To meet these threats effectively, clinicians, researchers, and health systems must have access to accurate, real-time data to keep pace with needs on the ground. ■

Above: Dragonfly, a point-of-care molecular diagnostic platform, in use.
Left: SmartLid carrying TurboBeds, held in place by the removable magnetic key.
Credits: ProtonDx

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Accelerating engineering biology for global resilience

Professor Paul Freemont, Chair in Protein Crystallography, Imperial College London

Biofoundries create spaces to embed responsible innovation in the activities of students, early-career researchers, and new startups. They are also, importantly, home to expertise, infrastructure, and networks that authorities and health systems can tap into in an emergency.

Above and right: London BioFoundry. **Top right:** Professor Paul Freemont, Credits: Thomas Angus, Imperial College London

Synthetic and engineering biology follow an engineering design cycle, which can be accelerated by automation and high-throughput workflows. Biofoundries are physical spaces that provide integrated high-throughput robotic DNA and organism engineering facilities[1].

Around the world, research institutions and not-for-profit organisations have been establishing biofoundries to expand their biotechnology development capacities.

Founded in 2016, the London Biofoundry specialises in the design, engineering and functional characterisation of synthetic DNA and organisms. Located at the Translation & Innovation Hub (I-HUB) at Imperial College London, it is a hive of activity with academic collaborators and industrial clients.

The biofoundry is one of several in the UK and many more around the world. It is a member of the Global Biofoundry Alliance, which was established in 2019 to coordinate global biofoundry activities. At the time, there was a growing realisation that biofoundries were an important piece of national infrastructure. They accelerate the process of biotechnology, enable the development of standards, allow interoperability, and facilitate the creation of a biotechnology ecosystem.

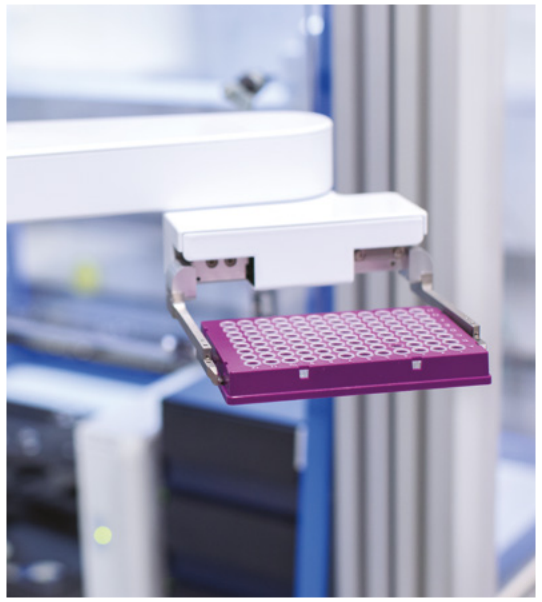
> … biofoundries are an often untapped source of expertise and infrastructure, which should be included in national biosecurity blueprints."

They are also, importantly, places to instil responsible research practices in up-and-coming researchers and cutting-edge companies.

And yet biofoundries are an often untapped source of expertise and infrastructure[1], which should be included in national biosecurity blueprints.

When a crisis strikes, these facilities can rapidly respond to emerging threats such as pandemics and novel pathogens.

During the COVID-19 pandemic, the London Biofoundry, with its automated infrastructure, was a hotbed of activity. Within a few weeks, the biofoundry team pivoted to work on developing diagnostic workflows that could test for the SARS-CoV-2 virus.



In March 2020, the UK's testing capacity sat at about 20,000 tests a day. Imperial researchers re-purposed the high-throughput robotic platform at the foundry to help NHS diagnostic labs increase their testing capacity. The foundry helped to establish workflows and testing platforms, and ultimately was responsible for nearly two million tests including the testing of all staff and students at Imperial and asymptomatic community testing in North West London.

A major strength of such facilities is that they are embedded in a variety of regulatory systems. This means that they can navigate technically demanding regulatory spaces and respond rapidly to emerging biosecurity threats.

For example, Imperial researchers at the foundry, working with colleagues in North West London Pathology services and the Department of Infectious Disease, managed to get the new testing platform UKAS accredited relatively quickly so it could be deployed as soon as possible.

