GLOBAL ARTIFICIAL PHOTOSYNTHESIS: CHALLENGES FOR BIOETHICS AND THE HUMAN RIGHT TO ENJOY THE BENEFIT OF SCIENTIFIC PROGRESS

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I Introduction

Thank you for inviting me to give the fifth annual Michael Kirby lecture. Justice Kirby and I share a common interest in Justice Lionel Murphy of the High Court of Australia. In vastly different ways Justice Murphy played a significant role in each of our careers. In Justice Kirby's case it was appointment to the Australian Law Reform Commission. In my case it was a much less prestigious appointment – as his associate in my first job after graduating from law school. I think, given his interest in science and law and his commitment to human rights, that Justice Murphy would have been very interested in the topic for tonight's lecture. I am deeply privileged to deliver this talk in honour of Justice Kirby.

So what is artificial photosynthesis and why is it important? Most of us knew that photosynthesis is the process whereby plants and certain bacteria have used sunlight as a source of energy to split water to create energy fro the production of food (starches) with the addition of atmospheric carbon dioxide, while producing atmospheric oxygen. Our policy makers seem to think that only plants will ever 'do' photosynthesis. This is a bit like the men at the end of the 19th century, who were convinced that only birds could 'do' controlled flight. If they were alive today their solution for long distance air travel might be to genetically engineer huge homing pigeons, capable of carrying passengers on their back.

Artificial photosynthesis began in the Cold War. It really was part of what was known in the 'Dr Stangelove' film as the 'mine-shaft' gap, part of the plan to enhance the capacity of the United States to keep its politicians,

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senior industrial and military people alive during a nuclear winter. Although artificial photosynthesis on some definitions includes synthetic biology (for example the genetic engineering of bacteria to produce lipid-based fuels) its core research involves Nano scale engineering. The Nano scale involves manipulating matter at the level of about a billionth of a metre, it involves making objects atom by atom. Some examples of how Nanotechnology is already improving the light capture, electron transport and water splitting and energy storage aspects of artificial photosynthesis will be presented later.

Perhaps the most significant aspect of artificial photosynthesis is the prospect that nanotechnology may allow the global domestic production of cheap, 'off-grid' solar fuels and food. With timely and coordinated government, academic, corporate encouragement, artificial photosynthesis may become a global phenomenon, deriving inexpensive, local (household and community) generation of fuels and basic foods from simple raw materials – sunlight, water and carbon dioxide – just like plants do, only better.

One way governance principles (such as those derived from international human rights) can assist this process is by assisting to create the normative architecture for a Global Artificial Photosynthesis project (GAP) (or Global Solar Fuels and Foods (GSF)) project. Such a macro science GAP or GSF project can be regarded as the moral culmination of nanotechnology. It could advance existing foundational virtues of international human rights such as justice equity and respect for human dignity, as well as emerging virtues such as environmental sustainability. In other words, this is one area where we need to have law and science rapidly and efficiently working side by side if it's going to work in time to make a difference and assist humanity to move from what (as we will see) is now no longer being called the Holocene, but the Anthropocene, towards the Sustainocene epoch.

One hitherto largely unexplored area of international human rights that could be significant in this context concerns the right to enjoy the benefits of scientific progress and its applications. This international human right is authoritatively expressed in article 15 of the United Nations *International Covenant on Civil and Political Rights* (ICESCR). That right here is examined here, in the context of related norms of bioethics, using a macro science GAP or GSF project as a case study.

II. Scientific Basis Of The Critical Challenges For Humanity

Access to low cost energy, food and water remain critical survival issues for the most disadvantaged people on earth and will be exacerbated as global population grows towards 10 billion by 2050 and human energy consumption rises from 400 EJ/Yr now to about 500 EJ/yr.[1]

Scientific research has been at the forefront in documenting the threats humanity and the biosphere it inhabits will face over the next hundred years or so. Such research underpins influential commentaries such as that of the Intergovernmental Panel on Climate Change[2] and the Stern Report,[3] as well as the United Nations *Millennium Development Goals*.[4] In fact scientific research has been argued that human activity has pushed this planet from the Holocene into what has been termed the Anthropocene period.[5] Five characteristic features of the Anthropocene epoch that tend to dominate its policy debates include: population; poverty, preparation for war, profits and pollution.[6]

The United Nations *Millennium Development Goals* represented an important encouragement not only for scientific research to focus on issues of energy storage, production and conversion, agricultural productivity enhancement, water treatment and remediation, but to do so with respect for basic virtues and principles of bioethics and international human rights, including environmental sustainability, justice, equity and respect for human dignity.[7]

One particularly cutting edge area of science related to the achievement of such goals is nanotechnology. Nanotechnology is still unfortunately widely known for the (somewhat disproportionately emphasised) risks it may pose or for its use in consumer applications such as lightweight, strong bikes or self-cleaning shirts. Yet increasingly scientists have begun to emphasise the

1 TA Faunce, ch 21, 'Future Perspectives on Solar Fuels' in T Wydrzynski and W Hillier W (eds), *Molecular Solar Fuels* Book Series: *Energy* (Royal Society of Chemistry, Cambridge UK, 2012) 506–528.

