WILL INTERNATIONAL TRADE LAW INHIBIT OR PROMOTE GLOBAL ARTIFICIAL PHOTOSYNTHESIS?

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**ABSTRACT**

Artificial photosynthesis (AP) is an area of well-advanced research involving large international groups at the cutting edge of synthetic biology and nanotechnology. In simple terms it offers to produce a cheap source of hydrogen for fuel through using sunlight to split water, as well as making basic starches by a process involving absorption of carbon dioxide via the enzyme RuBisCO. As the proliferating numbers of university-based research teams working in this area begin to combine, there will be a natural escalation of the expected time for a global roll-out of AP domestic and international devices. Policy attention will then turn to whether international governance systems (particularly including international trade law) will assist or hinder this process. The stakes are high – global AP offers a solution not only to human energy, food and water needs (burning hydrogen fuel creates pure water) but to the rising atmospheric carbon dioxide levels linked to climate change problems. This paper begins to examine how governments seeking to promote and subsidize AP products may interact with international trade and investment law. It involves analysis in this context of WTO multilaterals and U.S. bilaterals in relation to intellectual monopoly privileges (IMPs), “Doha-minus”

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provisions, definitions of technological “innovation,” non-violation nullification of benefits requirements, textual inhibitions on science-based cost-effectiveness assessment of new technologies, as well as investor-state dispute settlement provisions.

**KEYWORDS:** artificial photosynthesis, TRIPS, intellectual monopoly privilege, Doha-minus, international trade law, patents, investor state dispute settlement, non-violation nullification of benefit
I. INTRODUCTION: SHOULD ARTIFICIAL PHOTOSYNTHESIS GO GLOBAL?

Artificial photosynthesis (AP) is the subject of intense and advanced research by large groups of scientists in all developed nations.\(^1\) A dozen European research partners, for example, form the Solar-H network, supported by the European Union. These include Uppsala University, Uppsala, Sweden; Commissariat a l’Energie Atomique (CEA), Paris, France; Université Paris-Sud, Orsay, France; Max Planck Gesellschaft, Germany; Ruhr-Universität Bochum, Germany; Biological Research Center of the Hungarian Academy of Sciences; Wageningen Universiteit, the Netherlands; and the Universite de Geneve, Switzerland.\(^2\)

The U.S. Department of Energy (DOE) Joint Center for Artificial Photosynthesis (JCAP) led by the California Institute of Technology (Caltech) and Lawrence Berkeley National Laboratory has US$122 million over five years to build a solar fuel system. Caltech and the Massachusetts Institute of Technology have a US$20 million National Science Foundation (NSF) grant to improve photon capture and catalyst efficiency, while several Energy Frontier Research Centers funded by the U.S. DOE are focused on GAP-related endeavours.\(^3\) In Japan, Nobel Prize winner Eiichi Negishi has established an Artificial Photosynthesis Group, based on the Catalysis Research Centre, Hokkaido University, and including researchers at University of Tokyo, Tokyo Institute of Technology, University of Tsukuba, Kyoto University and Kyushu University.\(^4\) Their aim is to producing tradeable and marketable AP products.

The attractions of AP are great, not just for scientists, but governments committed to improving energy security and access to food and water. AP offers (with timely and coordinated academic, governmental and corporate encouragement) to provide inexpensive household and community generation of fuels and basic foods from the simple raw materials of sunlight, water and carbon dioxide.

Sounds simple, well it is and it isn’t. Plants have been undertaking photosynthesis for over a billion years and in doing so have created the oxygen, fossil fuels and food we rely upon to survive and flourish. Yet the idea that only plants can do photosynthesis is set to become as outdated as did the notion that only birds can fly. The secret ingredient is nanotechnology – the science of making things from components that are


\(^3\) See generally Jeff Tollefson, *U.S. Seek Solar Flair for Fuels*, 466(7186) NATURE 541 (2010).

not much bigger than a few atoms, less than 100nm (a nanometer is a billionth of a meter).

The challenge to rapidly develop nanotechnologically-based artificial photosynthesis involves advances in what is termed “light capture” (including light-harvesting artificial proteins, synthetic pigment arrays and with nanoparticle solar cells with increased surface areas), “photochemical conversion” (including structure of the photosynthetic reaction centers, robust water catalysis, optimizing photochemical quantum yield) and “energy storage” (including starch production through the enzyme RuBisCO from carbon dioxide).

But it also involves governance challenges to promptly advance such areas according to virtues and principles of social equity and environmental sustainability that may not mesh well with world trade and investment law. This paper first seeks to explain the nature of artificial photosynthesis and what economic and societal changes it may presage when it manages to develop tradeable and marketable products. It then explores some components of international trade and investment law that might hinder this global roll out of AP products.