The platform was also reagent-agnostic, which freed researchers and laboratories from having to rely on specific commercial kits. When the pandemic hit, there was a global shortage of reagents, both because of significant demand and disrupted supply chains. Imperial researchers created an open platform that could use any reagent, facilitating high-throughput testing at a time when laboratories around the world were struggling.

They also produced a proxy reagent for validation[2], so that researchers and laboratories did not need to work with live viruses and increase their risk exposure.

These innovations were made possible because there was existing biotechnological infrastructure that could be harnessed. While biofoundries are designed to accelerate biotechnology research, they can also pivot rapidly during national emergencies or biosecurity threats, using their expertise, infrastructure and international networks to support coordinated responses.

Around the world, biofoundries are a vital element of biosecurity, ready to refocus their capabilities when needed. ■

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Pandemic preparedness: healthcare systems as the frontline

Professor Paul Kellam, Professor of Virus Genomics, Imperial College London

Healthcare systems are always at the forefront of infectious disease outbreaks, epidemics and pandemics. They should be a top priority for interventions to protect staff and patients from infection, so the healthcare system can try to function normally while vaccines are being developed and deployed.

In the wake of the COVID-19 pandemic, the UK government conceived the 100 Days Mission (100DM)[1] during its presidency of the G7. At the Carbis Bay Summit, international governments, the Coalition for Epidemic Preparedness Innovations (CEPI), and the biotechnology industry committed to developing safe, effective and accessible vaccines within 100 days of identifying a new pandemic threat. But even an accelerated vaccine process takes time to test for safety and clinical efficacy, scale up, and distribution before it can be deployed at a population level.

During the pandemic, it took 362 days to dose the first person, 90-year-old Margaret Keenan. She received the first licensed COVID-19 vaccine produced by Pfizer. Less than a month later, 82-year-old Brian Pinker received the first dose of the licensed AstraZeneca vaccine. Over the next year, the UK embarked on a mass vaccination campaign, the likes of which the country had never seen. On 20 March 2021, more than 840,000 people received a COVID-19 vaccine, and over that entire week, more than 4.2 million people were immunised against the virus. Nevertheless, people in many countries had to wait much longer for vaccines to reach them, with a large cost to human life.

In the next pandemic, even with a successful 100 Days Mission, certain population groups such as primary healthcare workers and vulnerable individuals, are at great risk and can determine the trajectory of an outbreak response. Healthcare workers are always the frontline of a pandemic response. They are simultaneously vulnerable to infection due to exposure from infected people seeking healthcare, and essential for providing the healthcare. After initial in-country detection of pathogen transmission, there is a very small period to protect these groups from an outbreak-causing pathogen and help them weather the initial waves of infection.

Monoclonal antibodies (mAbs) are one way to do that. These laboratory-made antibodies can offer people immediate protection against a given infectious disease. After they have been administered, mAbs can neutralise pathogens directly, in contrast to vaccines that train the body over a few weeks to recognise the pathogen and fight it. The protection offered by mAbs is temporary, but they can span that critical six-month window as infection transmission increases.

Bottom left: Imperial's Data Observatory. Credit: Jason Alden
Right: Healthcare worker at Hammersmith Hospital, where Imperial has a medical teaching and research campus. Credit: Thomas Angus, Imperial College London

> "[Healthcare systems] should be a top priority for interventions to protect staff and patients from infection, so the system can try to function normally while vaccines are being developed and deployed."

There are already laboratories and companies that develop mAbs for a variety of pathogens. For example, I work for RQ Bio, a UK-based biotechnology company that works on mAbs to prevent seasonal virus infections. Universities are also vital in the discovery and characterisation of mAbs. Imperial College London, for example, has many groups working on mAbs for a range of infectious diseases, autoimmune conditions, and other ailments.

While it is impossible to exactly pinpoint the next emerging pathogen, or where it will come from, researchers are actively assessing which pathogens could potentially cause a pandemic, and trying to discover mAbs that can be used to neutralise them.

Authorities, research institutions, and companies should be prioritising research into these high-risk pathogen groups and preparing a suite of mAbs. These mAbs need to be at the point that, if the World Health Organisation were to declare a public health emergency of international concern, organisations are ready to initiate a Phase 1 safety clinical study and scale up production of the mAbs. Imagine the utility of having 20,000 doses of a mAb that prevents infection by the Bundibugyo strain of Ebola virus right now, and the ability to make more doses rapidly. Such a reality could be possible if action had been taken after the last Ebola virus outbreak in 2016.