2 IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change [Core Writing Team, RK Pachauri and A Reisinger (eds.)]. (Geneva, Switzerland: IPCC).

3 N Stern, *The Economics of Climate Change: The Stern Review. Cabinet Office HM – Treasury* (Cambridge University Press, 2007).

4 United Nations. Millennium Development Goals, available at: <http://www.un.org/millenniumgoals/>.

5 PJ Crutzen and Stoermer 'The "Anthropocene"' (2000) 41 *Global Change Newsletter* 17–18.

6 B Furnass, 'From Anthropocene to Sustainocene; Challenges and Opportunities', Public Lecture, Australian National University 21 March 2012.

7 United Nations Millennium Development Goals available at <http://www.un.org/millenniumgoals/>.

importance of nanotechnology systematically contributing to the alleviation of critical problems facing humanity and its biosphere.[8]

Experts have encouraged nanotechnology to systematically contribute to achievement of the United Nations *Millennium Development Goals* particularly energy storage, production and conversion, agricultural productivity enhancement, water treatment and remediation.[9] One of the main ways Nanotechnology may assist in relation to such issues concerns artificial photosynthesis and particularly its contribution to global domestic or locally-produced solar fuel. Such scientific and governance efforts could be critical in moving humanity from the Anthropocene to the Sustainocene epoch.[10]

III. Nanotechnology Improving Photosynthesis

In his *Narrow Road to the Deep North,* the Japanese Haiku poet Matsuo Basho (1644–94) records a prophetically interesting incident just prior to entering the town of Fukushima. Basho states that he heard it was the season for a beautiful form of iris called *katsumi*. He went from pool to pool asking every soul he met, but strangely no one had ever heard of it and the sun went down before he saw it. Fukushima, of course, has now achieved notoriety in Japan and internationally for a meltdown at a nuclear power plant that recently occurred there after a tsunami. As a result of that incident that Japanese government, we found in recent interviews there, is now much more interested in the concept of nanotechnology-based solar fuel, so to speak in 'finding the iris before the sun goes down.'

Humanity of course has access to a gigantic nuclear reactor safely sited away from any of our backyards. The solar energy potentially usable at ~1.0 kilowatts per square metre of the earth is 3.9×106 EJ/yr. The main focus on solar energy in energy security policy documents of governments around the world has been on establishing incentive mechanisms (such as 'feed-in-to-the-electricity grid' tariffs) for photovoltaic systems. Solar fuels or foods rarely even rate a mention in energy policy statements.

Photosynthesis is a natural process now increasingly understood at the molecular and atomic levels. It is the ultimate source of our oxygen, food and fossil fuels. It already traps a significant proportion of solar energy through the

8 F Salamanca-Buentello, DL Persad, EB Court, DK Martin, AS Daar AS et al, 'Nanotechnology and the Developing World' (2005) 2(97) *PloS Med*.

9 Ibid.

10 Furnass, above n 7.

vast amount of photosynthesizing plants over the planet.[11] Yet photosynthesis in its natural form requires much solar energy to be radiated away to reduce plant heat, uses a lot of water and energy to keep the plant alive and works with varying efficiencies in different ambient light and other environmental conditions.

The basic mechanism of natural photosynthesis requires that photosynthetic organisms absorb photons from various regions of the solar spectrum into 'antenna' chlorophyll molecules in cell membrane thylakoids; plants do the same in intracellular organelles called chloroplasts. The absorbed photons' energy is used by the oxygen-evolving complex (OEC) in a protein known as photosystem II which uses manganese (specifically the Mn_4CaO_5 cluster) to oxidize water (H_2O) to oxygen (O_2) which is released to the atmosphere. The electrons thereby produced are captured in chemical bonds by photosystem I to reduce NADP (nicotinamide adenine dinucleotide phosphate) for storage in ATP (adenosine triphosphate) and NADPH (nature's form of hydrogen).

