OPINION

2020 visions

For the first issue of the new decade, *Nature* asked a selection of leading researchers and policy-makers where their fields will be ten years from now. We invited them to identify the key questions their disciplines face, the major roadblocks and the pressing next steps. Visit go.nature.com/htW8uM to respond and to add your vision.

ILLUSTRATIONS BY JESSE LEFKOWITZ

Search

Peter Norvig*
Director of research at Google

Internet search as we know it is just one decade old; by 2020 it will have evolved far beyond its current bounds. Content will be a mix of text, speech, still and video images, histories of interactions with colleagues, friends, information sources and their automated proxies, and tracks of sensor readings from Global Positioning System devices, medical devices and other embedded sensors in our environment.

The majority of search queries will be spoken, not typed, and an experimental minority will be through direct monitoring of brain signals. Users will decide how much of their lives they want to share with search engines, and in what ways.

The results we get back will be a synthesis, not just a list. For example, today if I ask 'compare approaches to nuclear fusion', the major search engines agree that a general encyclopaedia article on fusion power comes first, followed by other similar articles. A decade from now, the result will summarize the major approaches, contrast their differences, automatically translate any foreign documents into my language, and then rank the results by efficacy or place them in a table or chart as appropriate. If I then ask for 'background mathematics for fusion theory', I will get an outline for an impromptu course concentrating on the necessary complex analysis, customized to specific applications in fusion and to my level of mathematical understanding. If I stumble, the course will be readjusted to fit my needs, or perhaps the search engine will connect me to a tutor or another student in a similar plight. Interaction with search engines will be an ongoing conversation; one that is integrated with the other ongoing tasks of our lives.

> "An experimental minority of search queries will be through the direct monitoring of brain signals."

One big challenge for search engines is to implement a measure of quality that is not based solely on popularity. Search engines must determine both relevance (is the item pertinent to the user's query?) and quality (is the item inherently accurate, useful and understandable, independent of the query?). Current relevance measures do reasonably well. Measures of quality require better models of the concepts and relations expressed in documents and how they relate to the reality of the world, as well as models of the trustworthiness of authors. Thus, a site that claims that the Moon landings were a hoax and seems to have a coherent argument structure will be judged to be lower quality than a legitimate astronomy site, because the premises of the hoax argument are at odds with reality. Understanding and improving these models is a key challenge for the coming decade.

Microbiome

David A. Relman
Chief of infectious diseases at Veterans Affairs Palo Alto Health Care System, Palo Alto, California

The human body is one of the most important ecological study sites of the coming decade. Humans depend on the microbial communities that colonize them for a surprising suite of benefits. These include: extracting energy from food, educating the immune system and protection from pathogens. Yet, despite the recent attention to this indigenous microbiota, we are relatively ignorant of what our 'extended self' comprises or how it works.

The human body consists of multiple microbial habitats, studied and defined so far on the basis of gross anatomical features, such as the skin, mouth, intestines and vagina. Only a subset of the relevant habitats and habitat boundaries across the human landscape have been identified — and important biology often takes place at such boundaries. Over the next ten years, molecular microbial surveys need to capture rare species and assess diversity at multiple spatial scales.

Although the organization of the human microbiota is not random, little is known about the rules that govern its assembly. What are the contributions of early exposures, dispersal, and species interactions? Is there selection at the community level, and if so, how? And, most importantly, how does the human body control community composition? With answers to these questions, the assembly of the microbial community, for example on the tooth surface or intestinal mucosa, could be guided towards states that confer health.

Equally pressing questions concern the stability and robustness of human microbial communities. How well do these communities resist perturbation by forces such as antibiotics, or return to their prior state after disturbance? How many healthy states are there? Does community resilience determine or predict human health? What mechanisms underlie resilience, and how can they be measured or reinforced?

Answering these questions requires understanding the functional properties of the microbiota. This means coupling DNA sequencing with direct measurements of RNA, protein products, functional assays and associated environmental variables. The existing national and international projects to map the human microbiome are a good start. In addition this field needs well-controlled, longitudinal clinical studies; non-disruptive, minimally invasive sampling methods; management and analysis strategies for complex, multi-dimensional data; and new partnerships between microbiologists, ecologists, clinicians, physiologists and technologists.

