MULTI-DISCIPLINARY ISSUES
INTERNATIONAL FUTURES PROGRAMME

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Industrial Biotechnology to 2030

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Abbreviation List

APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
DNA	Deoxyribonucleic acid
FAO	Food and Agriculture Organisation
GMO	Genetically modified organism
GPS	Global positioning system
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
NIH	National Institutes of Health
NGO	Nongovernmental organisation
OECD	Organisation for Economic Cooperation and Development
PCB	Polychlorinated Biphenyls
PLA	Polylactic Acid
UN	United Nations
WHO	World Health Organisation
WTO	World Trade Organisation

List of Text Boxes

1. Setting the Scene

This document presents two scenarios for industrial biotechnology to 2030: a baseline and an alternate scenario exploring how new forms of manufacturing may evolve and impact the future. The narrative includes text boxes with thoughts on how the scenarios might have occurred and what they might look like in different nations.

Industrial biotechnology is a very dynamic field and reflects the convergence of several fields of science and technology and engineering. While some components are very old (fermentation), the thinking around, and application of, the bioeconomy needs are new and still developing. Hence there are many possible interpretations on how Industrial biotechnologies (including bioenergy, bioprocessing and environmental biotechnologies) could have significant impacts on the global economy, international relationships and individual lives. Industrial biotechnology is expected to be both a fundamental driver of, and a recipient of, changes in agriculture and health technologies. A number of benefits are expected to arise from these changes, *e.g.* through creating new opportunities for industrial uses of plants and providing technologies to manufacture "lab on a chip" diagnostic tools for personalised medicine.

Industrial biotechnologies are also expected to have a critical role in political and economic stability in the 21st century, both in developing and developed countries, and to provide some of the more smart ways to combat man's impact on the planet. By 2030 industrial biotechnologies and products associated with them will have impacted on most people's lives and will not be contentious. Industrial biotechnologies will be associated with increased wealth in developing nations and have driven the emergence of new multinational entities that reflect the merging of manufacturing options. Examples of such options are fermentation facilities specifically to produce 2007-era top 12 platform chemicals (*e.g.* succinic acid), and imprinted bioplastics as a new electronics capability.

Current (2007) new partnerships, such as combinations of plant biotech, petroleum discovery, chemical, waste management, carbon credit investors, green venture capitalists, will have consolidated. While many of the new start up companies initiated in the first decade or so of the 21st century will have failed or merged, some will have become the new Nokia or Microsoft of industrial biotechnology. Their home base may well be in a developing nation of 2007. Examples include the waste management company W2 which developed technologies used for treating industrial wastes to facilitate onward manufacturing based in South East Asia, and Paleonomics which has grown to become a world-wide manufacturer of designer microbes for remediation purposes. They moved from the United States to base in South America in the early 2020s, reflecting indigenous rights to intellectual property ownership and development, legislative advantage and availability of a skilled labour force. Verinox, through their mergers combining engineering design and capability, enzyme discovery and biological processing intellectual property, has established lignocellulosic biorefineries across the globe with major bases in both the developed and developing countries of 2007.

1.1 Baseline Scenario – "Steady as She Goes"

1.1.1 Governments take a cooperative approach

The baseline scenario (**Steady as She Goes**) assumes that political frameworks remain relatively similar to today, but governments take a more "middle of the road" approach overall. There is consensus for many "cross party consensus" approaches in key areas such as health, environment, urban education and science strategies, only core areas define the differences between parties. Reaching such an "cross party consensus" consensus between parties representing middle, left and

right (but not extreme) in many places was driven by the consistent decline in quality of life and affordability of basic needs when market-only decisions dominated all aspects of society. Nations with small populations led the change, more recently followed by those with moderate size populations.

1.1.2 Governments help to drive change

Differences in the use of market drivers and regulatory/incentive drivers between nations remain, with no one common viewpoint. Market-led decisions were inadequate in changing societal behaviours and infrastructure with respect to the environmental drivers such as reducing energy needs and pollution. Development of standards for life cycle analysis or labelling of product composition/manufacturing processes (*e.g.* organic) remain market-led. However, most governments use a blend of market drivers and incentives to encourage change as well as more centralised initiatives in some circumstances. Critically, smaller countries are unable to buffer against companies based in very large countries. In these cases, market initiatives can become monopolies or monopolistic collusions, capital leaves after stripping profits, and there is little interest in national stability. Hence there is greater governmental control of strategic assets.

1.1.3 Quadruple bottom line reporting

Governmental and global societal concerns with respect to the environment and human rights are driving quadruple bottom-line accounting in 2030. Quadruple bottom line accounting includes reporting on economic activity, human development, environmental impact and accommodation of cultural differences and reflects the changes to accounting practise and investment criteria started in the first decade of the 21st century. This is a shift in emphasis for most well established businesses and requires that policies and legislation change globally if bigger picture planetary-wide goals are to be achieved.

1.1.4 Increased globalisation

The scenario assumes that the pan national agencies remain and are added to (*e.g.* WHO, FAO, UN, APEC, ASEAN, the World Bank, WTO), and that pan national agreements/conventions are more common and varied in composition and drivers (*e.g.* Kyoto, Free Trade Agreements, Convention on Biodiversity, Indigenous rights, patent, trademark, copyright, International Energy Agency, World Court, International Monetary Fund (IMF), space exploration, whaling, ocean and coral reef conventions, life cycle analysis standards). They have more power than previously and there is growing pan national consensus and use of common standards. This is because a generation has grown up with ease of information access through electronic media, and they have seen cause and effect very explicitly and understand the global connectedness of activities, often through their own travel or connections. They also have facility in using and interpreting electronic media and have close friends or family who travelled widely. Enforcement of rules is driven by penalties such as loss of markets, loss of status, isolation, local legislation to empower these. Breaking of rules or consensus agreements is easily captured through "whistleblowers" and electronic communication. The scenario assumes that companies and investments are global and choose where to base and where to operate.

1.1.5 Generation Y dominates

Immigration flows and travel are still relatively unlimited, depending on nation and economics. Demographics follows predicted trends to ageing populations, lack of females in key Asian countries, better education more widely available, including self education, and greatest people density in Asia.