In the 'dark reaction' part of photosynthesis, ATP and NADPH as well as carbon dioxide (CO_2) are used in the Calvin-Benson cycle to make food in the form of carbohydrate via the enzyme RuBisCO.[12] Evolution has provided this process as a legacy to humanity and life in our biosphere, but not necessarily in its most efficient form for our mutual current predicament.

AP is a field of renewable energy research that seems to have somehow escaped the publicity given to photovoltaic and hydrogen fuel cell production, despite encompassing these two academic silos in its light capture and chemical storage of solar energy components respectively. Although involving synthetic biology to some extent, AP is primarily driven by nanotechnology advances intersecting with multiple scientific disciplines in light capture, electron transport, water splitting and hydrogen storage. Examples include water oxidation systems utilising photosensitive components grafted by core-shell nanowires to a genetically engineered virus,[13] improving the efficiency of photosynthetic electron pathways by incorporating quantum computation into the energy transfer of quantum dots' light harvesting capabilities;[14] using mesoporous thin film dye-sensitive solar cells of semiconductor nanoparticles and allowing carbon nanotubes to harvest and conduct the resultant

11 Ron Pace, 'An Integrated Artificial Photosynthesis Model', in Anthony Collings and Christa Critchley (eds), *Artificial Photosynthesis: from Basic Biology to Industrial Application* (Weinheim Wiley-VCH Verlag, 2005) 13 *et seqq* at 24.

12 D Gust and Tom Moore, 'Mimicking photosynthesis' (1989) 244 *Science* 35 *et seqq*.

13 YS Nam et al, 'Virus-Templated Assembly of Porphyrins into Light Harvesting Nanoantenne' (2010) 132(5) *Journal of the American Chemical Society* 1462 *et seqq*.

14 GS Engel, TR Calhoun, EL Read et al, 'Evidence for Wavelike Energy Transfer Through Quantum Coherence in Photosynthetic Systems' (2007) 446 *Nature* 782 *et seqq*.

electricity.[15] The race is on between haematite, cobalt and manganese and leading candidates for an inexpensive (non rare-metal) water catalytic system which is self-repairing and operates under ambient conditions at neutral pH with non-pure water.[16] Synthetic proteins (maquettes) have been created to allow testing of engineering principles for artificial photosystems and reaction centers.[13] The fuel outcomes from this process may be hydrogen condensed and cooled.[17] Yet there are major safety concerns with hydrogen storage and transport and its low energy density and the results from potential solutions such as high pressure and cryogenic gas containers have not been cost-effective so far.[18] Other options have involved production of methanol[19] or the capacity of artificial photosynthesis systems to use hydrogen generated from water splitting and atmospheric carbon dioxide to store energy in formic acid.[20]

IV. Right to Enjoy the Benefit of Scientific Progress and its Applications

Article 15 of the United Nations *International Covenant on Civil and Political Rights* (ICESCR) provides:

1 . The States Parties to the present Covenant recognise the right of everyone:
   (a) to take part in cultural life;
   (b) to enjoy the benefits of scientific progress and its applications;
   (c) to benefit from the protection of the moral and material interests resulting from any scientific, literary or artistic production of which he is the author.
2. The steps to be taken by the States Parties to the present Covenant to achieve the full realisation of this right shall include those necessary for the conservation, the development and the diffusion of science and culture.

15 K Kalyanasundaram and M Graëtzel, 'Artificial Photosynthesis: Biomimetic Approaches to Solar Energy Conversion and Storage' (2010) 21 *Curr Op Biotech* 298 *et seqq*.

16 S Dahl and I Chorkendorff, 'Solar Fuel Generation: Towards Practical Implementation' (2012) 11 *Nature Materials* 100.

17 JA Turner, 'Sustainable Hydrogen Production' (2004) 305 *Science* 972–974.

18 L Schlapbach and A Zuttel, 'Hydrogen-Storage Materials for Mobile Applications' (2001) 414 *Nature* 353–358.

19 GA Olah, A Goeppert, GK Surya Prakash, *Beyond Oil and Gas: the Methanol Economy* (Wiley-VCH, Weinheim, 2009).

20 JF Hull et al, *Reversible Hydrogen Storage Using CO2 and a Proton-Switchable Iridium Catalyst in Aqueous media Under Mild Temperatures and Pressures* (2012) doi:10.1038/nchem1295 18 March 2012.

3. The States Parties to the present Covenant undertake to respect the freedom indispensable for scientific research and creative activity.
4. The States Parties to the present Covenant recognise the benefits to be derived from the encouragement and development of international contacts and co-operation in the scientific and cultural fields.