To be ready for the next pandemic, countries around the world need a plan today, so that they can mobilise quickly when they have to. And the first place that they could act is to protect the healthcare professionals, who are the first line of defence against pandemics.

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Harnessing synthetic biology for the future of biosecurity

Professor Karen Polizzi, Professor of Biotechnology, Imperial College London

Synthetic biology offers malicious actors a toolbox to threaten the environment and human lives, but it also contains the weapons to fight the same biosecurity threats.

The discipline applies engineering principles to biological systems. Its technologies, such as DNA synthesis and computer-aided design systems, allows scientists to produce novel systems or augment existing ones more quickly than they could with traditional genetic engineering techniques.

Above: Microfluidic in vitro synthetic biology platform for efficient production of chemicals, pictured at Imperial College London. Credit: Dave Guttridge, The Photo Unit.

Just 30 years ago, such capabilities were aspirational. It was much more difficult for malicious individuals or organisations to produce bioengineered organisms or systems that could survive in the real world and wreak havoc.

Today, with artificial intelligence and gene-editing technologies, such a scenario is more likely. However, the same tools bolster researchers', and authorities', ability to move rapidly against threats, making response systems more agile and responsive than they were 30 years ago.

There are many avenues in which synthetic biology research can thwart biosecurity threats, such as manmade novel pathogens and climate change.

At Imperial College London's Future Vaccine Manufacturing Research Hub, researchers are harnessing synthetic biology to create a blueprint for producing vaccines rapidly and on a large scale.

One example is virus-like particles, which are used in some vaccines. These particles comprise protein structures that mimic a virus's shell. Even though they do not contain any genetic material from the virus, they trigger an immune response against it within people's or animals' bodies.

My research team at Imperial is using yeast to develop cheaper and more efficient ways to make these particles for use in vaccines against serious diseases like rotavirus, human papilloma virus, and several hepatitis viruses.

> "Synthetic biologists are currently focusing on obvious biosecurity areas, such as vaccine development... But there are possibly other, more ambitious goals for these tools."

Since we are using yeast, the equipment for manufacturing the vaccines is very similar to that used in the brewing industry. By bringing down costs and increasing protein production, it is easier and faster to ramp up vaccine production when needed – such as when there is a large disease outbreak or pandemic.

However, synthetic proteins' applications extend far beyond vaccines. Similar technologies can also be used for food security. Climate change is increasing the likelihood of extreme weather events and broadening diseases' natural ranges, endangering agricultural yields. With synthetic biology, it is possible to engineer organisms, which can be mass produced to create continuity when agricultural supply of certain food products is low.

Below: Professors Karen Polizzi, Paul Freemont and Richard Kitney. Credit: Thomas Angus, Imperial College London.
Top right: Pipettes and microplate. Credit: Thomas Angus, Imperial College London

For example, there is global interest in producing milk-like proteins that could substitute cow milk. In 2024, global milk production reached 950 megatonnes, and is expected to rise over the next decade, according to the most recent Organisation for Economic Co-operation and Development, and the Food and Agriculture Organisation of the United States (OECD-FAO) Agricultural Outlook[1].

Already, the sector faces biosecurity threats. The Outlook flags the risk of avian flu, which has been detected in dairy cattle in the United States, and ongoing outbreaks of foot and mouth disease in the European Union.

At Imperial, researchers in the Bezos Centre for Sustainable Protein and the Microbial Food Hub are working with industry collaborators to create palatable protein-derived milk. The aim is to have non-animal milk that is identical on a molecular level to cow's milk. At the moment, the process is costly, but Imperial research is finding ways to reduce input costs and increase the 'milk' yield from the engineered organisms.

Synthetic biologists are currently focusing on obvious biosecurity areas, such as vaccine development and reducing reliance on agricultural systems that are vulnerable to climate change. But there are possibly other more ambitious goals for these tools.

We can't predict the biosecurity threats we'll face 30 years from now. The wide availability of suitable equipment and the growing ease of use of synthetic biology technologies are not only of benefit to researchers, but malicious individuals and organisations too. However, even as the threats become ever more sophisticated, synthetic biology will allow us to keep up and protect human health.