Generation Y (GenY) is now in its prime and a major influence on world politics. Critical aspects of this generation are global thinking, e-communications and internet facility of use, a passion for sustainability and comfort with technology and risk taking. But, GenY in Anglophone/western

countries differ from those of the same generation in developing countries in experience, indicating GenY expectations will not apply globally. For example, a child in the European Union has been surrounded from birth with information and electronic access to worldwide thoughts and developments. They participated in adventure activities, had reasonable wealth which is generally taken for granted and have watched the growing concerns relating to mans impact on the planet. In contrast, a child in a developing country has experienced or observed the benefits of increasing wealth and education, may or may not have had any access to world-wide information, is likely to have experienced or have someone close to them experience hunger or preventable ill health, and security of income may override participation in global concerns relating to the environment. In many such places societal values relating to life and the natural environment differ extremely (*e.g.* aphrodisiac wants, human dominance, family versus individual or national identity, female versus male). Lastly this scenario assumes that societies' triple/quadruple bottom line is a key driver alongside security and national stability for development of industrial biotechnologies and their embedding in economic activity.

1.1.6 Historical developments that enabled "Steady as She Goes"

Cheap Manufacturing and Risk

Key enablers for **Steady as She Goes** were as follows**.** From 2004 onwards the price of petroleum increased to remain consistently above USD 40 per barrel. Production of commodity consumer goods (including foods) moved from developed countries to cheaper developing countries. Labour costs and economic inducements drove production using non-renewables in the developing world. This was merely the transfer of a global problem, and ultimately an intermediate step. In the developed world penalties increased for carbon unfriendly practises and resource wastage. It was led by countries whose manufacturing had moved to cheaper places with greater available work forces. At home the ageing middle class population was prepared to pay more for non-economic aspects of goods and for security from fears about toxic or other dangerous practises in less developed places. They were risk averse about "not made/done here", especially where it could be demonstrated that human health could be affected. This became embodied in testing of materials and setting of standards for imported goods. The penalties became a new trade barrier, but also provided leadership in changing attitudes. This combined with increasing competition for petroleum and other non-renewable energy resources. However to modify human behaviour globally, the developed world needed to provide options to incentivise the developing world NOT to follow old practises. Among the solutions was training in new technologies "at home" as well as in the parent country, free key technologies funded by global philanthropic institutions, partnering between regions, companies and/or nations, and trade barriers specific to extreme polluting behaviours by manufacturers.

Exploring Bio Options

Between 2005 and 2015, differing initiatives globally encouraged various experiments on energy options which included industrial bioprocessing to augment profitability. In one large national grouping a well thought out and integrated approach was taken, with an initial focus on production of biodiesel. Governmental incentives and penalties relating to use of bioenergy lasted until 2020. In other OECD nations governmental directives and/or directives to government departments to purchase fixed amounts of carbon friendly products were enacted. Multiple development initiatives took place through the availability of large amounts of private investment dollars either by wealthy individuals (to be early winners in new technology discovery) or through pension schemes aiming at long term returns on investment. Globally, alternative non-bio options were also explored and technologies developed that combined bio components with non-bio options. Wind, solar, geothermal, gas, clean coal, hydro, and nuclear options were all explored again with fresh eyes alongside all bio-based possibilities. As all technologies had unsolved issues, decision-making on the best options to follow were fraught and varied because it was unclear which breakthroughs would

occur and which would remain challenging. However multiple combinations ended up being successful, no one result dominated globally.

Overcoming Bio Challenges
Among the biggest problems identified for adoption of biobased technologies during this time were: biomass resource availability, biomass conversion technologies, target bioenergy and efficient and cheap enabling technologies. Smart nations or investors who established collaborative partnerships with the bioenergy rich countries were winners. This was because the best partnerships (and wealth creation) were those that combined plentiful resources with those that had the most invested in advanced technologies – and the partnership ensured national survival and relative independence in an environment of limited resources and competition for these. Those who developed diagnostic and measurement systems that allowed reliability for bioenergy options were also winners. The diagnostic and measurement technologies were adopted by mediation companies who became certified to operate out of the International Court and were employed in solving disputes.

Carbon Trading
The failure of use of biofuels for transport in two large countries was due to lack of an internal quality assurance system. This had a big impact on speed of development of sustainable solutions in those countries and they lagged behind in carbon credit accumulation. Carbon credits were traded on stock exchanges and the internet and between governments, using the criteria for definition of a carbon credit agreed upon and signed up to by a majority. Mediation in disputes was again through the International Court, and as trading grew over time, and substituted for dollars in many instances, those without credits lost wealth and struggled to compete.

1.2 Alternate Scenario - "Urban World"

1.2.1 Difficulties in responding to rapid change

The Alternate Scenario "**Urban World**" describes a world where climate change has occurred faster than predicted and where biotechnology has been supplanted by non-biological approaches. Development of a local energy resource has been driven by security needs and speed to a solution. Biorefineries could not supply biofuels cost-effectively within 10 years and investment moved to non-biological research following breakthroughs in both solar and nuclear energy. Coal continued to be used in developing countries as a ready source of energy to develop quickly as manufacturers cope with increased demand, and pollution grew rapidly.

Legislation and policy has been driven primarily by local concerns over the past 30 years, and is generally not well connected globally, although there have been many international meetings and rhetoric to indicate alignments. Societies were resistant to change and demanded continuation in the choice of consumer goods and security of lifestyle. Education became undesirable in biological disciplines except in some places where biology was a source of advantage. Science in general was not really favoured for study compared to social sciences and arts.

The changes in climate have pushed large migrations to cities as the countryside has become harder to survive in. This has forced a demographic shift in the balance of power meaning that cities are more powerful than nations and alliances are forming that combine and complement individual city strengths. Asian cultural practises are starting to dominate society and global interactions in business and politics.

Unfortunately the setting aside of biological reserves has not been enough to compensate for society's impact on the climate and these reserves are also undergoing rapid extinctions (and where species can

cope – evolution). It is the most appealing area of biological research for many. But synthetic biology offers some hope of preservation of diversity through access to DNA databanks. Industrial biotechnologies are focussed on production of bioplastics and products using them, and modifications to bioplastics that enable them to be recycled in different ways. Environmental technologies, bioremediation and bioleaching and microbial sciences predominate. This scenario describes a snapshot of what might be the consequence of the impact of more rapid climate change than predicted and a decline in business opportunities within biological sciences. Other trends used to describe "**Steady as She Goes**" remain.

2. Baseline Scenario – "Steady as She Goes"

On December 31, 2030, the second global lottery draw for a year's worth of carbon credits to offset a community-based debit resulted in a win for a town of 20,000 in Indonesia. Tagged to the credits was a "help" package to assist in turning the community into a carbon credit rich unit. The internet was a key enabler of the lottery draw by being available to communities globally using satellite wireless technologies and portable biocomposite computer modules powered by biobatteries.

2.1 Carbon Credits

The credits, offered by the World Bank, were based on the Swiss Gold Credit standard and were sourced from their investments in forests in Brazil. These investments were the result of a deal between Brazil and the World Bank to allow the World Bank to manage the Amazon and other regions to prevent deforestation of the natural forests. Brazil, in return, benefited from investments that led to Brazil being one of the first carbon credit economies. Similar financial partnerships to manage key natural forest and wetland ecosystems have also been initiated in parts of Africa and Asia, sometimes as a direct deal with mining or logging companies with governmental and NGO oversight. Carbon credits are traded through e-auctions and the e-trading arm of stock markets.