Further statements of the human right to enjoy the benefits of scientific progress and its applications (REBSPA) are found in article 27 of the United Nations *Universal Declaration of Human Rights*. Article 12(2) on freedom from hunger refers to making full use of scientific knowledge, articles 2(1) and 23 of the ICESCR refer to scientific assistance in achieving the specified rights and there are implicit scientific aspects to the right to health in article 12 of the ICESCR.

Several significant and largely unresolved issues are immediately presented by any attempt to apply REBSPA to facilitate equitable global access to scientific advances in nanotechnology such as artificial photosynthesis.

The first concerns the jurisprudential basis of a right to enjoy the benefit of scientific progress and its applications. Other work on such economic, social and cultural rights confirms that they are subject to a margin of appreciation given the limited nature of State resources and competing demands, as well as varying cultural sensitivities.[21]

At a very fundamental level it is possible to argue that it must be part of any social contract science, that all citizens should be accorded just and equitable access to scientific knowledge and applications that reveal the basic order of things and relief human suffering and degradation of the biosphere. In the 17th century the philosopher Benedict de Spinoza wrote in *Ethics* (Bk II, Prop. XLIV), that it is the nature of reason properly applied to perceive things truly, that is, as they are in themselves not as contingently existing as revealed to us by sensory experience. This pronouncement and its implications have often been ignored or dismissed as a peculiar type of idealist rhetoric subsequently characteristic of human rights language. Yet Spinoza's realisation paved the way for major scientific as well as ethical breakthroughs in thinking— the realisation that there could be true statements about reality that did not appear to correlate with common sense. In the 18th century, for example, Immanuel Kant influentially contended that the capacity to form ethical concepts in the form of goals or end points for future actions based on universally-applicable principles, arises (like our understanding of time and space) *a priori* as necessary preconditions for accurate experience (rather than being

21 AR Chapman, 'Towards an Understanding of the Right to Enjoy the Benefits of Scientific Progress and its Applications' (2009) 8 *Journal of Human Rights* 1–36.

determined by it). We now readily accept, though this may not be part of our common experience) that reality is made up physical laws underpinning electromagnetism, gravity, general relativity and quantum physics but also human rights laws regardless of whether they are expressed in our Constitution or any international convention to which our State is a party.

Science has provided the basis for the emerging social virtue of environmental sustainability as influentially propounded by eco-economists such as the EF Schumacher (with his concept of 'small (and local) is beautiful')[22] and Kenneth Boulding (with his idea of 'Spaceship Earth' as a closed economy requiring recycling of resources).[23] Science, particularly through the laws of thermodynamics has also provided the basis for the economist Herman Daly emphasising entropy (dispersal of energy) to champion the idea of 'steady-state' economics that financially values maintenance of ecosystems equally with production and profits.[24]

A second problem with applying REBSPA to assist policy support for a nanotechnology-oriented Global Artificial Photosynthesis (Solar Fuels and Foods) project are that its constitutive documents do not provide a definition of 'science' or 'scientific'. A core definition of science is likely to include the empirical sciences – where knowledge is obtained from experiments about observable phenomena and is subsequently capable of being tested for validity (including being falsified or refuted) by other researchers working under the same conditions. Clearly, nanotechnology-based artificial photosynthesis falls within this definition. Yet other issues are that a workable definition of science should include formal fields such as mathematics, statistics or logic, but also have an ethical dimension necessarily linking science to foundational social virtues – justice, equity, respect for human dignity and environmental sustainability.

A major challenge then to interpreting this REBSPA as it applies to solar fuels involves defining its core components. On one approach the core component of the REBSPA aims to protect, fulfil and respect the scientific enterprise insofar as it contributes to achieving human rights obligations. It aims to protect the capacity of the scientific enterprise to bring benefits to everyone through encouraging measures that permit critical analysis, honesty and objectivity amongst scientific researchers and their employers, facilitate government regulatory systems based on scientific evaluation of the risks, benefits and cost effectiveness of new technologies. The right may be viewed

22 EF Schumacher, *Small Is Beautiful: Economics As If People Mattered* (Abacus, London, 1974).
23 KE Boulding, *Towards a New Economics: Critical Essays on Ecology, Distribution and Other Themes* (Edward Elgar, Hans, England, 1992).
24 Herman Daly, *Ecological Economics and the Ecology of Economics* (1999).

as seeking to support mechanisms whereby tradition knowledge may be incorporated into the scientific enterprise according to standards supported by international human rights. For the purposes of this right it is expected that states have an obligation to ensure that science conducted within their boundaries is coherent with international human rights.