Personalized medicine

David B. Goldstein*
Duke University

Over the past decade, powerful genotyping tools have allowed geneticists to look at common variation across the entire human genome to identify the risk factors behind many diseases. Two striking findings will define the study of disease for the decade to come. First, common genetic variation seems to have only a limited role in determining people's predisposition to many common diseases. Second, gene variants that are very rare in the general population can have outsized effects on predisposition.

For example, rare mutations that cause the elimination of chunks of the genome can raise the risk of diseases such as schizophrenia, epilepsy or autism by up to twentyfold. Some researchers view these major risk factors as aberrations. My guess is that as more genomes are sequenced, many other high-impact risk factors will be identified.

If so, here's one confident but uncomfortable prediction of what personalized genomics could look like in 2020. The identification of major risk factors for disease is bound to substantially increase interest in embryonic and other screening programmes. Society has largely already accepted this principle for mutations that lead inevitably to serious health conditions. Will it be so accommodating of those who want to screen out embryos that carry, say, a twentyfold increased risk of a serious but unspecified neuropsychiatric disease?

> "We are relatively ignorant of what our 'extended self' comprises or how it works."

Some advances will be relatively uncontroversial, such as the development of tailored therapeutic drugs based on genetic differences that are otherwise innocuous. Others will be transformational, such as the identification of definitive genetic risk factors that provide new drug targets for conditions that are often poorly treated such as schizophrenia, epilepsy and cancers. Over the next decade millions of people could have their genomes sequenced. Many will be given an indication of the risks they face. Serious consideration about how to handle the practical and ethical implications of such predictive power should begin now.

Energy

Daniel M. Kammen
Director of the Renewable and Appropriate Energy Laboratory, University of California, Berkeley

By 2020, humankind needs to be solidly on to the path of a low-carbon society — one dominated by efficient and clean energy technologies. It is essential to put a price on carbon emissions, through either well-managed cap-and-trade schemes or carbon taxes. Creative financing will also be needed so that homes and businesses can buy into energy efficiency and renewable energy services without having to pay up front. An example is the Property-Assessed Clean Energy financing mechanism, which my lab is helping to design and promote (http://rael.berkeley.edu/financing).

Government funding of research is crucial. Several renewable technologies are ready for explosive growth. Energy-efficiency targets could help to reduce demand by encouraging innovations such as net-positive-energy buildings and electric vehicles. Research into solar energy — in particular how to store and distribute it efficiently — can address needs in rich and poor communities alike. Deployed widely, these kinds of solutions and the development of a smart grid would mean that by 2020 the world would be on the way to an energy system in which solar, wind, nuclear, geothermal and hydroelectric power will supply more than 80% of electricity.

Mental health

Daniel R. Weinberger
Senior investigator, US National Institute of Mental Health

The search over the past decade for genes behind mental illness has led to the realization that mental disorders are not discrete conditions with specific causes. Rather, they are the result of interactions between risk factors that affect development; psychiatric symptoms can arise from many causes and are more interrelated than current disease models allow. By 2020, this insight, which has been slow to take hold, will have transformed how doctors understand and treat psychiatric conditions.

Finding specific genes for mental illness now seems a pipe dream. A more realistic endeavour for the next ten years is to look for genes that code for basic cellular and brain functions that modulate our responses to the environment and that come together in particular ways in individuals at increased risk. Many hundreds of genes may contribute to raised vulnerability, and such defects may affect brain development and function independently of any specific psychiatric diagnosis. There is no straight road to psychiatric illness, but a highly diverse network of developmental pathways.

This approach will lead to diagnosis and treatment based on a proper grasp of the underlying biology, rather than on an interpretation of symptoms. Psychiatric research is poised to realize Sigmund Freud's dream of a biological psychology, but it will require new applications of old thinking (see also page 9).

Hominin palaeontology

Leslie C. Aiello
President, Wenner-Gren Foundation for Anthropological Research

Most of the recent effort in hominin palaeontology has been focused on Africa and Europe. But the announcement in 2004 of the small hominin *Homo floresiensis* in Indonesia was a warning that we are naive to assume we know more than the basic outline of human evolutionary history. If *H. floresiensis* is indeed a surviving remnant of early *Homo* that left Africa around 2 million years ago, we have to reject the long-standing idea that *Homo erectus* was the first African emigrant. We also must reject many hypotheses concerning the prerequisites for this emigration, such as a relatively large brain size, large body size and human-like limb proportions. Importantly, we must confront our relative ignorance about human evolution outside Europe and Africa.