2.2 Urban Sprawl

Globally, urban sprawl is still a problem in combating climate change and in realising energy and bio-based product solutions to reduce carbon emissions. Cities have been identified as a major source of greenhouse gas emissions due to development of their infrastructure over a long period of time (and/or rapid unplanned development) leading to many inbuilt inefficiencies with respect to energy, water, waste, construction and movement of people. Cities such as London have huge investment in housing stock developed over centuries (energy inefficient and environmentally unfriendly), whereas those in the New World such as Los Angeles were developed in a time of abundant fuel supply and lifestyles that embraced personal transport systems. Hence tackling reductions in environmental impact is still fraught and, without total destruction, the challenge is to modify existing infrastructure and way of life. Initiatives in the developing world, however, have demonstrated ways to succeed through adoption of community-based solutions. Here recent urban slums have been removed after new planned neighbourhoods have been built using closed-loop concepts. For example all waste is reutilised within the neighbourhood, there is a localised energy supply mixing waste, wind, and sun, and water is recycled.

The European Union has chosen alternative approaches that utilise the long established urban areas and close knit living afforded by these. Here building and neighbourhood redesign has emphasised efficiencies and biobased materials have replaced many internal structural components. Windows are designed to maximise the diurnal efficiency of light energy inputs to reduce heating and cooling costs while maximising wavelengths that are used by plants for photosynthesis. Plants are grown indoors to

balance carbon and other volatile emissions, and to provide some foods (an internal allotment with recycling systems). Interior walls and structures are made of advanced biomaterials and are entirely removable, redesignable, and recyclable to adjust to the needs of different tenants. As buildings fail (either through fire or deliberate destruction) replacements are only built that have passed rigorous design requirements. New design options are being trialled throughout China in a major effort to maintain its global dominance as a provider of manufactured commodity consumer goods while reducing carbon debits and the consequences of pollution that could cripple the economy over the coming decade. Tourism has declined in China and surrounding areas and pollution is having a major effect on neighbouring countries such as Japan, Korea and South East Asia such as Malaysia, Vietnam, Taiwan, Philippines and Thailand. The China Sea is one of the most polluted bodies of water on earth, and this is now extending. The need for solutions is regarded as urgent.

2.3 Pollution

Environmental technologies have helped in cleaning eutrophic lakes in some wealthy countries and the algal blooms have been cleverly harvested to use as biomass feedstocks in some instances. A major pan national (Russia, Estonia, Finland, Poland, Latvia and Lithuania) effort on managing the algal blooms in the Baltic Sea is about to get underway. The algal blooms first originated in the late 20th/early 21st century due to increased sea temperature, growing urban household waste disposal directly or only slightly treated from cities and towns near the water's edge. Further contributors were increased intensity of land use requiring higher fertiliser use with concomitant increased nutrient run-off, increased economic development in the former eastern bloc states, and greater sea traffic. The first microbes developed to sequester various environmental toxicants, such as those associated with urban pollution or household waste, are now being reused in biorefineries to make new products. For example, microbes designed to capture waste iron are now used to manufacture new catalysts that remediate polluted waters.

2.4 Investments

Government incentives/regulations and local resources relating to bioenergy and establishment of biorefineries have played a large role in the success of some larger nations, and also in smaller nations with advantageous climates and land or alternate ecofriendly resources. These have contrasted with other large or small states where private investment and poor resource options and/or planning created haphasard and variable results. A large temperate-subtemperate nation has taken advantage of the warming due to climate change and the chance to grow new industrial crops on new land by becoming a major biomanufacturer. Parts of the Middle East and Northern Africa have remained among the most underdeveloped group of nations, exacerbated by the increased desertification and changed rainfall patterns. However, in some places reinvestment of 20th century petroleum earnings has allowed artistic development (*e.g.* new architecture, computer innovation software, astronomy) and non-biological approaches to energy needs and climate change opportunities (*e.g.* solar, underground sequestration of carbon dioxide in appropriate strata) to flourish. Clever technologies relating to water and its reuse and value extraction are being trialled on both a large and small scale. Parts of large Asian nations are still relatively poor.

Box 1 - The small isolated temperate-subtropical country with multiple resources success story

By 2030, this country had an independent multi-energy system and had moved from full petroleum importation to zero for transport uses. It had previously sat near the bottom of the OECD table of wealth in developed nations due to isolation, high importation levels and a biological base. A blend of wind, hydroelectric, solar and biofuel supplied 100% of the nations energy needs. Because the population was not dense and, spread across the country mass centralised energy solutions were not possible.

The government managed all energy through a centralised system of contracting. This is because a complete openness to market forces had failed in the past with monopolies developing stifling and controlling alternative approaches. In particular, undercutting strategies were used by external financial investors to remove particular technologies from the package. These were not to national advantage in the longer term and essentially removed competition before technology was sufficiently developed. Heat and electricity were provided by a combination of hydro, wind, gas and solar means with augmentation from biomass sources as a backup. Converted pulp and paper mills provided 70% of biofuel for transport needs using a combination of chemophysical technology and enzymatic/fermentation processes; the remainder was sourced from small built for purpose biorefineries that produced biofuels as a by-product from waste and specialised feedstocks. Paper production for global needs shifted to Asia and South America. Converted pulp and paper mills also became the site for industrial bioprocessing of bioplastics and lignin and tannin derived materials leading to substitution of a significant segment of the country's chemical imports. Because there was a large amount of land, a small population, a climate that was advantaged by the climate change predictions so plants were easier to grow, a biological skill base and a relatively high level of education among the population, the alternate measures were easily adopted once petroleum independence and biological substitution of imported chemicals was established as one prong of a sustainable nation initiative by cross-party consensus – an agreement across political boundaries that some initiatives are necessary.