Third, article 15 (2) of the ICESCR refers to ‘conservation, development and diffusion’ of science as amongst the steps to be taken by States Parties to achieve full realisation of the REBSPA. Challenges to interpretation of the right in this context include the extent to which ‘conservation’ refers to measures to prevent loss of scientific expertise and infrastructure relevant to solar fuels particularly in developing nations. Measures for consideration here include how policies of developing nations to retain scientific expertise in renewable energy relate to WTO *General Agreement of Trade in Services* (GATS) obligations.

Additional challenges with respect to ‘development’ of the science of solar fuels include reporting obligations on investments by State Parties in related science education, grant funding and science infrastructure. Challenges with respect to ‘diffusion’ include responsibilities of States Parties to facilitate community access to scientific information about solar fuels, fostering of open scientific debate and appropriate use of science in regulatory processes related to renewable energy. Amongst the challenges to be addressed here include the creation of mechanisms whereby public-funded research in artificial photosynthesis can recoup a reasonable percentage of profits ultimately produced by private sector involvement in research development, maintenance of the ‘research-use’ exemption for public funded universities, and measures to prevent any systematic inhibition, misrepresentation or concealment of scientific data by private or public research organisations

Fourth, article 15 (3) requires States Parties to the present Covenant undertake to respect the freedom indispensable for scientific research and creative activity. One challenge here may involve the need (in order to achieve full realisation of this right) for the equivalent of a ‘Hippocratic Oath’ for artificial photosynthesis researchers and senior management of research organisations utilising substantial funding by States Parties. Another challenge to full realisation of the right concerning solar fuels may involve consideration of laws that financially reward informants revealing fraud on public purse in scientific research. Consideration could also be given to the need for United Nations ‘Office of Research Integrity’ to generate guidelines and standards particularly to generate safeguards and procedures to protect vulnerable populations as well as measures to encourage active and informed participation of lay individuals and communities in policy decisions concerning science and technology, and measuring impact. The funding rules for award of research grants in the solar fuels area by States Parties may also be an important challenge under this head.

Fifth, article 15 (4) of the ICESCR refers to an obligations of States parties to fulfil, protect and respect the benefits to be derived from the encouragement and development of international contacts and co-operation in scientific fields such as artificial photosynthesis. Challenges for full realisation of this aspect of the right include the extent to which grant funding by states parties facilitate this aim (that is by including awards fostering such contacts and co-operation).

Sixth, full realisation by States Parties of the REBSPA concerning solar fuels necessarily involves considering challenges such as the role of evidence about scientific benefits and applications of related, energy, health and environment policies in particular before WTO Dispute Settlement mechanisms and also in investor-state dispute settlement mechanisms. As new scientific technologies become available to deal with crucial issues for States Parties such as energy security, water security, food security and climate change mitigation (such as artificial photosynthesis) a challenge will involve consideration of whether the right requires exceptions to WTO, bilateral and regional trade agreements that may particularly through increased monopoly privilege protections inhibit enjoyment by everyone of the benefits of that science and its applications. Other challenges to fully realising the REBSPA concern the regulatory dilemma created by the imprecise relationship between implementation of the precautionary principle and activation of investor-state rights, and the use of regional and bilateral trade agreements to undermine science-based mechanisms to evaluate the 'health innovation' of new technologies. Related policy suggestions include a tax on global financial transactions to fund critically needed scientific research in artificial photosynthesis. Citizens can justifiable begin to wonder why they have to pay a charge to banks every time they use electronic funds transfer, but the banks themselves never have to pay such fees when engaging in global financial transactions.

The REBSPA concerning solar fuels is likely to also be interpreted in policy makers in the light of bioethical statements such as the UNESCO Universal Declaration on Bioethics and Human Rights (UDBHR).

Article 15 of the UDBHR for example states:

> Benefits resulting from any scientific research and its applications should be shared with society as a whole and within the international community, in particular with developing countries. In giving effect to this principle, benefits may take any of the following forms:
>
> (e) access to scientific and technological knowledge;
>
> (f) capacity-building facilities for research purposes;
>
> (g) other forms of benefit consistent with the principles set out in this Declaration.

Article 21 of the UDBHR provides:

> 2. When research is undertaken or otherwise pursued in one or more States (the host State(s)) and funded by a source in another State, such research should be the object of an appropriate level of ethical review in the host State(s) and the State in which the funder is located. This review should be based on ethical and legal standards that are consistent with the principles set out in this Declaration.
>
> 3. Transnational health research should be responsive to the needs of host countries, and the importance of research contributing to the alleviation of urgent global health problems should be recognised.