One of the big challenges for the next decade is to begin to fill in the large gaps in our knowledge about human evolution in Asia. We need strong and creative international collaborations that have the financial, institutional and governmental support to carry out the necessary research and interpretation. The field needs large, focused support in Asia similar to that given to research in eastern Africa by the Turkana Basin Institute in Stony Brook, New York, the Max Planck Institute for Evolutionary Anthropology in Leipzig and the Heidelberg Academy of Sciences and Humanities programme on 'The Role of Culture in Early Expansions of Humans'. Fossil hunting is a high-risk venture and expeditions may not always produce the desired results. However, the number of new hominin species discovered in Africa and Europe in the recent past suggests that a similar effort in Asia would not go unrewarded.

Hopefully, by 2020, we will have many more pieces of the big puzzle of human evolution — how and why did hominins evolve and disperse worldwide over a period of around 6 million years? Advances can be expected from areas such as genetics, isotope analyses and palaeoclimate research, as well as from fossil discoveries. But we cannot answer the key questions about human evolution without working towards a more geographically complete fossil record.

Synthetic biology

George Church
Professor of genetics, Harvard Medical School

In the past decade, the cost of reading and writing DNA has dropped a million-fold, outstripping even Moore's law for exponentially increasing computer power. The challenge for the next decade will be to integrate molecular engineering and computing to make complex systems. The development of engineering standards for biological parts, such as how pieces of DNA snap together, will permit computer-aided design (CAD) at levels of abstraction from atomic to population scales. Biologists will have access to tools that will allow them to arrange atoms to optimize catalysis, for example, or arrange populations of organisms to cooperate in making a chemical.

The obvious application will be in manufacturing and delivering drugs more efficiently. However, these treatments might be superseded by smarter ones, such as oral vaccines and 'programmable' personal stem cells or bacteria (which exploit sensors, logic and actuators harvested from natural and lab evolution) that could, for example, sense a nearby tumour, coordinate an attack and drill into the cancer cells to release toxins. Another application is in the production of chemicals, biofuels and foods — for example, the development of parasite-resistant crops or photosynthetic organisms that can double their biomass in just three hours. As costs drop, such technology will allow developing nations to leapfrog fertilizer-wasting, fossil-fuel-intensive and disease-rife farming for cleaner, more efficient systems, just as they are leapfrogging costly landlines in favour of mobile-phone networks.

> "Corporate lobbying must be restrained, it is one of the greatest dangers to sustainable development."

Synthetic biology is already having an impact beyond its field, and by 2020 this will have increased significantly. Myriad technologies will be possible, such as nano-memory devices that harness the ability of certain bacteria to navigate Earth's weak magnetic field using magnetite nanoparticles. As electronic chips hit conventional manufacturing limits, they will be replaced by atomically precise and fault-tolerant biological circuits. Three-dimensional 'bio-printers' could make nearly all manufactured goods much less expensive. The grand challenge will be to anticipate the many unintended consequences of the synthetic biology revolution — ecological, economic and social — and to safeguard against them.

Universities

John L. Hennessy
President, Stanford University

The world faces increasingly complex challenges, such as maintaining our ecosystem while supporting 9 billion to 10 billion people, reducing poverty, increasing peace and security, and improving human health in both the developed and developing world. Universities must have a role in seeking solutions for these problems and in educating the next generation of leaders to tackle them.

Perhaps the largest threat to our research universities over the next decade is the financial challenge facing governments. In the United States, for example, budget deficits have caused many states to reduce their funding for public universities, and at the federal level, there is likely to be no growth or a cut in funding for research programmes.

To address these financial and intellectual challenges, universities need to be willing to change how they see their research and teaching mission. The scale and complexity of today's global problems demand a more collaborative, multidisciplinary approach.

Traditionally, universities have been structured around disciplines and departments. The agencies that fund research often reflect that structure in their financial support of projects. That rigidity can be a barrier to innovation, and to the need to educate students for a more collaborative working environment.

Therefore, universities and funding agencies need to encourage working across disciplines — for example, through academic centres based around broad themes rather than narrow fields. The challenge will be to do this without abandoning the traditional disciplines and the role they have in ensuring excellence.

As financial pressures increase, institutions may be forced to make difficult decisions — prioritizing areas in which they have sufficient existing strength or student interest and collaborating with peer institutions that have greater capability in other fields. Continuing support for fledgling cross-disciplinary efforts in difficult financial circumstances will require vigilance.