A well established carbon credit trading market was the place of choice for global trading. Transgenic plantation trees and cellulosic energy crops formed the basis for biofuel production and genetically modified plants were well accepted for non food purposes. The population enjoyed improved health options due to investment from nations that needed access to bioenergy and gave special access to preventative diagnostics. Size meant that initiatives could be enacted nationally and with the new wealth, the latest globalnet technologies were used to

2.5 Societal Goals

2.5.1 Awards

Other initiatives converged to assist the success of industrial biotechnologies. Several eminent global prizes were established by a consortium of green investors for sustainable community and building design. These built on the interest and need for new thinking to predominate among architects and town planners – both for commercial buildings and home housing. In particular three key awards were established for options specifically targeted at subtropical and tropical environments, and three awards were directed towards cold climates. In both cases, renewables and efficiencies featured as important characteristics. Energy efficiencies and use of bioplastics, fibres, bioresins, nano and bionanotechnology derived materials, clever (bio)sensors and smart glass structures (*e.g.* window or wall/roof designs that adapt to heating and cooling needs while allowing the photosynthetic spectrum to reach plants or algae that capture carbon dioxide and produce biomass supplying food or other values) have been integrated into building design. Some of these materials have been made locally using waste recycling and industrial bioprocessing. Environmental biotechnologies and waste management integration into neighbourhood design have played a part in the success of awardees.

These helped to bring to the fore several technologies and options that had been present in many places but had not been taken up by the mainstream building design and planning teams globally. In addition, major cities in the European Union put in place legislation to ensure sustainability aspects were required in order to build new buildings, and to make over (retrofit) older buildings over a period of 15 years.

In light of a global focus on biological issues and the environment, the Nobel Foundation announced a new prize – the Nobel-Gates award – for sustainability and contribution to minimising Man's impact on the planet's resources. The first award was given in 2025 jointly to the scientists who coordinated and designed the global climate change models and the forward thinking global green investor Grundle. In 2028 Smith from McKinsey won the Nobel Prize for economics for his early futures work in industrial biotechnologies.

Box 2 - The large tropically situated developing country with resource advantage and a head start success story.

As the world moved to bioenergy and alternate transport technologies, this nation had already established the ability to be self sufficient in transport needs and 80% self sufficient for heating and electricity. Solar energy and biomass were the most critical resources. The climate was ideal for cultivation of all forms of energy crops and most biomass development companies based their commercial field trials here. In particular transgenic technologies were welcomed. Early export of biofuels and early formal partnership with two mature manufacturing companies from a major intellectual property generating nation with excellent experience in intellectual property management contributed significantly to the current success. This was because there were wider diplomatic alignments and influence needs that were useful in global fora. Related technologies such as vehicle development also became success stories.

The government made smart decisions and united the nation, legislatively supporting development of local skills and implementation of bioenergy options in a planned manner. Regions were set aside for farming for food initiatives, with residues being used to provide energy for farming operations. Other regions were used for energy crops and infrastructure was established at critical spots in a planned manner.

Native forests had regenerated and ecotourists formed part of the financial support, using carbon credits as payment which allowed key areas of land to regenerate. Assistance from various world institutions ensured resources remained available for future generations and global companies invested in development of technological options.

The country was a test bed for biotechnologies for bioenergy application, and there is active investment in second generation biofuels. Alongside this, biorefineries have appeared in the bioenergy regions and a number of these manufacture platform chemicals for further modification or export.

The large population is relatively young and is now in its productivity prime. Innovators abound due to proactive education systems and global networking that was put in place. Legislative initiatives required investors in the country to contribute to education and health needs and to establish capital investment funds for local companies with profits from bioenergy sales.

2.5.2 GMO technologies

Genetically modified organism (GMO) technology used in industrial biotechnology processes has been accepted everywhere. This is because most processes are contained, microbes used have also engineered non-resistance to soil or aerobic survival, or markers have been incorporated to allow easy detection of escapes. GMO biomass feedstocks are either not considered an issue, or else an easy detection system has been inserted and the ability for sexual reproduction has been removed. In one or two wealthy nations food crops such as maize, soybean are the exception and must be non GMO. Here, if GMO material is used, biorefineries must use non-food feedstocks such as trees, grasses, weeds. In general, plants have been genetically engineered to capture maximal carbon with maximal growth rates and minimal fertiliser and water requirements to ensure sufficient biomass supply. For example plants may have nitrogen fixing metabolism and phosphorus uptake mechanisms sourced from microbes added to their genome alongside enhancement of carbon dioxide capture and metabolism for rapid growth and increased drought or heat resistance.

2.6 Biorefineries

2.6.1 Economic success

Several nations were totally self sufficient for energy and had completely substituted petroleum and fossil fuels with renewables. These nations had moved to export of excess biorefinery products, including biofuels and/or chemicals, as well as new bio-based products, and were carbon credit rich. They exhibited the fastest growth rates in the period 2025 to 2030, and were seen as the new economic success stories. Between them they had discovered and established intellectual property and processes to make new chemical resources that were either, very difficult and expensive to synthesise using petroleum and traditional chemistry, or were totally new compounds formed by biological (enzymatic) catalysts. Key drivers were government incentives such as those established between 2010 and 2015 to develop sustainable businesses with low environmental impact. Tax breaks were available for companies developing relevant technologies, auditable quadruple bottom line reporting resulted in lower taxation levels, and priority was given in tendering processes for demonstrated beneficial ecological footprints.

2.6.2 Technology development

The presence of a close-by and readily available optimal biomass resource (*e.g.* lignocellulosic or algal), as well as development of, or access to intellectual property, leading to high value new products was a critical component of success. A choice of low CO_2 and low pollution non-biological energy sources for heat or power also favoured success. Breakthroughs in conversion and purification technologies and acceptance of GMO biomass feedstocks have had a large part to play in the current buoyancy of industrial bioprocessing. One example was a breakthrough in the ability to concentrate biomass cheaply by removing water. Another was development of catalytic technologies that can treat any material, including those with metal components and water, and convert the material to gaseous or simple carbon molecules with only minor amounts of concentrated waste. Other key breakthroughs included enzymatic processes that provided a tenfold improvement, compared to 2010, in the efficiencies of conversion of biopolymers, and aqueous processes for extraction and concentration of materials/products of conversion processes.

The nations with successful bio-based economies promoted collaborative partnerships with investors and inventors who needed either carbon credits or renewable energy to implement technological discoveries globally. In the self-sufficient nations, there was active cross-licensing of intellectual property to share access to new technologies for industrial biotechnological manufacturing and

biorefining. Biorefinery design was holistic and included "neighbourhood" design characteristics such as recycling of water and other waste streams to become zero waste entities. This was because environmental impact and sustainability were key drivers in successfully steering through governmental regulations on establishing new business operations, and global advantage in selling products with quadruple bottom line accounting. Many nations had placed trade hurdles for products that had overall negative impact on the environment and climate change.

2.6.3 Product options

Biorefinery design has differed according to location and investment and mix and match options. Some, particularly those established early, have focused on biofuel as the main commodity product with a secondary sales based on co-products. The logistics associated with the biomass to bioproduct value chain has been a critical factor in the economic success of these. These have tended to be large biorefineries. Other biorefinery development has depended production of a few key high value products with biofuel as a secondary product. These vary in size of operation. Small biorefineries with mix and match modules are now being developed for poorer nations, particularly for use of waste as a resource. Some inventors have explored mobile biorefineries, but these are not yet in operation.

