1. Introduction

There is also a rhythm and a pattern between the phenomena of nature which is not apparent to the eye, but only to the eye of analysis; and it is these rhythms and patterns which we call Physical Laws.

– Richard Feynman, *The Character of Physical Law*

It is impossible to conceive anything at all in the world, or even out of it, which cannot be taken as good without qualification, except a *good will*…
to make itself a universal law is itself the sole law
which the will of every rational being spontaneously imposes on itself
without basing it on any impulsion or interest.

– Immanuel Kant, *Groundwork of the Metaphysic of Morals*

1.1 NANOTECHNOLOGY, VIRTUES AND LAWS FOR A SUSTAINABLE WORLD

During my last years in law school at the Australian National University my interests gravitated towards constitutional, international, science and environmental law, as well as haiku poetry (through a Japanese language subject in my arts degree). I was interested in law as an ideal. When required to study the compulsory subject property law I achieved a certain notoriety amongst the academic staff with an essay entitled ‘midline cerebral commissurotomy and the law of mortgages’, arguing for a historical progression from right-brain symbolic ceremonies of livery of seisin to the left-brain written documents that today govern sale and purchase of land.

It was fortunate that my first job after graduating was as research associate to Justice Lionel Murphy in the High Court of Australia, situated beside Lake Burley Griffin in Canberra. Justice Murphy had achieved honours in both science and law at university and possessed a mind that not only sparked ideas, but as an Attorney General in the federal government was also courageous in applying them to further the legislative pursuit of justice and equity. In his office, where other judges had a picture of the Queen, Justice Murphy placed an image of a nitrogen-abundant supernova remnant (SNR) N86 in the Large Magellanic Cloud. This had been named after him by astronomers at the Australian National University’s Mount Stromlo Observatory. A supernova remnant results from a star exploding...
its atoms outward at velocities near 1 per cent the speed of light and temperatures over 10 million K. The analogy those astronomers perceived with Justice Murphy’s impact on the law remains pertinent. The laws he created (both as Attorney General and as a judge) continue to illuminate the firmament of individual civil and political human rights against governmental injustice and inequity.

From the judge’s chambers you could see beyond the lake sunlight and clouds play above the beautiful mountains surrounding Australia’s well-treed national capital. It was an appropriate setting for one of the most important cases the High Court heard that year. This was the constitutional challenge to federal legislation preventing the construction of a hydroelectric dam on the last wild river in Australia – the Franklin River in Tasmania.

The appeal papers proved the dam was a wonderful piece of technology. It promised to increase the renewable energy available to significantly provide for Tasmania’s industrial and domestic use of electricity. Yet the dam would also have destroyed a beautiful wilderness, as well as archeologically significant sacred sites of the aboriginal people of Tasmania. The case arose from a nationwide campaign of protest and civil disobedience that finally resulted in the election of a federal government prepared to pass legislation preventing the dam. The appeal against that legislation was argued chiefly over interpretations of the power of the federal government to pass laws about corporations and foreign affairs (the river had been placed on the UNESCO World Heritage List that created binding international law obligations for its protection for signatory nations such as Australia).

The Franklin River was saved – by a narrow judicial majority (4:3). It flows free today, from source to sea, in a National Park. A decade later, after graduating from medical school, I canoed down that river and experienced how serenity and idealism seem to permeate your being from its remarkable natural beauty. Whatever might have been the technical legal grounds on which the Franklin River Dam case was fought and decided, those of us involved closely in that struggle felt that here was an instance of law responding to a new call in social conscience – not necessarily to right injustice or inequity, but to prevent environmental degradation in accordance with international obligations. Involvement in that case started me thinking about how law (and international law in particular) should shape our use of new technologies so that they benefit rather than degrade our environment. It also emphasised to me how a society, by manifesting a commitment to apply a universally applicable principle in the face of obstacles, can shape virtues, a collective character.
Nanotechnology fits within a category of historical examples of transformative technologies including tool and shelter making, growing and cooking food, the wheel, boats, metallurgy, hay-making, knitting, spinning machines, paper, the printing press, steam power, internal combustion engines, aircraft, electricity, nuclear energy, satellites, spacecraft, the Internet and genomics. Like those examples, nanotechnology is about to set the symbolic tone and practical agenda for a new stage of human moral as well as material progress.

So what is nanotechnology? Let’s first examine some definitions. A nanometre, or 10⁻⁹ m, is a billionth of a metre. An atom is about one cubic nanometre (the important unit of one Ångström is approximately equal to the width of an atom and is 0.1 nanometre). Nanotechnology, as commonly specified, involves research in physics and chemistry and development of products utilising engineered ultra-small particles (with unusual names like quantum dots, oxides, nanocomposites, nanowires, Fullerenes and single or multiwalled carbon nanotubes) having at least one dimension less than approximately 100 nm and related distinctive properties. Yet, this definition of nanotechnology (more precise ones are being developed by the International Organization for Standardization (ISO)) seems sanitised from the great global challenges this new research area should be responding to.

The wavelengths of the form of electromagnetic radiation we know as visible light fall roughly into the range 400–700 nm. This means that atoms, as well as the nanoparticles made from them, cannot be viewed using an optical microscope, but can be discerned through techniques such as the scanning electron microscope, as well as light, X-ray and neutron scattering. Below the nanoscale is the subatomic picoscale (a picometre is a trillionth of a metre), the realm of quantum physics and the smallest scale of matter, space and time – the Planck scale. After that come realms of metaphysics where matter, time and space may merge into a single field of ‘mental-type stuff’. As James Jeans put it in his marvellous book The Mysterious Universe: ‘the rolling contact of our consciousness with the empty soap-bubble we call space-time […] reduces merely to a contact between mind and a creation of mind […] the tendency to thinking the way which, for want of a better word, we describe as mathematical’.

Part of the reason for the considerable contemporary industrial and scientific interest in nanotechnology is that the physical and chemical properties of engineered nanoparticles (ENPs) differ from bulk equivalents in potentially temporally very useful ways. ENPs, for example, have larger surface area per unit mass (increasing strength and binding but also biological reactivity) and many have quantum physical effects below about
10 nm involving altered electrical conductivity, catalytic properties, wavelength of emitted light and magnetisation. The benefits of things engineered from nanoscale components include proportionally greater surface area and strength with less weight as well as enhanced energy storage and transmission (particularly from their capacity to harness quantum effects).

Nanotechnology offers to fill opportunity niches in a wide range of manufacturing, food, health and energy systems. Vast amounts of money are invested in nanotechnology research globally. Many of its most marketed applications appear to reflect our immaturity as a species (given the public health and environmental challenges we face) – sunscreens that look nice, lighter and stronger golf clubs (presumably so as not to overload the golf cart and resist being smashed against trees), socks and shirts that don’t smell, washing machines without grime.

Some of the most common marketed nanomaterials include carbon black used in products such as automobile tyres and antistatic textiles as well as to colour rubber, ink and leather. Also in widespread use are carbon nanotubes (nanometre scale rolled sheets of graphite). Their strength has seen them applied to consumer items like tennis rackets, golf clubs, skis and bicycles, as well as building materials including pavers. Owing to their large surface area, high electrical conductivity and adsorption capacity, carbon nanotubes have applications in energy storage products, electromagnetic shielding and super capacitors. There are major safety concerns about inhalation of carbon nanotubes – their relative length and biopersistence creating a heightened risk (based on animal models) of asbestosis-like lung injury.