Universities have a dual charge: to advance the boundaries of knowledge and to educate students. Through this dual role we have the potential to make contributions that can shape the future. The challenge of the next decade is to live up to that potential.

Global governance

Jeffrey Sachs
Director, the Earth Institute

By 2020, the world needs an effective system of global governance for managing sustainable development. It will require systematic improvements in four areas.

First, politics must take account of technical expertise. In international negotiations such as the Copenhagen climate process, negotiators spend a lot of time arguing over the legalities of agreements but little time discussing technological options. There is a tendency to announce targets without technical strategies, and then to miss the targets. The United Nations should follow up the Copenhagen meeting by setting up expert groups to support the practical tasks of climate-change mitigation and adaptation. Within a few years, a new world environment organization should be established to oversee and provide technical support for the major treaties.

Second, public and private investments in new technologies should be managed as part of an integrated system. Almost all environmental challenges, from greenhouse-gas emissions to the depletion of groundwater resources, demand technological transformation. Achieving this will need a mix of public and private enterprise. The public sector will be responsible for issues such as monitoring, regulation and public safety and awareness; the private sector will take the lead in profit-oriented investments, in particular in research and development. Both sides will need to harmonize their actions and seek effective partnerships.

Third, corporate lobbying must be restrained: it is one of the greatest dangers to sustainable development. In the United States, corporate influence through lobbying, campaign funding and misleading advocacy campaigns has been an enormous obstacle to effective regulation of the economy and environment. For example, heavy lobbying by Wall Street contributed to the financial deregulation that helped cause the recent crisis, and pressure from the energy industry has delayed action on climate change. Some countries have successfully constrained such influence through public financing of elections and other means. The United States should follow suit.

Finally, global financing for poorer countries must improve if international agreements on climate, land use and biodiversity are to succeed. The record of aid delivery to poor countries is dismal. Rich countries regularly promise support that never arrives. Two proposals have been made that could improve things: a small tax on cross-border financial transactions, and a global levy on carbon emissions. Both should be implemented alongside more traditional forms of aid to secure a more reliable source of development finance.

Astronomy

Adam Burrows
Vice-chair of the Board on Physics and Astronomy of the US National Research Council

Key questions for the coming decade include determining the nature of the dark matter that permeates the Universe — it would be a major embarrassment if the dark matter paradigm was not verified within 40 years of its inception by the direct detection of the associated weakly interacting particles. Some people single out the nature of dark energy as the most fundamental puzzle confronting astronomy. Others want to know how tenuous gas and dust is converted into dense stars and planets and how many Earthlike — and habitable — planets populate the Galaxy. Answers to all these questions could be found by 2020, but the astronomy community must decide which to prioritize.

Prioritization will not be easy. Future technologies will inevitably be more complicated and expensive. Ground-based astronomy has become big science and space-based astronomy struggles to balance creativity and affordability. As a consequence, the operating budgets for current telescopes are constraining future telescope construction projects. Moreover, the life cycle costs of the James Webb Space Telescope, due to be launched in 2014, have and will continue to cut into budgets for smaller, cheaper and more nimble astrophysics missions.

To craft an exciting and integrated strategy for achieving in the next decade the promise of the previous one, the United States has embarked on its decadal survey of astronomy, due to be completed before the end of 2010. Astronomers have submitted an avalanche of public white papers articulating the scientific and engineering cases for missions and facilities that collectively could cost more than US$70 billion. This exceeds the likely funding for new initiatives in the next decade by at least four to five times. Therefore, the survey committee is charged with finding the right balance between large and small projects and the proper mix of ground and space observatories. It must also address the coordination between public and private telescopes, a unique feature of American astronomy, as well as determine the optimal suite of instruments for those telescopes.

This is astronomy's golden age. The potential for startling breakthroughs remains great, but considerable money and skill will be necessary to realize even a fraction of it. Will humankind baulk on the threshold of a comprehensive understanding of the Universe? Policy decisions in the next year or two may well decide the issue.

Drug discovery

Gary P. Pisano
Professor of Business Administration, Harvard Business School

The next ten years will witness an acceleration of the upheaval in the pharmaceutical industry. Profound changes in drug research and development, competition, government policies and markets will continue to challenge existing business models and strategies. Many established players will not make the transition. Some venerable companies have already disappeared through acquisitions.