In the poorer performing nations/companies, various scenarios occurred caused by a range of factors:

- Either broad based quality assurance schemes (*e.g.* bioethanol purity, absence from toxic contaminants in bioproducts, biorefineries themselves caused major pollution problems) were unable to be enacted, or;
- the region was too bare of alternatives but still petroleum/alternative energy rich (independent and secure but not biobased), or;
- piecemeal independent solutions were in place so no advantage due to consistency of approach and strategy was possible (*e.g.* a mishmash of biodiesel, biobutanol, bioethanol of varying qualities produced, or small quantities of high value chemical produced but with varying qualities).

In many instances bioenergy options were incompatible with commodity traded technologies, or with products such as new vehicles, or else bio-substitution of a product was not able to be engineered due to performance standards. By 2030 China is a leading producer of polylactic acid (PLA) based commodity bioplastics and platform chemicals in biorefineries, but development of biorefineries has not been approached holistically and environmental impact is relatively high through both the biomass supply chain and biorefinery operations. Water pollution is still an issue.

Box 3 - The large densely populated region with temperate-cold climate and minimal resources and strong legislation and technological know-how.

Here personal vehicles and air transportation are almost obsolete. Multiple types of electrified vehicles, augmented with bio batteries in case of electrical failures, circulate underground and above ground connecting high density population units. Vehicle design is modular and most components are biodegradable or recyclable although much of it is imported from regions with biological richness. Roadways are reducing in density and some are becoming eco-corridors for leisure activities and to build carbon credits through new plantings of trees. Walking has been rediscovered, and health problems in the older generation are decreasing.

Buildings are state of the art, multi-storied, multi-tenanted, and form independent energy modules, based on conversion of waste, solar entrapment and efficient building design. Legislation has enforced all materials and products used to be biocompatible and sustainable, and older buildings to be redesigned. This supported development of new biotechnology based industries locally using environmental and industrial biotechnologies to supply products. Some basic elements of food are locally grown but supply only 10% of needs; the region has therefore formed trade agreements on a favourable basis with a bioenergy rich and a food rich nation. This has reduced risk of lack of fuel and food supply. Some building entities trade or exchange benefits with others. Almost all urban buildings are owned either cooperatively by the tenants (leaving shares behind when departing) or by the government, and also contain resources for physical activities and social interactions. Group ownership of buildings was increasingly favoured because it could provide moderately priced housing while meeting stringent technical requirements for building design, quality of construction, and resistance to extreme weather events.

Taxation systems strongly support initiatives that create further sustainability and development of bioentrepreneurs. The central government provides energy resources for business and government. Connectedness is through the globalnet and only 10% of people travel widely. Children are treasured and education promotes philosophy, the environment, community thinking and similar priorities. The population is very mixed ethnically as a result of multiple migrations (both in and out) and there are no truly poor.

2.7 Transportation

Transportation varied according to the opportunities within each region. Where there were large concentrations of people – electrified public transport systems predominated, using vehicles that were at least 70% biodegradable or recyclable. Such vehicles were lighter and more fuel efficient that the 20th century car. Electricity was generated locally through waste conversion systems associated with household and industrial rubbish. Such systems were a key part of new building design in densely populated centres such as in the European Union. In successful situations, governments defined the priorities for electricity usage between local building needs and transportation needs, and interfaced local with intercity transport. Only 30% of such populations now owned a private vehicle.

Where populations were more spread out, and less dense or in smaller communities, individual transportation and cars still remained important. However vehicle design differed. Vehicle engines were compatible with a range of energy sources, body parts were all biodegradable and lighter but stronger. Emissions of greenhouse gases and toxins are half of the global average in 2000. Emissions still come from vehicles using petroleum as a fuel as society transitions to new inventions. Kits with immobilised microbes that can capture toxins such as CO and heavy metals and survive in the engine-exhaust systems of vehicles are being trialled in three countries, as are microbe kits that can be used to clean air in housing associated with traffic corridors.

2.7.1 New vehicles

The new multicar is now being built in satellite countries close by major wealthy nations and in ex-developing countries by the new car manufacturing company that grew out of mergers between Volkswagen, Toyota and Bhanod (a new car manufacturer based in India). The goal is to manufacture globally in each country by local producers. The multicar features:

- solar-framed biobatteries embedded into its body;
- body parts completely manufactured using biological materials, and;
- the ability to switch between at least four energy sources (*e.g.* electricity, bioethanol, biodiesel and methanol).

Speed and efficiency controls are an intrinsic part of design, as is global positioning system (GPS) and driverless steering, both using bionanocomputer chips.

Box 4 - The large temperate/subtropical/subtemperate country with multiple resources but with environmental limitations and free market approach story.

Different regions have adopted different bioenergy solutions which are often incompatible with neighbours. Biomass forms the basis for energy solutions in about 50% of regions, but nuclear power and petroleum are the basis for the remainder. Biomass resources and biofuels generated also differ and cars locally get makeovers, both for use of renewable fuels and in environmentally friendly componentry and emissions reduction. Transportation systems do not connect uniformly and the same vehicles can only operate across some of the regions. Legislation across the country only requires that regions attempt to be sustainable and can trade their way to a zero balance. The hands-off approach has led to competing technologies and companies, and inefficiencies in infrastructure development. Infrastructure was developed in different regions without coordination – some required that bioethanol be transported long distances, in others the biomass was transported; water excluding systems were required for bioethanol storage, but not for biobutanol storage. Many companies became bankrupt in the fight to win, and local legislation has often allowed a particular technology to survive. The fight to win has involved definition of impurities in the biofuel, and unfortunately different feedstocks result in radically different impurities. Process technologies also impact quality standards. The country still exists on earlier advantage.

Air flight is standard and people travel generally by plane for any distance. Cars made from metals are still driven in some areas and obesity is rampant leading to a declining demographic in age survival. Technologies supporting the elderly are starting to be more unevenly distributed and the gap between haves and have-nots has grown. Many other health issues are becoming apparent including poor nutrition. Overall the government has turned the country inward to aim at self sufficiency and security and barriers exist at the borders that make it a privilege to enter. The population is starting to decline. All food is produced internally and is highly processed and migration is kept low. While connected to the globalnet, connections are monitored and policed. Decreasing numbers of entrepreneurs arise and quality education is hard to obtain.

Many legal cases are waiting in the courts where IP has been ignored and deals broken. Individuals have insurance cover for travel as well as health and globalnet infringements. Those travelling outside the country are often legal representatives protecting national IP. Trading externally has reduced and per capita GDP is also starting to decline.