Silicon-based nanomaterials are utilised in biosensing and bioimaging, batteries, microelectronics, and in photovoltaics. Nanosilver is widely used in consumer products (food packaging, washing machines, socks and shirts) as an antimicrobial. Major issues surround the accumulation of nanosilver in our sewerage treatment systems, waterways and the food chain. Nanotitanium dioxide and nanozinc oxide provide UV cosmetically attractive protection in ‘invisible’ sunscreens and face creams as well as outdoor paints. Although cell models confirm damage from these nanoparticles, the dead outer layer of human skin (stratum corneum) prevents most of them getting into the bloodstream, though this provides less comfort for those with damaged or frequently cut skin.

Nanocerium oxide is commonly employed in semiconductors, in electrolytes for solid oxide fuel cells, in oxygen sensors and in car exhaust catalysts. It has been developed as a product that reduces fuel consumption and greenhouse gas emissions (CO₂), and particulates emissions when added to diesel fuel.
This is just a small sample of the current uses of nanotechnology. Nanotechnology also offers the promise of revolutionising fields as diverse as building materials and clothing, energy generation, food production, water and soil purification, medicines, computing and weapons production, as well as the process of manufacture itself.

It is quite realistic to imagine a future where almost every product we use has a nanotechnology component, where nanotechnology has become a ubiquitous part of our civilisation, integrating itself not only into our social structures, but also our bodies and the very way we exercise our freedom of will and conscience. This book tries to embrace such a vision – of a nanotechnology-embedded world – then to imagine its moral and legal implications. Inevitably this involves critically analysing the jurisprudential foundations and intersections of different realms of law with new technology – something I expect Justice Lionel Murphy would have found fascinating.

Most official definitions of, or business plans to develop nanotechnology globally lack a moral or normative element – a developed connection to the great ethical principles, societal virtues and legal rights that have shaped human civilisation and that many of the most influential human thought-leaders have posited are part of the natural structure of the world.

In fact, as we’ll examine in subsequent chapters, many of the major stakeholders involved in researching and developing nanotechnology are driven by their constitutive documents to self-interestedly prioritise maximisation of shareholder profits (in the case of supranational corporations) and equally self-interestedly defined sovereign interests (in the case of nation states). Indeed, the dominant governance focus on nanotechnology has been on whether its use in consumer products presents us with unusual and important toxicological problems. Some civil society organisations (such as Friends of the Earth) even claim there should be a moratorium on the use of ENPs until such toxicological issues are thoroughly resolved.

Having accepted the imminent existence of a nanotechnology-based global society, this book then considers a related postulate – whether such a society is more likely to explore the idea that social laws may be developing in synergy with (and in fact might represent harmonics of) the physical laws underpinning the universe even as they are shown not to readily correlate with our common experience.

It is now well established in modern physics, for example, that many aspects of reality are true, despite conflicting with how we generally reason about the world based on sensory information. Some notable examples include light’s uniform speed regardless of its source, the extinction of matter in black holes, the invisibility of dark matter, the slowing down of time (relative to us) for an object whose speed approaches that of light, the
The capacity of matter to warp time and space, the alteration of particle position through the act of observation and the simultaneous existence of all matter and energy (presumably including us) as a particle and wave.

The world we are bequeathing future generations (where nanotechnology has become ubiquitous) may be one in which scientists verifying key aspects of string theory with equipment such as the Large Hadron Collider have unified the mathematical equations (laws) of microscale quantum mechanics and macroscale general relativity. They might, for example, have proven the existence of 'supersymmetric' partners for every known subatomic particle species, evanescent mini-black holes created by collisions of subatomic particles, or the existence of more than three dimensions of space and one of time that dilute gravitational force and the energy from particle collisions over tiny distances; indeed, that we in fact reside in a multiverse.

One hypothesis developed here is that such a world may also be one in which the fundamental symmetry increasingly revealed by geometry, mathematics and physics has assisted the development of social virtues and laws more coherent with such understandings, for example respecting our environment and promoting the expansion of human consciousness to identify with a vantage point broader and more timeless than our own. It will be argued here that widespread use of nanotechnology actually may promote this global normative evolution ('norm' in this context meaning social principle or rule) and become a crucial bridge to ages predominantly influenced by even more subtle forms of technology and hence more refined moral conceptions.

As mentioned, influential and well-respected non-governmental organisations are robustly opposed to the widespread use of nanotechnology in large part because they allege that process is failing to follow principles and rules that adequately limit the harm it may do humans and the environment. Part of the case advanced here is that such a restrictive governance approach, whilst commendably focused on safeguarding public health and the environment, fails to take account of the critical role that nanotechnology can play in advancing our moral progress and (which may turn out to be the same thing) coherence with the fundamental symmetry and harmony revealed by physical laws.

Let’s approach this insight another way. The physicist Richard Feynman gave the spur to the nanotechnology revolution with a 1959 lecture claiming that there was ‘plenty of room’ to build things at the scale of less than 100 nm (10⁻⁹ m). Feynman once said that true discovery (such as that likely to lead to nanotechnology) comes with an accumulation of paradoxes, with existing laws being proven to give inconsistent results. Feynman believed (if one can say that in connection with such an iconoclastic
experimentalist) that we sought new physical laws to reduce complexity; we think of an ideal like symmetry, put the information in mathematical form and then guess the equations. Feynman influentially recognised that our world tends to reflect geometric and mathematical patterns, but thought it unlikely that the laws of geometry extend down into infinitely small space.

The task of proving that ‘laws’ go all the way down in reality is complex because as matter and time reaches its smallest extent (the Planck scale) quantum effects make everything including points, velocity, length and curvature fluctuate, become indeterminate and uncertain as soon as we try to observe them. Thus at a Planck length of $1.6161 \times 10^{-35}$ (which squared gives the Planck area of $2.61177 \times 10^{-70}$ m$^2$), or a Planck time of $5.39072 \times 10^{-44}$ s, or Planck mass of $2.17665 \times 10^{-8}$ kg, gravity starts to become as strong as the electromagnetic force and, with the strong and weak nuclear forces, distorts the very essence of space and time. Planck units, like the elementary electric charge and speed of light, are natural ‘laws’ in that they are based on universal physical constants, rather than any historically located human definition.

The geometer Shing-Tung Yau considers that geometry might be the ultimate source of such ‘natural laws’, shaping multiple dimensions of space and time even in the absence of matter. The string theorist Edward Witten has argued for a new type of quantum geometry in which all the basic ‘laws’ of matter might be harmonics of strings vibrating (and dissipating gravity and energy) in those multiple additional dimensions.

The notion explored here is that embedding nanotechnology in our world is likely to take the reasoning behind its governance arrangements towards such speculations if only initially as a source of analogy. This book, in other words, considers whether the ‘laws’ of global governance systems then may come to be viewed at their most fundamental as not merely contingent manifestations of political compromise and judicial interpretation, but (when considered from the appropriate perspective) likewise aspects of a universal geometric and mathematical symmetry.