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Response

Building an immune atlas for future pandemic threats

Professor Robin Shattock, Chair in Mucosal Infection and Immunity, Imperial College London

An atlas of human immune responses to candidate vaccines could give health systems an advantage when faced with the next pandemic. Developing this knowledge should be a top priority to protect people from future biosecurity threats.

Pre-emptive immunology uses immunological tools and knowledge to prevent or limit a pandemic. It is a cornerstone of preparedness, as it allows scientists to predict human immunity to potential threats and respond rapidly if they materialise. However, we lack data about how the human immune system responds to potential infectious threats.

Biosecurity risks are multiplying from both natural sources and manmade threats. In 2024, the international Global Preparedness Monitoring Board said that the world was "acutely vulnerable" to pandemic threats[1], despite improvements in surveillance and responses. Increased globalisation and urbanisation, antimicrobial resistance, climate and environmental change, and human-animal interactions are driving the risk of novel pathogens emerging and larger outbreaks of more transmissible organisms.

For example, Avian influenza – which has killed billions of farmed and wild birds and has been detected in dairy cows – is a couple of mutations away from being transmissible between humans. It is one of several known zoonotic pathogens that scientists expect to eventually jump into humans. At the same time, technological advances, such as gene-editing and artificial intelligence tools, increase the risk that bad actors intentionally develop harmful, transmissible pathogens. Meanwhile, the rise of antimicrobial resistance means that prevalent bacterial infections may become untreatable.

The Coalition for Epidemic Preparedness Innovations (CEPI) aims to produce safe, effective and accessible vaccines within 100 days of identifying a new pandemic threat. But there is currently a theoretical gap between the detection of a novel pathogen and being able to design effective vaccines tailored to induce protective human immunity.

Emerging pathogens are likely to arise in similar families. For example, COVID-19-causing SARS-CoV-2 is a coronavirus, a family whose members also cause Severe Acute Respiratory Syndrome and Middle East Respiratory Syndrome. When the COVID-19 pandemic hit, there was

> "To increase biosecurity resilience, research institutes and companies could already be testing candidate vaccines against potential infectious threats and mapping how the human immune system responds to them."

already a wealth of knowledge about how humans responded to vaccines targeting those diseases. It was fortunate that this knowledge existed, as it accelerated the development of COVID-19 vaccines. The recent outbreak of the Bundibugyo strain of Ebola is another example. It is one of three strains known to cause large outbreaks, and advancing our understanding of the human immune response will accelerate the development of pan-Ebola vaccines.

To increase biosecurity resilience, research institutes and companies could already be testing candidate vaccines against potential infectious threats and mapping how the human immune system responds to them. Rather than embarking on full-scale vaccine development, which is costly and time-consuming, researchers can use predicted designs of infectious threats to challenge the immune system in small clinical trials. These studies could also identify potential therapeutic monoclonal antibodies (mAbs) for those who respond poorly to vaccines, such as those whose immune system is suppressed during cancer therapy.

Imperial's Centre for Precision Vaccinology has the expertise to develop and test a number of these potential threats in advance. Its researchers have built the capacity to use RNA technology and to manufacture clinical-grade material affordably. These skills could be harnessed to generate a seedbank of candidate vaccines and an atlas of human immune responses. Such knowledge could offer a blueprint for vaccines against emerging or engineered pathogens.

Currently, there is insufficient data to predict how human immune systems will respond to novel infectious threats, and this knowledge gap presents a significant vulnerability to our biosecurity.

AI and machine-learning tools thrive on data, and the lack of human immunological information is limiting scientists' ability to harness the AI revolution to develop potential candidates. Generating data on immune responses to different pathogen families will further facilitate AI use and help us respond even more rapidly to biosecurity threats.

This approach represents a new model for biosecurity. Generating vaccine candidates and human immune-response data before a crisis emerges shifts preparedness from reactive to predictive, enabling potential countermeasures to be developed and evaluated in advance rather than under the pressure of an unfolding emergency.

It is no longer a matter of time before humanity faces another novel pathogen that could cause a pandemic: it is a matter of when. Now is the time to generate the knowledge needed to develop vaccines more rapidly, ultimately saving lives and enhancing our biosecurity.

Above: Professor Robin Shattock, Dr Hadijatou Sallah and Dr Paul Mckay. Credit: Thomas Angus, Imperial College London.
Left: Imperial vaccine researcher.
Credits: Thomas Angus, Imperial College London

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A space for notes

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