REBSPA appears to go beyond international economic, cultural and social human rights law related to food, health, an adequate standard of living, water and freedom of expression by aiming to protect, fulfil and respect the core components of science itself and its contributions to achieving the non-anthropocentric goal of a sustainable and bio diverse environment. In this sense REBSPA can be considered to be at the forefront of new generation biosphere-focused human right. It protects government regulatory systems based on scientific evaluation of the risks, benefits and costs of new technologies- from threats to their integrity such as fraud by individual researchers or corporations engaged in scientific research, from corporate lobbying or religious fanaticism that seeks either to use scientific advances in ways contrary to human rights or environmental sustainability, or to distorts scientific conclusions or inhibits their incorporation into rational policy

Some ways in which governments could facilitate REBSPA promotion of nanotechnology-based artificial photosynthesis include toxicology labs allowing individual citizens to request scientific testing of potentially toxic water, soil, air or food related to the research. Public access to database of all related research trials being conducted (including their subject information sheets and consent forms) would also be valuable. So would the capacity for individuals and communities to lodge submissions on the impact of

WTO dispute resolution proceedings or investor-state dispute settlement proceedings on REBSPA solar fuels applications.

Relationship between the REBSPA and the right of creators to the protection of their moral and material interests is something that will specifically considered in a subsequent section. The author favours replacement of the terminology 'intellectual property rights' with 'intellectual monopoly privileges' chiefly because he does view the former as a de-facto species of natural right of citizens under a social contract. REBSPA in this context will also have to take into account how national security, military or foreign policy objectives interact with solar fuels research. Should related ethical obligations be part of a specific code for scientists and scientific-funding corporate CEOs?

As the private sector becomes more involved in solar fuels research REBSPA could be an important vehicle for engaging UN human rights mechanisms, states, civil society, including the academic and scientific communities in appropriate regulatory endeavours for the public good. Self-regulation of corporate sector made need to be replaced with strong anti-monopoly and anti-fraud systems as a dominant model of regulation.

IV. Existing Artificial Photosynthesis Projects and Governance Challenges

Could a 'big science' approach to artificial photosynthesis represent the single most important global scientific effort of our generation? Prior to this talk at the Southern Cross University the author has presented to idea for a Global Artificial Photosynthesis (GAP) Project as a defining endeavour of planetary Nanomedicine at the *Nanotechnology for Sustainable Energy* Conference sponsored by the European Science Foundation in July 2010 at Obergurgl, Austria and at the 15th *International Congress of Photosynthesis* in Beijing in August 2010. This talk at Southern Cross University is the first time that the related governance challenges have ever been considered in a presentation at a faculty or college of law. It is the theme of a major international conference I will be coordinating at Lord Howe Island in August 2011 under the auspices of the UNESCO Natural Sciences Sector.

Numerous competitively funded nanotechnology-focused AP research teams already exist in many developed nations. A dozen European research partners, for example, form the Solar-H2 network, supported by the European Union.[25] The US Dept. of Energy (DOE) *Joint Center for Artificial Photosynthesis* (JCAP) led by the California Institute of Technology (Caltech) and Lawrence

25 H Solar network, see <http://www.fotomol.uu.se/Forskning/Biomimetics/solarh/index.shtm>.

Berkeley National Laboratory has US$122m over 5 years to build a solar fuel system. Caltech and the Massachusetts Institute of Technology have a large National Science Foundation (NSF) grant to improve photon capture and catalyst efficiency, while several Energy Frontier Research Centers funded by the US DOE are focused on GAP-related endeavours.[26] In Japan, Nobel Prize winner Eiichi Negishi has established an Artificial Photosynthesis Group, based on the Catalysis Research Centre, Hokkaido University.

A macro science Global Artificial Photosynthesis (GAP) or Global Solar Fuels (GSF) Project to speed up the progress in this field by uniting these large research groups must overcome various organisational, financial and jurisprudential challenges (particularly those related to intellectual property). The scientific challenge for the analogous Human Genome Project HGP was more clearly defined. As with the HGP, GAP Project work is likely to be distributed across a variety of laboratories in different nations, rather than being focused in one place like the European Organization for Nuclear Research (CERN) or the international project on fusion energy (ITER). The lesson of CERN and the Hubble Space Telescope (funded by NASA in collaboration with the European Space Agency) may be to have many nations funding 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 agreeing to share scientific data, procurements, finance, staffing.