Second generation lignocellulosic biofuels (ex-wood, bark, leaves and other resinous material) are being compared between different countries (testing for impurities and potential toxins) following relative success of cellulosic (stalks of crops and leaf materials often mixed with starch) technologies in effectively using 90% of the available carbon in conversions. Engine and structural components have been redesigned and spare parts are manufactured by composite/bioplastics companies locally using computer-aided design and manufacture. Panel beating is a career of the past. Rubber used for tyres is now supplied partially by biorefineries using a latex biomass resource, partly by traditional means, and new *in vitro* synthesis (synthetic biology) processes are being trialled at prototype level. This has also allowed new rubber design and tyres which are longer lasting and biodegradable when placed in the ground.

2.8 Trade

Global trade shifted in favour of the bioenergy rich/smart nation partnerships. The OECD list of developed nations now contains several new members, including Malaysia, Vietnam, Brazil, and China. Smart nations had large investments in bioenergy/biomass rich nations, and developed many of the technologies used to supply bioenergy or run biorefineries. Several petroleum moguls had invested heavily in alternate biotechnologies and by 2030 had transformed into biotechnology companies, while still controlling access to particular petroleum resources and technologies. Those wishing to invest in further petroleum and coal discoveries were discouraged by political penalties in developed countries and focussed their attention on the poorest nations with potential fossil fuel resources although expensive to access and the oceans at their doorstep giving access to undersea resources of the economic zones. Exploration has required technology development, both in discovery and in mining in adverse conditions.

2.8.1 Consumers and their impact

In the newly developed countries that supply the majority of the world's commodity consumer products, many people were extensively exposed to new environmental toxins and weakened immune systems have caused a myriad of new medical and economic productivity problems. Infertility is on the rise and there are strong tensions between the price of food and the price of energy internally. Food is exported from nations that chose to concentrate on food production and remained GMO-free, but consumers with the ability to pay are rare as the prices of production and transport are high, and those same consumers are also very conscious of the environment, quadruple bottom line accounting, and life cycle analysis. This strategy is failing and these nations are becoming impoverished. Heavy subsidies are present in both food importing and exporting countries but they are increasingly penalised globally for taking that route. In some newly developed nations the population demographics now show signs of reversing, with decreased births and earlier or unchanging ages of death due to environmental issues and lack of preventative health care. The ability to undertake exercise has been impeded, because the population density is too great, external environments are polluted or "boring". Access to buddy systems for encouraging exercise, or access to facilities is limited by income. Due to the small size of living environments and the high quality of public transportation, it is difficult for older people to maintain an exercise regime of even 5000 steps a day.

The first human food generated by production in vats and algal "blooms", and then converted to protein/carbohydrate rich foods with augmentations of minerals and vitamins, was launched successfully in 2027. Bioenergy and alternate energy sources as well as other industrial biotechnologies have been a key feature in the affordability of these new food products, which can now mimic real meat sources. At least 60% of animal feed was generated in the same manner by that time. Ironically, while targeted at the poor, demand caused price increases so that only the wealthy nations could afford it. Artistic food is the new fashion, designed by top designers and combines

shapes, textures, flavours and appearance from a basic "food" mould. The IMF and the United Nations (UN) are contemplating stepping in and building vats in food-poor nations. Nations are food-poor for various reasons, the major ones being factors that limit crop productivity such as desertification and salination of soils, and extreme weather events including natural "disasters". Global food security is exacerbated by the significant amount of agricultural land that is used to grow livestock feed for the production of meat and dairy products for wealthy consumers.

At least 30% of new products traded in 2030 have relied on industrial biotechnologies for components. The new personal diagnostic kits "lab on a chip" that are being trialled in 20 different nations have relied heavily on industrial biotechnology manufacturing processes. Enzymes for DNA extraction in a tube and chips using specially designed and engineered bioplastics are two key industrial biotech products used in the kits.

2.9 Connecting People

Free education is available globally through the globalnet and portable biocomposite computers. Skills in searching and evaluating information are prized, and most large companies employ futures departments. Futures activities have become embedded into education and political decision-making. English is still the global language for communication, but Mandarin/Cantonese and Spanish are equally used and most travellers and business people have skills in all three. Often these skills are sourced through bionanotranslaters attached as earrings.

Individuals still use air travel and although aeroplanes are now considered one of the major sources of green house gas emissions, they use carbon credit cards as acceptable currency in return for seats. Carbon credits as a tradable currency was first established in 2023 by businesses needing to balance the sustainability books. Planes now fly only over wide ocean or land tracts and no longer feature in densely populated areas such as the central European Union.

2.10 Global Initiatives in 2030 and Beyond

Greenhouse gas emissions globally have not reduced sufficiently to start climate change reversal. Debate on sustainability of the planet has increased and is a key strategic component of national and international elections to governing bodies. Pollution, as opposed to greenhouse gas emissions, in some areas of the world (both water bodies and land mass) is more than 10 times greater than 2015 levels. Some of this increase is due to delayed appearance or understanding of significance of impact on the environment (reminiscent of the days of enthusiasm for PCBs and asbestos and computer parts using beryllium and mercury) and to the use of large landfills and ocean dumps of non biodegradable waste until 2015. The oceans are suffering (pollution as well as acidification from lack of reduction in greenhouse gases) and extinctions are occurring more rapidly. New global initiatives are under discussion, and are being debated over the globalnet across national boundaries. More than ever it is clear not enough has been done and several parts of the planet have now become increasingly uninhabitable, causing even more pressure on urban environments.

3. Alternate Scenario – "Urban World"

In midsummer 2030 representatives from all the giant cities met in Beijing for their annual meeting. They rival the G7 of 2010 in power and influence, as they represent 70% of the world's population. The city "nations" established their annual meetings in the mid 2020s as it became clear that they all had similar problems and threats to survival:

- increasing slums and poverty;
- inability to keep services functioning;
- pollution;
- pandemics owing to density of populations, and;
- increasing population pressure.

Most people in cities provided "services" and generally operated as small enterprises trading their skills. The office is in the home, and housing is high density above and below ground. Due to lack of action in the first and second decade of the 21st century, contributing factors to global climate change, such as greenhouse gases, continued to be produced in escalating quantities. Furthermore, the movement of people and impact of migration has been much greater than predicted. Policies and agreements on climate change and resource exploitation (including ocean habitats) – both local and pan-global - were "hands off" and non binding and by 2015 there were new concerns relating to the balance of economic power, and patching up local problems. Generation X predominated in the western world and this meant consumerism became a major driver for economic activity until the crash of 2024 when it became apparent that wealth was concentrated among only a few. People no longer travel much around the globe.