Such a potential synergy of basic ‘laws’ of nanotechnology and foundational principles of global governance is illustrated in the life and work of the futurist Buckminster Fuller. Fuller believed that the fundamental geometry of the physical universe involved tetrahedrons (a perspective very similar to that of esteemed ancient philosophers Plato and Pythagoras). He drew on this insight to create the stable geodesic domes that made him famous. Graphite nanostructures shaped like a geodesic dome (with applications in superconductivity) were named Fullerene{s} in recognition of Fuller.
Yet Fuller’s philosophy of the basic building blocks of the universe also stimulated his idea that human society had to renegotiate its basic principles of social interaction. We were no longer, Fuller thought, living in a time where we needed to compete violently for resources. Instead, our survival and flourishing, when viewed as a system trying to operate most efficiently, was critically dependent on our ability to conserve and recycle.

Another way of expressing this is to suggest that it is the virtues of curiosity and love of harmony, as well as more unpredictably valuable character traits such as pride and determination, that have assisted our species’ progressive understanding not only of natural ‘laws’ such as those underpinning physics, biology and chemistry, but also synergistically of the closely related principles, rules and laws designed to govern our relationships with each other and the environment. On such a view the human species (at least in its most intellectually refined manifestations) seems to love to champion geometrically elegant ideas and that has given it a practical survival advantage in terms not only of technological development, but also of social governance. Love and conscience may themselves be manifestations of a human impulse to promote symmetry and coherence in this universe.

Yet, our collective practical success in engineering, manufacture and to some extent in politics has encouraged a contrary idea that now threatens our existence. This is the perspective that ‘nature’ (and by this we have traditionally meant the non-human aspects of the Earth as we experience it) is an objective ‘other’. Many of our most dominant political and business governors have found it useful to regard ‘nature’ not as our nurturing co-partner in evolution, providing in its inherent symmetry the impetus for our moral and social organisation; but as an entity valued chiefly for its seemingly inexhaustible resources. This attitude looms as a significant adverse factor in the contemporary regulatory context in which nanotechnology is becoming a global phenomenon.

For some such leaders a corollary of the view that our technological developments and ethical and religious understandings are outcomes of humanity’s evolutionary struggle against ‘nature’ is that it’s not only necessary, but also sufficient to examine human genes, hormones and neural synapses to discover the material source of every virtue, moral belief, or legal norm that has facilitated humanity’s to-date successful contest for survival in this world.

The increasing specialisation of scientific research about ‘nature’ (including the unwillingness of scientists to seriously consider problems outside their metaphoric disciplinary silo) has meant that morals are increasingly regarded in that sphere as a matter largely of private concern and law as related chiefly to issues such as grant funding rules, patents, occupational
health and safety requirements, politics, traffic rules, taxation or the divorce courts (not necessarily in that order of priority). Many nanotechnology scientists thus believe that a rigorous commitment to objective methods in order to discover truth provides adequate virtue to justify their lifetime of professional endeavour. Their duty, they might say, is to reveal nature’s truths within the intellectual and collegial constraints of their discipline, and dedicated performance of that duty brings its own rewards in terms of good character.

Nonetheless, to reprise our emerging theme, science in so many fields underpinning nanotechnology is not only confirming the complex way in which ‘nature’ remains our nurturer, but is also revealing physical laws that prove ‘nature’ is structured around geometry and mathematics in ways diverging from the mental images of it we create by sensory information and common reasoning. Kurt Gödel’s proof that there will always be some unsolvable mathematical proofs is but another example revealing that uncertainty is also an embedded ‘law’ of nature. The physicist John Wheeler has even argued that the laws of physics, like social laws, are evolving in step with our understanding of them. Is it only our limited temporal and spatial perspective that prevents us seeing how our social laws and our governance arrangements locally and globally are likely to emerge from our scientific attempts to discover, replicate and enhance patterns of universal symmetry?

There is a pressing need for such a fresh governance approach. At present the combined effect of many aspects of the advanced technology, as well as the social systems we’ve developed over the last few hundred years, threatens to destroy us as well as our biosphere. Unfortunately this is not an unwarranted, alarmist claim.

The critical global public health and environmental problems of our age (those we have bequeathed to so many future generations) include: increasing global population and demand for energy from old photosynthesis fuels (for example coal, oil and natural gas); a non-localised economy whose lack of social responsibility is exacerbated by corporate and governmental corruption as well as by democratic unaccountability; extreme and unpredictable weather events (floods, cyclones, droughts), rising sea levels and ocean acidification.

Disruptive climate change is being driven by higher atmospheric levels of human-produced, solar heat-trapping CO$_2$ (390 ppm) than the world has ever experienced (Arctic ice core studies going back 800,000 years show a range of 180–300 ppm). Other causes of anthropogenic climate change include increased emissions of methane (CH$_4$) and nitrous oxide (N$_2$O). Warming of high-latitude northern hemisphere areas and the Antarctic peninsula is changing the climatic temperature gradient, decreasing solar
heat reflectivity and disrupting (perhaps beyond the point of recovery) the global carbon cycle, as land and oceanic ‘sinks’ become overloaded. There are also closely related challenges of massive biodiversity loss, degradation of ecosystems, as well as famine, poverty and inequalities in provision of the basic preconditions of life including security and access to basic food and essential medicines.

One proposed way morals and law may assist in remedying these issues involves setting ‘planetary boundaries’, or global governance principles designed to specify parameters in the natural world consistent with a safe operating space for humanity as assisted by its technologies (particularly in future by nanotechnology). These might include limits on human population (non-coercively, for example, through increasing educational opportunities for prospective parents), constraints under international and domestic law on atmospheric temperature and greenhouse gas levels, subsidies for renewable energy, as well as specifications of the amount of water and vegetation necessary to undertake photosynthesis across the globe.

At present, however, the idea of such ‘planetary boundaries’ is far from being incorporated in binding legal obligations (breach of which justifies damages or sanctions) in national statutes or international conventions. Indeed, for many people such ‘planetary boundaries’ seem now (in the context of existing global governance arrangements) to be as much idealised, paradoxical and anomalous entities as once were atoms, or are presently the notions of string theory and parallel universes.

This book explores the apparently anomalous idea that implementing such critically important environmental limits to human growth and exploitation of natural resources will necessitate a reconsideration of the basis by which global society should support laws (external constraints) mandating use of emerging technologies (such as nanotechnology) to promote sustainability of the natural environment. The mechanisms involved, as we shall see, not only may involve converting environmental ‘boundary’ principles into rights enforceable in national and international courts, but also fostering community, individual, corporate and governmental utilisation of public purpose-developed nanotechnology.