The industry will bifurcate into firms that pursue a long-term commitment to creating novel drugs and those that focus on marketing. The latter may do better in the short term but are doomed to failure eventually. The development of effective treatments is the only sustainable source of value for the pharmaceutical industry. Given the paucity of therapies for many serious diseases and the mediocre efficacy of many existing drugs, the opportunities are huge. There are risks in trying to discover new drugs, but the risks of backing away from that commitment are higher.

I do not envisage one dominant model in terms of size or organizational structure. We will see an ecosystem of few large global players with deep scientific resources and many more specialized companies. Globalization of drug innovation will continue. No one should be surprised to see the emergence of a major Chinese multinational drug company with strong innovation capabilities.

> "No one should be surprised to see the emergence of a major Chinese multinational drug company."

Demographics

Joshua R. Goldstein
Executive director, Max Planck Institute for Demographic Research

As population growth marked the twentieth century, population ageing will mark the twenty-first. By 2020, the average European will have fewer years of life expectancy remaining than years he or she has already lived. East Asians will soon follow. Humankind will spend much of the coming decade grappling with questions about how to organize and pay for the care of an increasing elderly population and about who will produce what the elderly consume.

In the longer term, a return to moderate fertility rates in those countries with very low fertility, and increases in immigration can do much to moderate population ageing. Sweden and Japan face quite different demographic futures, because fertility in Sweden is closer to replacement and a small but steady stream of immigrants will make up the difference. In Japan — the world's leader in longevity — fertility remains low, and immigration a major social challenge.

We need demographic research on four fronts addressing population ageing. Low birth rates can perhaps be increased by measures that reconcile work and family, enabling people to have the children they say they want. Fostering the social and economic integration of immigrants is another priority. Health research, helping people to stay younger longer, is already a priority of ageing societies; indeed, so far, the healthy period of life has been lengthening as fast or faster than life expectancy itself. But now — as the first 65-year-old baby-boomers prepare to blow out their birthday candles — we must address the larger question of rescheduling life's turning points, so that people can remain active and productive. The societies that respond to ageing successfully will be those that take advantage of longer life.

Chemistry

Paul Anastas
Center for Green Chemistry and Green Engineering, Yale University

The future of chemistry should look very different from the past. Traditional, reductionist, highly specialized academic chemistry has transformed food, energy, health, transportation, communications and the quality of modern life. It has also — accidentally — depleted finite and rare resources, endangered workers and contaminated ecosystems. Green chemistry is the way forwards: it combines expertise from synthetic, physical and biological chemists, together with that of toxicologists, environmental health and life scientists, to deliver sustainable chemical design.

Making chemical products and processes that reduce or eliminate the use and generation of hazardous substances is an inherently systems approach. The 'twelve principles of green chemistry' unite all aspects of the molecular life cycle, from obtaining the feedstock and starting materials, through the synthetic and manufacturing process, to the end of commercial life and ultimate disposal of products. These principles are based on the latest fundamental discoveries on the interaction between anthropogenic substances and the natural world.

Scant research funding, and hence insufficient effort, is devoted to sustainable innovation in chemistry. As a first step, chemistry needs to adopt a clearly stated research imperative that researchers in molecular science must maintain their creativity while not doing harm to people and the planet. We need to turn all of chemistry green.

NIH

Richard Klausner
Column Group
David Baltimore
California Institute of Technology

The National Institutes of Health (NIH) serves the US biomedical community by providing resources for experimentation, but it does so in ways that bias the enterprise towards short-range and unimaginative thinking. Our recommendations for the NIH of 2020 call for a profound change in its culture and in its decision-making processes.

First, funding criteria will put more weight on judgements about the individual who is applying, not the details of the proposed project. It is creative minds that we want to foster, and when the NIH identifies someone who has been innovative and productive, that person should be adequately supported so they can express their creativity in their own way.

Notably, the current system of hyper-specialized study sections for reviewing research proposals discourages risk-taking. They should be replaced or augmented by broad, institute-based interdisciplinary review teams, which assess greatly simplified applications that focus on the goals of the research, the importance of the problem and the quality of the investigators. The technical part of the review will shift from assessing the feasibility of the plan to the capabilities of the investigators.