3.1 Impact of Climate Change

Large areas of the world have become uninhabitable through desertification, flooding, and destructive storm cycles, causing migration to cities that are not exposed to threat. Due to positive climatic feedback loops, sea levels rose several metres – at the high end of Intergovernmental Panel on Climate Change (IPCC) predictions in 2010. Venice collapsed in 2027 and Amsterdam flooded. What was left of Bangladesh merged with India, and the Mekong River spread across huge areas of delta lands making them uninhabitable. Spain has only a narrow inhabitable strip around its coastline, while Madrid is one of the major city states. Several Pacific and Caribbean island nations have vanished completely. New York has been surrounded increasingly by high-tech dykes that may be difficult to sustain if the trends continue, and the population is shifting to the mainland. Washington, DC is now the second largest city in the United States due to the shift of populations from low lying coastal areas to the higher land in the Maryland suburbs. In several places it is no longer possible to grow crops due to both spread of diseases and lack of nutrients for growth. Pollution has also affected the air and ground water and forests have been dying. Other natural environments are changing rapidly; coral reefs, in particular, are dying and species diversity is reducing. New nuclear power plants have been built in many places to power the cities, but uranium supplies are tightly held and jealously guarded. Cities have become home to a melting pot of nationalities and languages, computer and artistic skills.

3.2 Education

In the early century, the biological revolution was closely linked to sustainable thinking. This has been abandoned, although there are several commercially successful applications of biotechnology, particularly in a few biotech city states. The application of biology to sustainability was discredited by insufficient technological breakthrough, despite promises and expectations, and through a lack of scientific researchers passing through the education system to renew the effort. Those who are sufficiently educated are focusing on the new challenges of synthesising uranium from more common elements, or making fusion work. Survival has become more important in people's minds, and policies reflect this. Understanding the natural world and weather became favoured study choices for those with a biological bent, and the establishment of a large number of ecological reserves was believed to be the best approach to stabilising the climate and impacts of man's activities. Farming and healthcare are not desired careers and pay poorly, as does research pertaining to these, especially after the spectacular collapse of the "big pharma" business model in 2015.

3.3 Investors

Major investors who poured money into biological options ("green investors") failed to find sufficient success to be worthwhile and investments began shifting in 2015 to new technologies for uranium exploration, re-examination of the challenges of thorium based energy generation, petroleum exploration and new technologies for housing in cities. They also invested in solar solutions for energy and discovery of more ways to use silicon as a base material. By 2030 research was escalating to make greater use of geological sources of materials to create new minerals and carbon. Some success has been obtained in sequestering carbon dioxide in a non-gaseous form in underground strata as a means of greenhouse gas removal, but it has not yet been transformed into a usable carbon based resource again through newly emerging technologies discovered in 2029 that can substitute for the processes and pressures causing liquefaction and carbonisation underground. The sequestration technology is only now being trialled on a large scale over a 10 year time frame to see if it has any impact on global reduction of green house gases, with trials located under some of the deserts and mountain ranges in three parts of the world. The shift to non biological investment was part of the backlash on the failure to discover viable cost effective solutions to producing bioenergy, harnessing bioprocessing or tackling environmental problems in the right timeframes. It was also due to a lack of overall investment in R&D.

3.4 Trade

China has become a dominant economic force, and now is one of the biggest power brokers. This was partially based on the long-term framework it naturally occupies in strategy and thinking, family loyalty, and partially due to the rapid riches built in the first two decades based on manufacture of commodities for the world. Production was kept so cheap that even sanctions and trade hurdles didn't quell growth. Patents became too expensive to maintain and impossible to prosecute during that time, as copying was easy and proof of validity of variations too expensive to defend. The World Court vanished as its only value was in prosecuting war crimes (not economic), and legal contracts between "partners" declined in number. Loss of patent protection was another contributor to the failure of biotech solutions. Since then investors and developers have maintained tight secrecy on inventions and first to the market position became more critical. This behaviour has fostered a wealth of know-how around secrecy and stealth, including eavesdropping, Internet leaks/reach-in, hacking technologies and processes, and continual monitoring. New professions relating to industrial spying and protection and ability to copy proliferated between 2020 and 2030.

Asians (particularly Chinese and Indians) who spread across the Pacific Rim over the past 50 years are now wealthy power brokers in the city alliances that predominate instead of individual countries. This is promoted by the merger and absorption of nations into larger entities with an independent identity. Mixed Asian-European or mixed Asian-Asian leaders now manage the city states across the globe, and are counted among the new rich. Many have invested in the arts that make money (*e.g.* film, avatar alternate worlds on the internet, fashion), others invest in infrastructure and food supply, controlling large proportions of basic starch and protein sources, produced in much of the non reserve land of the tropics and new subtropics and temperate areas arising from climate change (*e.g.* from 35^0-50^0 latitude). The shift in balance of the globally rich from the European Union and the United States to Asian economies is causing a shift in the way business is carried out. Adversarial approaches to law and short term partnerships in business are now declining. Diplomacy is critical to success in both business and politics, as trust matters more than legal agreements, and face-to-face meetings and social interaction are essential for success.

3.5 Society in Biological Alliances

Several city alliances retain the biological know-how built earlier and still have biological resources. They have been quietly working and using it to advantage – but for substitution of imports rather than for export – in an attempt to become globally independent. They also supply the small food market that can afford "real food" such as fresh fruit and vegetables. They farm fish as the predominant source of protein for the wealthy. They have also continued to explore construction of economic biorefineries. Key developments include ways to rapidly turn over biomass as part of the biorefinery substructure and production of all the catalysts necessary in the biorefinery itself. The alliances use a blend of energy sources, but not nuclear or biological, to provide energy for production and transport. Photosynthetic proteins have been arrayed on metallic frameworks and capture sunlight and turn it into electrical energy extremely effectively and in a rechargeable manner.

These city-based biological alliances consist of what were independent nations occupying a specific latitude – where temperate has become semitropical with more rapid climate change than expected and where floods and storms have not become major factors affecting the ability to grow crops. Plantations of food crops or trees predominate, with natural ecosystems maintained to evolve as they can. Biodiversity corridors, such as the corridor set up in 2008 along the length of the east coast of Australia, allow animals, plants and insect species to migrate as the climate changes. Databanks of DNA and other biological signatures are maintained globally by the Food and Agriculture Organisation (FAO) and the National Institutes of Health (NIH) to record extinctions, and illegal trade in biological materials. Illegal logging of natural forests has been virtually stopped by FAO monitoring processes and tools and prosecutions of all parties have had an impact. Plant biotech tools using DNA detection of wood in products and the ability to track this backwards using marker technology and biosensors has been part of the success.