Such efforts to promote nanotechnology in the context of environmental sustainability could be viewed as a Quixotic modern day psychomachia – a naïve ‘techno-fix’ dressed up as a global contest of virtue against vice. Organisations such as Greenpeace, or the Ecovillage and Slow Food movements, as well as the Greens political parties, for example, though highly motivated to shape norms of sustainability in our governance arrangements, remain far from convinced that nanotechnology is or will ever be of great value in creating a sustainable world.
It should be clear now that a backdrop to our exploration of global governance strategies for nanotechnology involves examining whether there are necessary synergies between the collective enterprises of physical law-discovery and societal law-making. What we mean by a ‘law’ in this context will be one of the recurring questions examined in this text. For example, if we say that a concept is a ‘law’ do we mean we expect it can truthfully predict outcomes and has never yet been proved false, or that we must accept it is a law because others with authority (be they scientists or lawyers) have told us it is?

To summarise, an important aspect of our sustainable future is likely to reside not only in conceptually unifying all the laws of physics, but exploring the hypothesis that such a scheme is also coherent with moral theory and jurisprudence as well as widespread use of nanotechnology. Central here is the thought-experiment of considering physical and social laws from the standpoint of eternity, a perspective we’ll investigate in greater detail in the next section.

1.2 GLOBAL NANOTECHNOLOGY GOVERNANCE FOR ETERNITY

I was fortunate enough to be born and grow up in one of the most naturally and artfully vegetated cities in the world – Canberra. Canberra, the national capital of Australia, was designed to nestle beneath the forested Brindabella Mountains by the vegetarian architect Walter Burley Griffin in the early 1900s. Griffin had a very difficult time convincing the bureaucrats involved in constructing the city to incorporate his futuristic ideas about urban dwelling in sustainable harmony with nature. Griffin’s perspective of planning a city fit for eternity didn’t gel with men accustomed to justifying their worth by the balancing of the next budget. The benefit to science and governance of adopting a longer view is the theme of this section.

My family continues to live in this beautiful city. Each day (particularly since we can view the growth of the National Arboretum from our front window) Canberra’s landscape reminds me of the central tenet of ecosystem science – that sustainability in all of its formulations is critically dependent upon photosynthesis.

Photosynthesis has been building up food, fuel and oxygen on Earth for 2.5 GYr, since a time known in geological circles as the great oxidation event (GOE). Photosynthesis in one view may be regarded as the Earth breathing. It accounts for a global annual CO2 flux of 124 PgC/yr and an annual O2 flux of $\sim 10^{11}$ t/yr. Photosynthesis globally traps around 4,000 EJ/yr solar energy, in the form of biomass.
Photosynthesis generates carbohydrate from the carbon dioxide whose industrial production and atmospheric accumulation is dramatically altering our climate systems. It thus provides the primary food and energy source (in forms of ‘old photosynthesis’ – such as oil, coal, wood and natural gas) for human occupation of the world’s ecosystems. It also makes the oxygen we breathe (by using solar energy to split water) and creates the atmosphere that protects us from damaging solar irradiation. The central importance of photosynthesis to human and environmental sustainability is an insight that global governance systems, particularly those related to new technologies (such as nanotechnology), have not yet properly appreciated or integrated.

Because of the centrality of photosynthesis to the sustainability of life on Earth (however we come to define that concept) it is worth briefly reviewing its key components. Photosynthetic organisms absorb energy from the sun in the form of photons (as Albert Einstein proved to win his Nobel Prize) but also waves in a particular band of the electromagnetic spectrum (~430–700 nm). They do this by utilising ‘antenna’ chlorophyll molecules in cell membrane thylakoids, or intracellular organelles called chloroplasts. The absorbed photons create an electric current that powers the oxygen-evolving complex (OEC) with the assistance of manganese (in the MN₄CaO₅ cluster) and a protein known as photosystem II (PSII) to oxidise water (H₂O) to hydrogen and oxygen (O₂) that is released to the atmosphere. In effect, bacteria and plants designed their own sustainable electricity supply billions of years ago – a point we haven’t yet reached.

The electrons thereby produced are captured in chemical bonds by photosystem I (PSI) to reduce NADP (nicotinamide adenine dinucleotide phosphate) for storage in ATP (adenosine triphosphate) and NADPH (nature’s form of hydrogen). In the ‘dark reaction’, ATP and NADPH as well as carbon dioxide (CO₂) are used in the Calvin-Benson cycle to make food in the form of carbohydrate via the energy-expensive enzyme RuBisCO (Ribulose-1,5-bisphosphate carboxylase oxygenase).

The photosynthetic system thus involves a tiny solar-powered electric current interacting in proteins to split water and combine the output with absorbed carbon dioxide. It has proven robustly capable of maintaining life on Earth for billions of years. Yet in its natural form photosynthesis is an outcome of the climatic conditions in which it evolved and is not that efficient. The average percentage conversion of incident light energy to chemical energy through photosynthesis, for example, is approximately 3 to 6 per cent with a theoretical maximum of about 13 per cent (much lower under suboptimal conditions such as low ambient light and reduced water availability). The interaction of nanotechnology with photosynthesis and
governance concepts of sustainability is a base line running through this whole book that emerges as a melody in the concluding chapters.

Let’s reprise the argument so far. We have provided introductory material on nanotechnology and the biologic process crucial to sustainability of life on Earth. We have demonstrated that nanotoxicology is an important regulatory issue. Indeed, some non-governmental organisations consider the unresolved problems of toxicity so great that global nanotechnology research and development should indefinitely be put on hold, leading to a deep future in which use of nanotechnology is carefully circumscribed, if allowed to exist at all. They argue, with considerable justification, that, although increasing attention is being paid to questions of safety by design, green chemistry and environmental footprint in nanochemistry laboratory work, the ecotoxicology of nanoparticles is still in its infancy.

Despite such concerns, we have shown that nanotechnology is already becoming a global industrial phenomenon. Its marketed applications are presently predominantly high profit-oriented consumer goods for the developed world. Yet (as will be examined particularly in Chapters 5, 6 and 7) with appropriate governance nanotechnology has significant potential applications in fields as diverse as energy supply, medicines, chemicals, manufacturing, food processing and military defence. We now begin to explore some of the key conceptual underpinnings that will permit nanotechnology through such applications to promote the social virtue of environmental sustainability as a foundational condition of global governance.

We have already argued that, to think properly about benefiting humanity now and in future generations, our policy-makers (both governmental and corporate) need collectively to adopt a perspective that has proven very fruitful intellectually in both philosophy and science. This involves viewing complex societal interactions and the anomalies they throw out as if from eternity, making logical extensions from proven laws even if that counters existing conceptions. Nanotechnology, for instance, when regarded from eternity, can be considered, like all our technologies, as a manifestation in time and space of our collective consciousness as shaped by material (matter-based) and moral (conscience-based) pressures upon it.

This book won’t discuss whether or how to encourage humanity to adopt such a perspective (for example through a global culture promoting expansion of consciousness through altruistic service combined with contemplative detachment from memories that inhibit one-pointed concentration). Rather, it will examine what are the likely positive outcomes of global governance systems adopting such an extreme long-term approach to understanding and resolving complex policy issues. A major practical justification for the ‘eternity’ approach to global nanotechnology governance is that it is coherent with the emerging normative interest in the
consequences of our actions for future generations and the sustainability of ecosystems.