How to properly manage for the public good and environmental sustainability industry involvement (either as suppliers of equipment or resources or customers of outputs) in a GAP or GSF project will be a major jurisprudential issue given the example of tensions between public and private rights exhibited in the final stages of the HGP. This could be a major area in which REBSPA provides a useful stimulus to appropriate and necessary regulation. Lessons for such regulation can be learnt from the SEMATECH (SEmiconductor MAnufacturing TECHnology) non-profit consortium, the *Center for Revolutionary Solar Photoconversion* (CRSP) involving public funding from two separate sources (US DOE and NSF) with multinational corporate members, the International Renewable Energy Agency (IRENA), the World Council for Renewable Energy (WCRE) and EUROSOLAR, the non-profit European Association for Renewable Energy.[27]

26 K Sanderson, 'The Photon Trap' (2008) 452 *Nature* 400 *et seqq* 402.

27 International Renewable Energy Agency (see <http://www.irena.org/>); American Council on Renewable Energy (see <http://www.acore.org/front>); European Association for Renewable Energy (see <http://www.eurosolar.de/en/>).

Potential governance models for a GAP or GSF Project that implementing the REBSPA could promote involve gradual evolution from the status quo, or active promotion and coordination in collaboration with leaders of the largest national AP projects through a series of conferences or workshops on GAP collaborative research and governance such as the GAP I conference that took place on Lord Howe Island on 14-18 August 2011 under the auspices of the UNESCO Natural Sciences Sector.[28] An open-access model might involve funding rules requiring public good licensing, technology transfer, ethical and social implications research as well as rapid and free access to data. A public-private partnership model might involve members' access to non-exclusive licenses over intellectual property.

A governance structure for such a GAP or GSF Project emphasising international law under RESBSPA might protect photosynthesis from damage or excessive patents within the class of United Nations treaties involved with protecting the common heritage of humanity (for instance moon, outer space, deep sea bed, world natural heritage sites) with obligations to roll out AP technology equitably.

For artificial photosynthesis to emerge as a dominant form of local as well as industrial power production, a major issue, as mentioned that the REBSPA will have to confront involves regulating the intellectual monopoly privileges (IMPs), such as patents which are allowed over the development of the necessary novel structures and systems.[29]

IMP such as patents provide incentives for innovation, but may inhibit effective scientific collaboration in the solar fuels area.[30] A pertinent extant example might concern patents over synthetic organisms and proteins such as those that may be used in the creation in enhanced nanotechnology versions of core photosynthetic proteins such as PSII and PSI.[31] Likewise, IMPs claimed over GAP components (such an antenna 'light capture' systems, reaction centres and water catalysts) will be hard to identify, fragmented across many owners and sometimes overly broad.[32] Such factors may make it harder for

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28 'Towards Global Artificial Photosynthesis: Energy, Nanochemistry and Governance' (see <http://law.anu.edu.au/coast/tgap/conf.htm>).

29 TA Faunce, 'Governing Nanotechnology for Solar Fuels: Towards a Jurisprudence of Global Artificial Photosynthesis' (2011) 2 *Renewable Energy Law and Policy* 163–168.

30 M Blakeney, 'International Intellectual Property Jurisprudence after TRIPS', in D Vaver and L Bently (eds), *Intellectual Property in the New Millennium* (Cambridge University Press, 2004) 3 *et seqq*.

31 MK Cho and DA Relman, 'Genetic Technologies. Synthetic "Life", Ethics, National Security, and Public Discourse' (2010) 329 *Science* 38 *et seqq*.

32 G van Overwalle et al, 'Models for Facilitating Access to Patents on Genetic Inventions' (2006) 7 *Nat. Rev. Genet* 143 *et seqq*.

would-be GAP or GSF innovators to get licences and patents as GAP research advances.[33] REBSPA-backed governance strategies to circumvent such problems could open-source sharing or variations of governance techniques designed to protect global public goods. [34] Many of the debates that will impact on global use of solar fuels here are already being played out in relation to synthetic biology.[35] If solar fuels patent ownership becomes fragmented, researchers may find 'follow-on' research hampered by the cost and difficulty in negotiating contracts with large numbers of GAP IMP owners.[36]

REBSPA-backed regulatory mechanisms could begin to unravel the complexities of a few supranational corporations coming to dominate the solar fuels field, or corporations called 'patent trolls' acquiring patents simply to parasitically profit from the evolving research needs of solar fuels researchers.

REBSPA would also support accelerating the pace of GAP or GSF-related research through firms and universities (for incentives such as raising profile, obtaining reciprocal access and building a user base) by donating part of their data to open source projects.[37] Additionally, companies involved in public-private linkage projects with researchers involved in a GAP or GSF project could be required to specify as part of their grant application the nature and length of the IMP protection they will need; competition from other applicants providing an incentive for voluntarily limiting the claimed patent duration. Members who joined an open-source-structured GAP or GSF Project might be contractually granted brief periods of exclusive ownership in return for a promise to afterwards receive access to a confidential data base governed by trade secrets and copyright laws which are less expensive or restrictive than patents. Such researchers could publish information they supplied at any time- so blocking third parties from obtaining patents.