3.6 Industrial Biotechnologies and the Environment

Environmental technologies and biotechnologies have been key factors in the success of several city states, along with plant biotechnologies that enhance carbon and nutrient uptake efficiency and are important in supplementing the food supply in cities. Kits that grow plants in roof top gardens, or in apartments and underground with artificial light sources, are the latest urban fad. These gardens consist of genetically transformed plants engineered to grow miniature fruits or vegetables in a short space of time, using recycled household waste. The spent plants then also enter the waste recycling system. Catalysts based on modified silicon and/or containing specialised microbes are part of each home and remediate solid waste and water so that it can be reused many times. These form part of a community recycling system that employs green chemical techniques interfacing with environmental

biotechnologies. Used catalysts are regenerated by a building manager as part of the city housing services.

Microbial discovery programmes in the early part of the century led a wave of inventions around designing biological materials without a living component (synthetic biology). This now forms the basis of the industrial bioprocessing options under discussion at the scientific pre-meeting to the Beijing meeting. They are seen as a necessity for the future to produce sufficient food, so starches and proteins will be produced in a tube/vat/bioreactor. The predominance of nuclear energy, the risks associated with this, and the need to recycle waste also promoted evolution and discovery of microbes that can dwell happily in a nuclear environment. These microbes produced mutation resistant DNA-repair enzymes and carbon-capture proteins which are produced now in bioreactors associated with nuclear power stations. These are now being explored for effectiveness in use for synthetic biology processes. The flexible carbon capture proteins can use any gaseous form of carbon and provide the carbon for constructing sugars and other simple molecules.

3.7 Pollution

Discussion is also centring at this Beijing meeting around environmental biotechnology solutions to pollution and bioleaching, particularly of water, as water and its reuse is critical to use of nuclear power and petroleum-based materials. Consideration is being given to how to contain pollution in the oceans – a major challenge. Concern has been expressed about the late 20th century dumps of radioactive waste, major nutrient and toxin wash from the land with the increased flooding and storms, and old repositories of rubbish including non degradable materials.

Bioplastics are the one big success of industrial bioprocessing and bioplastics have replaced most of the petroleum based plastics globally, especially in Asia. Production is cheap and there are many processes, both plant and microbial, GMO and wild type. Production is in biorefineries with closed loop design where waste is recycled into feedstock. Microbial remediation is critical for the process and both GMO and evolved wild type organisms are used. Microbes have also been designed that degrade bioplastics and bioplastic-containing products in feedstock sorters which also contain microbes that capture metals. Any form of waste is regarded as a challenge by researchers in developing a microbial solution, even apparent toxins. Forced evolution technologies have had a big part to play in developing this aspect of industrial biotechnologies, involving ways to either expose living beings to evolve rapidly to cope with difficult or new environments, or to carry this out in a test tube using only a substrate and an enzyme. For example, microbes have been evolved that can extract valuable uranium from seawater. These are processed to provide fuel for nuclear energy plants.

A new challenge is how to use the latest silicon know-how with microbial technologies to tackle old landfills of glass and fibreglass, asbestos and other durable materials. This is critical as cities reshape and reform, and recent legislation has been passed (voluntarily at the 2028 cities meeting) concerning illegality of putting waste in the ocean or on the land.

3.8 Transport and Housing

In cities, electrified transport predominates, mostly communal, and vehicles are larger multiperson (*e.g.* with a capacity of ten) or individual. In the most advanced cities personal vehicles can plug into the city grid and be guided by GPS and clip into tracks above ground – meaning accidents are very rare and traffic flow is controlled. Below ground is an extension of the underground systems already designed in different parts of the world.

Design of cars and vehicles includes the ability to switch between electric and liquid (petroleum with some tolerance for biofuels). Recent vehicle parts design has taken advantage of new mixed nanotech technologies where metal molecules blend with bioplastics and are moulded into damage resistant frameworks. The same technologies have been developed further in housing.

In most cities, particularly in Asia, there is very little private land ownership, with the main infrastructure centrally designed with a premium on long-term sustainable structures. It has become too expensive to purchase and maintain developed land (*e.g.* rates payments). Only a few elite can do this and cities have generally purchased land to enable change and to prevent concentration of ownership and power. Cooperative ownership developed as a solution to several problems with the free market, including continued asset inflation and the failure of the market to provide affordable solutions for many residents, to comply with regulations and standards, and to construct durable structures. Large numbers of buildings that had been built for short term speculation suffered spectacular collapses (especially in Asia where increasing storms and flooding added to the risks of poor construction), leading to major homelessness and poverty.

People mould their living environments using "collapsible" internal structures that are made from any number of materials, including primarily, but not only, composites. All homes have external interaction areas and here glass and other opaque materials developed from bioresources are "fit for purpose". Biocomposites (construction materials based on renewables such as fibres and bioresins) are expensive items, especially as they are sourced from only a few parts of the world where the plants can grow in sufficient quantity to provide the fibre sources needed. Interior design has become a huge career, and living environments incorporate e-interfaces, social robots, and water features. Sound proofing is critical, as is flexibility to change the entire internal design space. Buildings have internal communication networks and people socialise in set-aside communal spaces.

Outside the cities, airports are the major hubs for connectivity for the wealthy and there are interfaces between these and undergrounds or roads/train/ferry systems connecting to the cities or small villages that align with consumer products manufacturing bases. Across the landscape in most places are dotted private homes of the very wealthy, farmers, or holiday bases in ecoparks, reflecting a reduction in the rural populations, and the impact of pollution and climate change.

3.9 2030 and Beyond

How far climate change will continue and what will the impacts be is a key question again. Change has been sufficient for people to experience it. Most serious is the question of the oceans and how irreversibly they are impacted. The greater concentration of people is causing tensions, both in terms of health (epidemics such as malaria and the new Shanghai flu virus which mutates rapidly and lack of exercise) and in social skills (including more social disorders such as psychoses and depression), and the city structure is more exposed than ever to the potential for terrorist success, especially bioterrorists. Fears concerning uranium generated nuclear power, and the scarcity of this element are driving the development of recently discovered uranium concentrating microbes and revival of efforts to process the widely available thorium in a cost effective manner. The global population is achieving replacement-only earlier than expected due to disease (dense living environments leading to rapid mutation of microbes, ease of spread and poor immune challenges early in life), disaster (*e.g.* weather and poor planning), reduced births (too expensive) and the euthanasia discussion continues as many of the baby boomers do not want to continue in their current lifestyle. Cities are now considering investing heavily in biological research to understand how to manage epidemics and the expected impacts of future climate change. Sustainability is back on the agenda.

4. Sources

In addition to the specific Internet resources listed below, the scenarios drew inspiration from a number of informal conversations around related topics, general information gathered on the internet, and a wide disciplinary variety of journals.

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