In furthering our argument, we’ll start in what may seem an unusual place. This is with Benedict de Spinoza’s *Ethics*, specifically Bk II Prop. XLIV Coroll. II. Spinoza there writes that in terms of logic the best way to understand a thing truly is to try to perceive the idea of it under what he terms ‘a certain species of eternity’. Spinoza might just as well have stated ‘eternity or infinity’, as his argument concerned the value of imagining such outer limits of time and space as our hypothetical conceptual vantage points in moral decision-making. Phrased in contemporary language, Spinoza claimed that making moral decisions from an eternal vantage point stimulates our powers of reason to detect patterns of symmetry and harmony that encourage us to transform personal self-regard into empathy and altruism.

Immanuel Kant propounded a similar view in his *Critique of Pure Reason* when he stated that logically space and time should not be considered as derived from temporal sensory experience, but as preconditions to our perception and thinking. In his *Introduction to the Groundwork of Metaphysics of Morals* Kant applied this insight about physical ‘laws’ to expound the view that the ‘universal’ viewpoint is the correct one from which to view the rightness of a moral decision. We should strive, Kant wrote, to apply moral principles that are capable of universal application because in doing so we achieve the only possible unqualified good in that universe.

That we view the world truly from eternity seems a rather abstract recommendation (fit for moral philosophy but not hard physics). Yet this is not true when we consider the many physical laws (many directly underpinning nanotechnology) discovered by philosophers and physicists such as Pythagoras, Kepler, Galileo, Newton, Maxwell, Einstein, Bohr, Schrödinger, Dirac, Witten, Calabi and Yau, by adopting just such an approach. To give but one example, both the discovery of astrophysical black holes and the development of string theory (as a means of unifying the equations of quantum physics and general relativity) are indebted to the geometric insight that, because the curvature of a sphere is inversely proportional to the radius squared, as the radius goes to zero the curvature goes to infinity.

Modern physics appears to be confirming that eternity and infinity are hard-wired into the immediate reality of ‘nature’ as we know it. If we consider, for example, how what is known as the Higgs Field gives mass to fundamental particles in different regions of the universe, then what might appear as eternity outside such a region may be infinity at each moment within it. Further, when physicists try to mesh the equations proven to
predict the activities of the very small (quantum physics) with the very large (general relativity) they end up with infinite probabilities. This is mathematically incoherent unless our world has many more dimensions than we are used to or, indeed, inhabits an infinite number of universes. The ‘big bang’ or initial low entropy state that commenced our expanding universe appears to have also initiated time from a preceding condition that might as well be termed eternity. ‘Eternitists’ even claim that according to modern physics past, present and future may well be equally real, though that is certainly not our common experience.

Expressing this point another way, our usual approach to comprehending ‘nature’ (and that includes developing technology and the making of moral choices about its sustainable use) involves applying what we consider to be our common sense as it routinely operates in the three familiar dimensions of space and one of time. By considering anomalies in such experience from the perspective of eternity (or infinity), on the other hand, we facilitate our reasoning reaching a richer and potentially more accurate understanding of ‘nature’. Geometry and mathematics provide elegant ways this can be done (for example, string theory physicists can coherently write the geometry of 10 or 24 dimensional space though that confounds our common sense).

At the nanoscale (a billionth of a metre) these issues manifest most pointedly. It is at the nanoscale that the laws of classical physics (more readily conformable to sensory experience) begin to interact with the much more uncertain features of quantum physics. Techniques such as neutron scattering and transmission electron microscopy (used to elucidate particles at the nanoscale) produce data involving indeterminacy, wave-particle duality and many other problematic features of the quantum world. Pico-technology, as a hypothetical future technological manipulation of subatomic matter (gluons, quarks, super strings, the quantum fluctuations that give rise to the universe’s large amount of ‘dark energy’) will involve such anomalous features of reality as even more prominent factors.

Fundamental physics involves the search for laws governing the elementary building blocks of matter. When one reads physics texts stating that equations run just as well backwards as forwards in time, that everything in the universe is tending towards loss of complexity and dissipation of energy, a person interested in conscience might ask ‘Why should any decision ultimately be valued more than another?’ Why does being good ultimately matter? When we manifest virtues by acting on conscience what are we adding to the universe that wasn’t there before? Is it a form of energy, or something else? If it is something else, what is its relationship with matter and energy, time and space?
Modern physics has shown (for example through the uncertainty principle) that an observing consciousness does alter fundamental states of matter and energy in space-time. Perhaps those fundamental states are designed to promote a special type of consciousness that we are striving towards in the guise of morality. The insight that reality (including human moral purpose therein) appears most clearly when viewed at the extremes of sensory experience (eternity and infinity) suggests a hypothesis that physics is working towards a unified theory not just of electromagnetism, the strong and weak nuclear forces (quantum mechanics) and gravity (general relativity), but also (as Kant supposed so many centuries ago) the moral law within us.

How does this apply to the use of new technology such as nanotechnology to create a sustainable world? Thinking properly about our responsibilities to future generations must involve considering how to preserve essential systems long term. Eternity is as long term as you can get. Industrial and technological revolutions resembling that involved with nanotechnology have occurred before, in more recent times characterised by a mindset that the natural resources they require (for example coal and oil) were infinite or could be utilised without much consideration that they were exhaustible.

The finite legacy of millions of years of photosynthesis provided the coal and oil that powered blast furnaces, steam and internal combustion engines, as well as making fertilisers for mass-production agriculture. The resultant material success promoted models of human prosperity based on ideological commitment to endless economic growth, technological innovation and global trade in manufactured goods and food drawing upon comparative advantages in abundance of raw materials, technological excellence and cheap labour. This created vast urban populations divorced from routine association with the natural world that they presumed would somehow indefinitely support their existence. The thinking of men who dominated these technological revolutions, in other words, tended to prioritise short-term profit and disregard long-term perspectives. The global governance structures they spawned reflected this focus – nation states and corporate globalisation in large measure drew their strength from increasing utilisation of raw materials taken (often with the assistance of military force) from the environment at the threat to sustainability of local communities.

Policy-makers continuing to embrace the corporate globalisation model of social development are likely to view as risky and threatening ideas that humans should try to use any new technology to sustain the environment as a dominant governance focus. The notion that the prime focus of our newest technology innovation (nanotechnology) should be to facilitate the
social virtue of environmental sustainability probably seems to them unnecessarily idealistic and threatening to the social fabric. Yet it is important as a conceptual foundation of global governance structures to establish that this linkage of nanotechnology and sustainability is the outcome of a very logical process of reasoning.

The policy debate about environmental sustainability when viewed in the short term may seem a values contest about the use of the world’s natural resources between proponents of public and private interests with no obvious chance of reaching substantial or imminent consensus. This, however, when viewed from a perspective we have conveniently described as ‘eternal’, is to misunderstand not only the mechanism by which humans make laws, but also the importance of jurisprudence making social laws coherent with those that underpin nature – the laws of physics. We return to the point, in other words, whereby idealist approaches to developing governance norms (such as human rights or environment protection legislation) may parallel methods in the physical sciences that utilise thought-experiments in which the observer’s vantage point is eternity or infinity.