At the same time, we should be encouraging new generations of independent scientists to begin productive careers by aiding their development outside the usual academic routes. So, instead of all trainees being graduate students and postdoctoral fellows under supervision by elders, there should be alternative pathways for independent or self-guided study.

By 2020, the NIH should see some of the fruits of its programme to revitalize clinical research. The clinical trials it supports (some 15% of the agency's overall budget) should be asking questions that enhance the scientific basis of medicine. For instance, NIH-sponsored trials should focus on streamlining trial execution and should pioneer new technologies for patient subtyping, testing biomarkers and determining biologically meaningful surrogates for clinical responses. That might mean fewer trials than now, but each should be designed to extend clinical science as a whole.

The intramural programme of the NIH represents some 10% of its funding and should remain strong. However, it lacks a defined mission and has deteriorated in quality. It does have a powerful and unique instrument in its new but underutilized clinical centre, which needs to move to the forefront of the NIH's translation efforts.

Individuals are also key to progress in clinical research. In the extramural community, we need an expanded cadre of clinical research scholars to pursue cross-disciplinary studies of human disease physiology, and to challenge the current one-way route from bench to bedside.

If the NIH carries out these reforms by 2020 (even better, by 2015), the United States' preeminence in biomedical research will be ensured.

Soil

David R. Montgomery
Author of *Dirt: The Erosion of Civilizations*, University of Washington

To avoid the mistakes of past societies, as 2020 approaches, the world must address global soil degradation, one of this century's most insidious and under-acknowledged challenges. Humanity has already degraded or eroded the topsoil off more than a third of all arable land. We continue to lose farmland at about 0.5% a year — yet expect to feed more than 9 billion people later this century.

> "Business as usual is not an option when it comes to soil. It's time for a greener revolution."

During the twentieth century, the Haber–Bosch process (allowing the mass production of nitrogen-based fertilizers) and the Green Revolution effectively divorced agriculture from soil stewardship. Increased yields were supported by intensive fertilizer inputs and mechanization that simplified and devastated soil life, reducing native soil fertility. For example, research in some conventional agricultural settings shows that other species such as bacteria have virtually replaced mycorrhizal fungi, which deliver soil nutrients to most plants. In a post-petroleum world, as the era of cheap fossil-fuel-produced fertilizers comes to an end, conventional, high-input agriculture is neither sustainable nor resilient. Ensuring future food security and environmental protection will require thoughtfully tailoring farming practices to the soils of individual landscapes and farms, rather than continuing to rely on erosive practices and fertilizer from a bag.

Towards these ends, governments should aggressively fund research on and promote the adoption of agricultural practices and technologies that cultivate beneficial soil life and sustain soil ecosystems. Over the next few decades, approaches such as low-till and organic methods could restore native soil fertility and store enough soil organic matter to offset global fossil-fuel emissions by 5–15%. Offsets, and soil fertility, could be further increased through adding biochar — charcoal made by heating organic wastes.

The thin layer of minerals, living microorganisms, dead plants and animals blanketing

the planet is the mother of all terrestrial life and every nation's most strategic resource. Yet we treat it like dirt. Business as usual is not an option when it comes to soil, food and people. It's time for a greener revolution.

Lasers

Thomas M. Baer
Stanford Photonics Research Center
Nicholas P. Bigelow
Department of Physics and Astronomy, University of Rochester

Those who conceived and invented the laser 50 years ago this year could not have predicted the roles that it has had over the past half-century: from communications to environmental monitoring, from manufacturing to medicine, from entertainment to scientific research.

By 2020, lasers will probably emit beams with spot sizes of the order of 1 nanometre — the size of a small molecule. Objects with dimensions less than a wavelength cannot usually be resolved using lasers or microscopy unless the photons are emitted from an aperture smaller than the object. Microscopes that incorporate laser sources with apertures the size of a single molecule will be useful in fast, direct sequencing of biomolecules such as DNA and RNA. These miniature beams will also provide hard-disk storage at densities 100 times greater than those available today — petabytes of storage in a personal computer.

Ultraprecise, laser-based clocks will measure the drift in fundamental constants as the Universe expands, challenging our theories describing the origin and evolution of the cosmos.

Next-generation lasers will allow the creation of new states of matter, compressing and heating materials to temperatures found only in the centres of massive stars, and at pressures that can squeeze hydrogen atoms together to a density 50 times greater than that of lead. The resulting fusion reactions may one day be harnessed to provide almost limitless carbon-free energy. Enough fusion fuel is present in the oceans to supply the current energy needs of the entire world for longer than the age of the Universe.