A REBSPA-backed GAP or GSF Project governance structure emphasising international law might seek to protect natural and artificial photosynthesis from excessive patents promoting inequitable or unsustainable use within the class of United Nations treaties involved with protecting the common

33 Intellectual Property Office, *UK Innovation Nanotechnology Patent Landscape Analysis* (2009) (available at <http://www.ipo.gov.uk/types/patent/p-informatic/p-informatic-report.htm>).

34 TA Faunce, 'Global Artificial Photosynthesis: A Scientific and Legal Introduction' (2011) 19 *Journal of Law and Medicine* 275–281.

35 JA Goldstein, 'Critical Analysis of Patent Pools', in G van Overwalle (ed), *Gene Patents and Collaborative Licensing Models* (Cambridge University Press, 2009) 50 *et seqq*.

36 J Henkel and SM Maurer, 'Parts, Property and Sharing' (2009) 12 *Nature Biotechnology* 1095 *et seqq*.

37 G van Overwalle (ed), M Spence, *Gene Patents and Collaborative Licensing Models* (Cambridge University Press, 2009) 161.

heritage of humanity (such provisions cover, for instance, outer space,[38] the moon,[39] deep sea bed,[40] Antarctica[41] and world natural heritage sites[42]).

Five core components are generally regarded as encompassing the Common Heritage of Humanity concept under public international law. First, there can be no private or public appropriation; no one legally owns common heritage spaces or materials. Second, representatives from all nations must manage such resources on behalf of all (this often necessitating a special agency to coordinate shared management). Third, all nations must actively share with each other the benefits acquired from exploitation of the resources from the commons heritage region, this requiring restraint on the profit-making activities of private corporate entities and linking the concept to that of global public good. Fourth, there can be no weaponry developed using common heritage materials. Fifth, the commons should be preserved for the benefit of future generations.[43] [44]

The claim for GAP and its core components to common heritage status have as the closest analogies claims that genetic diversity of agricultural crops, plant genetic resources in general, biodiversity or the atmosphere should be treated as not just areas of common concern but subject to common heritage requirements under international law. A non-binding UNESCO *Universal Declaration on the Bioethics and Human Rights of Natural and Artificial Photosynthesis* could support the REBSPA by declaring in Article 1 that: 'Natural and artificial photosynthesis underlies the fundamental unity of all life on earth. In a symbolic sense, it is the heritage of humanity.' Article 2 might state: 'Photosynthesis in its natural state shall not give rise to financial gains.'[45]

38 United Nations, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, art 1 Jan 27, 1967, 18 UST 2410, 610 UNTS 205.

39 United Nations, *Agreement Governing Activities of States on the Moon and Other Celestial Bodies* art 1, Dec 17, 1979, 18 ILM 1434.

40 United Nations, *Convention on the Law of the Sea*, art 1, para 1, Dec 10, 1982, 1833 UNTS 397.

41 Antarctic Treaty art VI, Dec 1, 1959, 12 UST 794, 402 UNTS 72.

42 UNESCO, *World Heritage Convention*, available at <http://whc.unesco.org/en/conventiontext/>.

43 J Frakes, 'The Common Heritage of Mankind Principle and the Deep Seabed' (2003) 21 *Wisconsin International Law Journal* 409 *et seqq*.

44 A Pardo, 'Whose Is The Bed Of The Sea?' (1968) 62 *Proceedings of the American Society of International Law* 216 *et seqq*.

45 UNESCO, *Universal Declaration on the Human Genome and Human Rights*, available at <http://portal.unesco.org/shs/en/ev.php-URL_ID=1881&URL_DO=DO_TOPIC&URL_SECTION=201.htm>.

V. Conclusion

It has been argued that a GAP or GSF Project could be a defining scientific endeavor for our species. The author has argued in a recent book that it will be the moral culmination of nanotechnology.[46] It has also been argued that new generation, less anthropocentric human rights such as REBSPA and common heritage of humanity may be governance methods to protect natural and artificial photosynthesis so it is allowed to satisfy key bioethical and international human rights goals related to the United Nations *Millennium Development Goals*. In doing so technology and law may by marching together on a grand scale, assist our progress from the Anthropocene to the Sustainocene epoch.

46 T Faunce, *Nanotechnology for a Sustainable World. Global Artificial Photosynthesis as the Moral Culmination of Nanotechnology* (Edward Elgar, 2012).