Jurisprudence is the field of knowledge traditionally concerned with defining societal ‘law’. Mostly this law-defining appears to represent an alternation between what we may describe as the idealist perspective of eternity or infinity (responsible for inspiring many constitutional and international law human rights pronouncements) and, on the other hand, social organisation ideologies maximising for example the sovereign interests of Western nation states or the financial concerns of their major private interest groups (increasingly including supranational corporations).

As is the case in many other areas of human life, jurisprudence scholarship thus reflects the opposition between scholars, judges and politicians embracing the perspective of eternal ideals such as justice, equity and sustainability and political, judicial and corporate leaders more content with the conservative view that society should reflect virtues such as security, predictability and certainty (for example as embodied in the rule of law) that allow individuals the freedom to strive, acquire and prosper according to their own lights. Something inherent in human society (at least when it operates as a functioning democracy rather than as a military dictatorship or corporate resource) seems to drive this tension between progressive and conservative governance philosophies, making it as necessary as positive and negative poles for electric current or magnetic fields.

Physicists or biologists are tempted to denigrate jurisprudence for the imprecision and lack of objective verifiability of the ‘laws’ it considers (and economics with greater justification, but that may be a personal prejudice). Yet they should consider how speculative and vulnerable to ridicule some
early formulations of physical ‘laws’ have been (Albert Einstein, for example, did his PhD to prove whether atoms existed and what size they were). Scientists should more frequently imagine in what peril they and their work are placed if the rule of law (the support of which arguably is a central task of jurisprudence) breaks down – as it has in many failed states today. In those disrupted nations governance by rules is replaced by arbitrary arrests, torture and executions, corruption and abuse of power, often cloaked in nationalistic propaganda, religious fundamentalism, or free market ideology.

Let’s recall the key components of the argument so far. The perspective of eternity is a mathematically and geometrically robust route to truth in physics. The application of a similar technique in regard to the nature and purpose of putative social laws is generally characterised as an idealistic, rather than pro-symmetric process. When social laws about sustainability are considered this way it is likely to be erroneous to regard their central purpose solely in a self-interested or anthropocentric manner. The key word here is ‘solely’. On this eternity approach, the appropriate way to view conservative political and legal positions may be as particles, while idealistic ones can be considered waves.

In recent years substantial numbers of idealistic humans have fought for the legal rights of other species and ecosystems. Likewise, scientific research increasingly confirms the critically threatened interdependence of life, and modes of rapid global communication like the Internet appear to be magnifying public awareness of this. Such examples provide indirect evidence of an increasing collective interest of humanity in championing norms about environmental sustainability in human governance relationships. Yet those opposing such ‘wave-like’ positions propose equally valid arguments supporting fiscal responsibility and societal stability.

Let’s consider more closely how the concept of sustainability (emphasising future generations) is emerging in global governance systems. Environmental sustainability (chiefly focused on in this book) has received much less attention in this context than the more widely debated notion of developmental sustainability. The Brundtland Report in 1987 influentially defined ‘sustainable development’ as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’. Sustainable development, however, is a policy concept that places the interests of humans at its core. The notable economist Robert Solow in his *An Almost Practical Step Toward Sustainability*, likewise, defined sustainability as a social virtue arising from consistent application of the ethical principle that the next human generation must be left with ‘whatever it takes to achieve a standard of living at least as good as our own and to look after the next generation similarly’.
In recent years, legal documents such as the *New Delhi Declaration of
Principles of International Law Relating to Sustainable Development* have
highlighted the need to develop governance structures that facilitate sus-
tainable use of natural resources and precaution against their damage or
loss. The International Law Association (ILA) is actively investigating how
to embed such principles in the broad framework of international law as
applied, for example, by the International Court of Justice (ICJ), the
International Tribunal for the Law of the Sea (ITLOS), human rights
courts at national, regional and international levels, World Trade Organiza-
tion (WTO) dispute settlement arbitral tribunals, inspection panels of
multilateral development banks and compliance committees of multilateral
environmental agreements.

Yet the jurisprudence of developmental sustainability is becoming
closely linked with ecosystem science. The Intergovernmental Science-
Policy Platform on Biodiversity and Ecosystem Services (IPBES), for
example, plans to conduct periodic assessments of Earth’s biodiversity and
‘ecosystem services’ – ecosystems outputs, such as fresh water, fish, game,
timber and a stable climate, that benefit humankind. These assessments,
based on reviews of the scientific literature, aim to answer questions about
how much biodiversity is declining and what the implications of extinctions
and ecosystem change might be for gaps in global governance and research
on issues such as land management. The Nature Conservancy and the
World Wildlife Fund have been working with academics to draw upon such
research to develop the concept of ‘natural capital’ so that ecosystem
‘services’ (such as flood protection, crop pollination and carbon storage)
can be valued in dollar terms and included in the economic assessments of
business, community and government decisions.

Further, influential academic works such as William Vogt’s *Road to
Survival* (1949), Rachel Carson’s *Silent Spring* (1962), Garret Hardin’s *The
Tragedy of the Commons* (1968), Paul Ehrlich’s *Population Bomb* (1968)
and Stephen Morse’s *Sustainability: A Biological Perspective* (2010) have
emphasised the critical challenge of ensuring that our world continues to
involve harmonious interaction between all life forms. Principle Four of the
*Earth Charter* similarly enunciates ethical obligations to (a) recognise that
the freedom of action of each generation is qualified by the needs of future
generations and (b) transmit to future generations values, traditions, and
institutions that support the long-term flourishing of Earth’s human and
ecological communities.

The notable economist Amartya Sen in his *Idea of Justice* is another of
those striving to expand the concept of sustainability beyond economic
considerations so that it includes issues about access by future generations
to political and legal freedoms and capabilities. Sen questions the idea that
sustainability must be a human-centred virtue, one that has ‘typically been defined in terms of the preservation and enhancement of the quality of human life’. Equally important have been theorists such as CS Holling who have advocated adaptive governance for sustainability in the context of promoting emergent complex system properties such as resilience and discontinuous changes in social response to new technology.

To summarise the argument in this section, scientific research confirming our interdependence with ‘nature’ is a major factor driving the collective conscience of humanity and then its governance systems to embrace the social virtue of environmental sustainability (as scientific theories such as evolution earlier did with governance virtues like justice, equality and liberty). This virtue when considered truly (as a species of ‘eternity’ as Spinoza put it, or from a ‘universal’ perspective as did Kant) and not contingently (for example as something useful to this particular generation or its dominant interest groups) may represent a planetary acknowledgement of fundamental interconnectedness that eventually will be explicable according to physical laws. Such a vision is behind projects such as the EarthSeeds project of the Spaceship Earth Foundation, which plans to place a picture of Earth from space in every classroom in the world.

Perhaps nanotechnology, complemented by breakthroughs such as the conceptual unification of the physical laws of quantum physics and general relativity, will provide a new point of reference for including social laws within such unification. This approach, emphasising individualised local (domestic and community) application of universal principles related to governance of nanotechnology for the global good of environmental sustainability, could even be referred to as ‘nanogovernance’.

The concept of ‘nanogovernance’ brings together and extends ideas that have underpinned my publications over the past seven years. These include not only consideration of how to justly and equitably regulate the development of new health-related technologies, but also the relationship of laws of physical reality to conscience, the rule of law, the social contract, free market globalisation, state sovereignty and international civil society. How to begin extending the idea of nanogovernance to the global level is the subject of the next section.