By 2020, lasers will generate ultrashort bursts of photons — with pulse widths shorter than the time it takes for light to traverse an atom. These attosecond pulses will allow strobe pictures to be taken of chemical reactions — stop-action pictures of electrons in motion. When amplified to ultrahigh intensities, these lasers will be used as engines to accelerate electrons and protons to velocities close to the speed of light. This will mean that table-top accelerators can be created to generate particles with kinetic energies that rival those in today's biggest particle accelerators at a fraction of the size and cost.

What are the challenges to achieving these remarkable goals? Developing new laser materials, sources, optics that can survive enormously high intensities and new nanofabrication technologies. Will all of this happen in the next decade? We believe so. Like the inventors of 1960, we are probably still underestimating the full potential and impact of lasers.

Ecology

Robert D. Holt
Department of Biology, University of Florida

The greatest practical challenge facing ecologists over the next decade is that much of what we wish to study may vanish before we can really fathom it. The planet is increasingly dominated by ersatz ecosystems — human-sculpted landscapes occupied by haphazard assemblies of introduced species and tolerant natives. These are legitimate objects of study, but there are considerable practical, aesthetic and moral costs of losing natural ecosystems before we can even fully document and understand them.

> "Ecology will be viewed increasingly as an essential dimension of the Earth sciences."

A key task will be to predict and mitigate this loss of biodiversity and the degradation of ecosystem function. One step is to gauge the resilience of ecological networks such as food webs — in particular, their capacity to withstand disturbance and species loss. This will require insights from many disciplines. Stable isotope analysis and genetic bar-coding should provide a clearer picture of who eats whom in a community.

Change takes place at multiple levels, from individuals to populations, to spatially linked ecosystems. I predict that by 2020, ecological theory will be increasingly concerned with the often subtle biological details of organisms, as well as the implications of evolutionary dynamics. Microbial ecology will become mainstream. At the same time, it will be essential to look at how species and communities fit into Earth's history. In a decade's time, ecology will be viewed both as a core part of biology, and increasingly as an essential dimension of the Earth sciences.

Metabolomics

Jeremy K. Nicholson
Head, Department of Surgery and Cancer, Imperial College London

The analysis of the chemical fingerprints left by metabolic processes has already started to play a crucial part in personalized medicine, particularly cancer therapy. This stems from the understanding that humans are metabolic superorganisms carrying the genomes of many symbiotic organisms, all of which can affect an individual's physiology. Human metabolism is heavily influenced by interactions between our own genes and the activities of gut microbes, as well as by diet and environmental stressors. The products of this metabolic interplay have a direct influence on susceptibility to disease.

Determining how the body's metabolic processes interact with those of gut microbes is a priority in the coming years, because many conditions, including ulcerative colitis, Crohn's disease, obesity, diabetes and autoimmune disorders, are linked to poor gut health and microbial imbalances. By 2020, personalized health care could involve doctors monitoring the metabolic activities of a patient's gut microbes and, possibly, modulating them therapeutically. The use of mathematical models to interpret metabolic data obtained using nuclear magnetic resonance spectroscopy and mass spectrometry will help us to understand the changing patterns of human disease on a global scale, and generate new targets for drug or nutritional interventions. ■

*Authors declare competing financial interests: details accompany the article online at go.nature.com/rSQXyc.

TOMORROW'S GIANTS

On 1 July 2010, *Nature* and the UK Royal Society are organizing a meeting called Tomorrow's Giants (see go.nature.com/PWNbfI). It will ask what is required to enable academic achievement of the highest quality in the coming decades. The conference will look across themes such as measuring and assessment, science organization, data and interdisciplinary work. In the second half of last year, the Royal Society hosted a series of regional workshop meetings for researchers to exchange views on these topics, in particular identifying the impact of web 2.0 on how scientists share data; communication between industry/services and academia; and issues affecting careers and research. We invite Nature readers to participate, in the first instance by joining the Nature Network forum (at go.nature.com/b1tvCA).

The conference takes place at the Queen Elizabeth Hall, the Southbank Centre, Belvedere Road, London SE1 8XX, UK. It forms part of a week of celebrations for the Royal Society's 350th anniversary (see go.nature.com/VLSTMT).