1.3 WHY A GLOBAL NANOTECHNOLOGY FOR SUSTAINABILITY PROJECT?

As mentioned, when people talk of regulation of nanotechnology these days they are usually debating methods to investigate and control its potential toxicological impacts. My first exposure as an academic to the
Introduction

concept of regulating nanotechnology arose from a decision to help Richard White, a man who’d contracted silicosis from sandblasting fuel tanks at an Australian airforce base. Richard was dying from his disease, yet he wanted to leave a legacy that might assist other sufferers of similar toxic exposures. Together we helped set up a parliamentary enquiry into workers’ compensation from injury by toxic dusts. At the last moment the terms of reference were altered to include nanoparticles, an area of research previously unknown to me. Sometime later (after many publications and conference presentations in the area) I received an Australian Research Council grant to study nanoregulation and became engaged in public policy debates over the potential toxicity of nanoparticles in sunscreens. This is a big issue in Australia where skin cancer is so prevalent. My research also explored ways in which our medicines’ cost-effectiveness regulatory system could scientifically examine the community ‘health innovation’ of nanomedicines and how nanotechnology might impact on questions of national security.

In the course of this research I became surprised at the extent to which the pre-eminent regulatory challenges for nanotechnology were expressed in terms of time-framed goals for developing instruments to assess air and water exposure of organisms to engineered nanoparticles, as well as methods and strategic programs to evaluate their toxicological impact. Surely, I started to think, we should spend more time focusing on how this wonderful new technology can help us solve the potentially catastrophic public health and environmental challenges we now face.

This is not to say that nanotoxicology isn’t a serious problem. Regulators and policy-makers have known for many years that many ENPs cause cellular toxicity, though the precise mechanism for this remains largely unknown. Human risk analyses and the principles and rules developed in conjunction with them are not easily extrapolated to strong in vitro evidence that ENPs elicit reactive oxygen species that cause cellular and DNA damage.

Regulators also now know that inhalation of particular types of ENPs such as multi-walled carbon nanotubes (like asbestos – relatively long and biopersistent fibres) can produce life-threatening problems (for instance a chronic inflammatory response resembling mesothelioma). Yet although occupational health and safety standards remain substantially underdeveloped for carbon nanotubes, research and business communities continue to invest heavily in these nanomaterials for a wide range of consumer products under the twin assumptions that they are profitable and no more hazardous than graphite.

If we wait for nanotoxicology research to conclusively prove that every aspect of ENP use is unambiguously safe, the nanotechnology revolution may stall and fail to reach what can be described as its moral potential. It is
likely, for instance, that, even after further decades of nanotoxicology research, no regulatory agency will possess adequate data to completely back up their standards or methods to monitor ENP exposure risks, either in the laboratory, manufacturing processes, workplace or home. It is a reflection of this scientific uncertainty that, though some health technology and chemical regulators now specify distinct safety regulations/requirements that must be met by manufacturers of ENPs, most manufacturers or lab managers have no legal obligation to tell workers or researchers they are working with ENPs, to keep sufficiently detailed OH&S data sheets that are nanospecific, or to report ENP-related hazards.

Important regulatory systems for ENPs do need revision. Existing models focus on triggers for action related, for example, to amount manufactured per year, historical toxicity of a related macroscale substance and classification as a new chemical entity (not routinely used for nanotechnology). The risks of nanomaterials, however, are more likely to be determined by particle number, surface structure and surface activity including the fluxing corona of proteins that encrust nanoparticles when they enter biological systems. Such problems are compounded by the fact that nanotechnology is no longer developing in a context of local experimentation, but has emerged as a globally pervasive system that challenges both trial-and-error established toxicological protocols and existing models of national technology regulation. All this makes nanotoxicological research a viable candidate for coordinated global scientific and governance effort. Such a global project, however, will not of itself help solve the critical public health and environmental problems humanity faces.

Exceptions to the predominant focus on nanotoxicology in nanotechnology regulation have begun to emerge. Nature Nanotechnology, for instance, in 2007 contributed two articles to the Council of Science Editors’ Global Theme Issue on Poverty and Human Development involving scientific journals in 37 countries. The articles focused on nanotechnology for clean water and the export of rare metals for nanotechnological applications. A related editorial began: ‘It is easy to see nanotechnology as something that is being funded exclusively for the benefit of the developed world.’ In urging a more altruistic vision, the editorial cited a survey of experts that claimed nanotechnology was capable of positively contributing to achievement of the United Nations Millennium Development Goals. The three leading applications were energy storage, production and conversion, agricultural productivity enhancement, and water treatment and remediation. What these editors were saying, in other words, was that nanotechnology needed to symbolically and practically link itself in the popular conscience with coordinated scientific efforts to help resolve some of the critical problems facing humanity and its environment.
This text not only supports such arguments, but seeks to develop them in the normative (‘rule-making’) realm for practical global applications. It makes the case that there are moral and human rights obligations upon the nanoscience and nanotechnology communities in particular to address global problems such as access to shelter, fuel, food and water. More unusually, it also proposes that the process of reasoning resulting in the discovery of the physical laws underpinning nanotechnology itself supports such ethical and legal obligations.

We should remind ourselves about some of the critical problems this world is facing. Access to shelter, fuel, food and water are central survival issues for those living in poverty and will be exacerbated as global population grows towards 10 billion by 2050. By that time world energy consumption (which varies greatly on estimates, for example, by the United National Development Program or the International Energy Agency) will have risen from 400 to over 500 EJ/yr. At the same time the predicted 2–3°C increase in atmospheric temperature and water vapour will have had unpredictable and likely adverse impacts on the yield of staple crops, even in a CO₂ rich atmosphere.

Because it is so central to the arguments that follow, it is now also necessary to take a little time reviewing some key scientific issues behind humanity’s energy crisis. At present, daily power consumption for a citizen of a developed nation is about 125 kWh/day (~250 kWh/day for an adult person in the United States); much of this power being devoted to transport (~40 kWh/day), heating (~40 kWh/day) and domestic electrical appliances (~18 kWh/day), with the remainder lost in electricity conversion and distribution.

The kilowatt-hour (kWh) is a standard unit of electricity power production and consumption. One kilowatt-hour equals 3.6 x 10⁶J and one 40W light bulb constantly switched on uses 1 kWh/day from the electricity grid. To understand what this means it is important to note some physical laws responsible for defining power as the rate at which energy is used. One joule of energy is equal to the work done when a force of 1 newton moves its point of application 1 metre. One newton represents the force which will give a mass of 1 kg an acceleration of 1 metre per second per second. One watt of power equals 1 joule/sec (1 kilowatt = 1000 watts). Recall that the average citizen in a developed nation uses 125 kWh/d. Exajoules per year (EJ/yr) (exa (E) = 10¹⁸) is a measure of global power supply and consumption (the current estimate being over 400 EJ/yr).

This is crucial information relevant to our individual and collective energy ‘footprint’. It highlights how central to human survival the problem of energy is. Our use of what may be described as ‘old-photosynthesis’ fuels to supply this energy is causing loss of a significant number of species not
only on Earth, but also in the oceans as a result of acidification. It is
possible that if Earth remains intact the numbers of some species may
regenerate (possibly with the help of genetic engineering). That, however,
will be a complex and difficult task unlikely to recreate all the marvellous
complexity reflected in evolution of life on Earth over millions of years. If
humanity survives without its present technology (a frequent occurrence in
human history) the reserves of oil and coal we are now rapidly depleting
may be critical to the recreation of civilisation.

It is reasonable then to assume that if nanotechnology is to assist
resolving the great public health and environmental problems of our age it
must be relevant to our energy crisis. The political will of nation states to
look to new technology for energy solutions is manifest in international
agreements such as the Copenhagen Accord (2009), which included a moral
commitment to support renewable energy initiatives through an adaptation
safety net (US$30 bn for 2010–2012, rising to US$100 bn per annum by
2020) and the Copenhagen Green Climate Fund supporting a technology
transfer mechanism ‘to accelerate technology development and transfer
[…] guided by a country-driven approach’.

The most obvious source of renewable power that nanotechnology may
make more readily available is the gigantic nuclear reactor that our Earth
orbits. The annual solar energy intercepted by the Earth at ~1.37 kW/m² is
5.5×10⁶ EJ/yr (although the annual solar energy reflected by the atmos-
phere back to space at ~0.3 kW/m² is 1.6×10⁶ EJ/yr). Thus, the solar energy
potentially usable at ~1.0 kilowatts per square metre of the Earth is 3.9×10⁶
EJ/yr. This is exponentially more than our current (400 EJ/yr) or projected
(500 EJ/yr by 2050, 1000 EJ/yr by 2100) global levels of human energy
consumption.

Raw sunshine at midday on a cloudless day, for example, can deliver
~1000 W/m² in mid-latitude regions and ~1200 W/m² in low-latitude dry
desert areas. If we take into account the Earth’s tilt, as well as diurnal and
atmospheric influences on solar intensity, then this figure becomes approxi-
mately ~110 W/m². This produces a potential practically usable solar
energy of between 1,500 and 50,000 EJ/yr. Photovoltaics (the capture of
solar photons and their transmission to the electricity grid), as we’ll
examine in Chapter 8, is a major existing focus of nanotechnology research
– displaying increasing efficiencies of energy capture and storage. Should
photovoltaics then be the major global policy focus of nanotechnology
and, if so, by what mechanism? What are the alternatives? How should
global nanogovernance systems promote them?

The chapters that follow explore the reasons behind, the obstacles to, the
likely candidates for and the governance structures of a global nanotech-
nology for sustainability (NES) project. Nanotechnology applications in
clean water, food supply and medicines and renewable energy will emerge as prominent candidate topics for such a project, particularly because of the large amounts of existing government and corporate funding and research interest in these areas.

Some may detect evidence of convergent (or even emergent) global consciousness in the fact that scientists and policy-makers have an established record of coming together to plan and coordinate such macroscience projects focused on the achievement of global public goods. The Human Genome Project (HGP) is a notable instance of this type of ‘Big Science’ project that undoubtedly accelerated research in a crucial area for human health. Some such global science projects are focused in one place like the European Organization for Nuclear Research (CERN) or the international project on fusion energy (ITER). The HGP was not.

Appropriate governance arrangements are vital to their success. CERN, for example, involves an agreement between many nations to fund expensive new equipment (such as the Large Hadron Collider) open to use by independently funded physicists from around the world. ITER highlights the benefits of signatories undertaking in such an agreement to share scientific data, procurements, finance and staffing. As with CERN, the Hubble Space Telescope (funded by NASA in collaboration with the European Space Agency) allows any qualified scientist to submit a research proposal, successful applicants having a year after observation before their data is released to the entire scientific community.

The following pages advance more detailed arguments for a global NES project. Those who read stories to their children at night and like to see their own work as ultimately benefiting that next generation might like to view what follows as a treasure map.

The next two chapters thus may be imagined as depicting the conceptual travellers (for example personified as the characters Sustainability, Law, Conscience, Corporations, Humanity, Physics, Free Markets and the Environment) meeting in a tavern, hearing tales and deciding to go on a journey where much of the benefit arises from what they learn about each other and themselves along the way.

Chapter 2 allows us to meet the foundational governance concepts likely to underpin global NES. It explores, for example, the deep-rooted moral reasons for such a project. It considers what commonly agreed features should constitute a social law, or a sense of legal obligation requiring focus on nanotechnology in this way. In particular it focuses on how the less human-centred virtue of environmental sustainability should mesh with established social virtues such as justice, equality and respect for human dignity (that provide the influential theoretical foundations for many existing systems of legal obligation). It explores how such an endeavour
critiques the intersections between basic legal ideals (such as the social contract and the rule of law) and the laws of physics underpinning nanoscience.

Chapter 3, to briefly continue the dramatic analogy, confronts us with those that may be considered the (often unwitting) villains of the piece. It introduces and explores some key global governance structures and actors likely to hinder nanotechnology from assisting to resolve our critical global problems. It examines, for example, many of the well-analysed reasons, apart from toxicological concerns, why policy-makers, regulatory scholars and corporate executives are reluctant to emphasise the role of nanotechnology in facilitating a sustainable world. Major barriers we’ll scrutinise here include the interest of governmental oligarchies in protecting what they perceive to be their sovereign interests and the way international trade and investment agreements have created unprecedented leverage for supranational corporate lobbyists to oppose public good focused domestic health and technology policy.

Chapter 4 considers how widespread use of nanotechnology by future generations (in what is termed a ‘nanotechnology-embedded world’) may support the foundational social virtue of environmental sustainability. This section concludes by proposing certain criteria that might be useful in deciding what would be the best macroscience global NES project.

Chapters 5 to 8 apply these criteria to the strongest potential candidates for a global nanotechnology project most suited to promoting social virtues such as environmental sustainability and human flourishing. Chapter 5 looks at whether it would be best to work on a global project involving nanotechnology’s contribution to food supply as well as safe drinking water. Chapter 6 considers whether nanomedicine, particularly the use of nanotechnology to improve pharmaceuticals and medical devices, might be a good candidate. Chapter 7 likewise considers the possibility for nanotechnology in connection with global peace and security. Chapter 8 reviews the prospects for an international nanotechnology project dealing with issues of climate change and renewable energy.

What these case studies are seeking to establish is where policy-makers should focus in seeking to discover a globally accessible, cheap use of nanotechnology that can rapidly be rolled out on a scale large enough to resolve the critical contemporary problems for human society and its environment. As the physicist Freeman Dyson pointed out, all we need to save the world is one cheap and successful technology, achieved before our capacity to do so runs out.

Chapter 9 sets out the case justifying a Global Artificial Photosynthesis (GAP) project as the most likely candidate to satisfy the proposed criteria.
for a global macroscience NES project. That chapter analyses the governance issues that will need to be solved to bring such an endeavour in planetary nanomedicine to fruition and critiques different models that might be employed. It argues that an NES GAP project can justifiably be regarded as the moral culmination of nanotechnology.