II. IMPORTANCE OF PHOTOSYNTHESIS TO WORLD ENERGY AND FOOD

More solar energy strikes the Earth’s surface in one hour of each day than the energy used by all human activities in one year. At present the average daily power consumption for a citizen to flourish in life with a reasonable standard of living is about 125 kWh/day. Much of this power is devoted to transport (~40 kWh/day), heating (~40 kWh/day) and domestic electrical appliances (~18 kWh/day), with the remainder lost in electricity conversion and distribution. World energy consumption is currently in the region of 450 EJ/yr, but vastly more than this is the solar energy potentially usable at ~1.0 kW/m² of the earth – 3.9x10⁶ EJ/yr. If we take into account, however, the earth’s tilt, diurnal and atmospheric influences on solar intensity, then power form this source becomes approximately ~110 W/m².

Photosynthesis, the ultimate source of our oxygen, food and fossil fuels, has been operating on earth for 2.5 GYr. Photosynthesis creates a global

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7 A. BARRIE PITTOCK, CLIMATE CHANGE: THE SCIENCE, IMPACTS AND SOLUTIONS 177 (2d ed. 2009).

8 MACKAY, supra note 6, at 38.

annual CO₂ flux of 124 PgC/yr\(^{10}\) and an annual O₂ flux of \(~10^{11}\) t/yr.\(^{11}\) In its present technologically-unenhanced form, photosynthesis globally already traps around 4,000 EJ/yr solar energy in the form of biomass.\(^{12}\) The global biomass energy potential for human use from photosynthesis as it currently operates globally is approximately equal to human energy requirements (450 EJ/yr).\(^{13}\)

Natural photosynthesis is capable of substantial improvement with nanotechnology. It is estimated, for example, that even if 3000 m\(^2\) per person is devoted to it, biomass fuel from natural photosynthesis will indirectly (via intermediate energy carriers) contribute only 36 kWh/day per person.\(^{14}\) Photovoltaic energy systems are improving their efficiencies towards 25%, and the cost of the electricity they produce is nearing or has past grid parity in many nations. But they are not an “off-grid” solution and so do not presumptively encourage new community-based governance patterns more likely to emphasize environmental sustainability. Even large solar farms (for example taking up 200 m\(^2\) per person with 10% efficient solar panels) could produce but \(~50\)kWh/day per person.\(^{15}\) This is still a long way short of \(~125\) kWh/day average developed nation consumption and still leaves the problem of power storage for night use and transport. Clearly if we are to make better use of the ratio of available solar energy to world annual energy consumption then a better way to convert solar energy into fuel needs to be developed.

III. SOME KEY SCIENTIFIC CHALLENGES OF ARTIFICIAL PHOTOSYNTHESIS

Researchers now are actively redesigning photosynthesis to achieve, for example, low cost, “off-grid,” direct (without intermediate energy carriers) conversion of sunlight, water and carbon dioxide into fuel for heating and cooking.\(^{16}\) One such approach is to genetically manipulate or

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\(^{10}\) See generally Christian Beer et al., \textit{Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with Climate}, 329 \textit{Science} 834 (2010).


\(^{12}\) Ajay Kumar, \textit{Energies, in Biomass Thermochemical Gasification: Experimental Studies and Modeling} 556 (Ajay Kumar et al. eds., 2009).


\(^{14}\) MACKAY, supra note 6, at 43-44.

\(^{15}\) MACKAY, supra note 6, at 41.

even synthetically reproduce photosynthetic plants and bacteria to maximize their light capture and carbon reduction activities. Another, more focused on here, is to use nanotechnology to create enhanced non-life-based models of the photosynthetic process.

One basic idea of AP research is to develop solar fuel products that improve on how plants absorb sunlight and use it to create an electron flow and hydrogen by splitting water. This “light capture” involves nanostructured materials or synthetic organisms absorbing photons from a much wider region of the solar spectrum (photon absorption by antenna chlorophyll molecules in thylakoid membranes of chloroplasts, for example, currently is restricted primarily to ~430-700nm). The technology behind this improved light capture system may include mesoporous thin film dye-sensitive solar cells of semiconductor nanoparticles and carbon nanotubes harvesting and conducting the resultant electricity. Nanomaterials and hybrid organic-inorganic nanostructures are being developed for improved the conversion efficiency of existing PV units and have pushed the boundary of the Shockley-Queisser limit, for example by the technique of multiple stacking of solar cells with increasing band gap energies to exploit the solar spectrum more profitably.

Scientists are striving to allow light capture devices to separate charge efficiently over macroscopic distances using inexpensive materials. They are seeking better understanding of how the molecular dynamics of bridge molecules in a donor-bridge-acceptor system control long distance electron transport, allowing the preparation and characterization of new self-assembling antenna building blocks that elicit formation of a reaction center over multiple cycles of photon absorption and charge separation. They are drawing upon new knowledge of how self-assembly is obtained,

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17 Arthur J. Ragauskas et al., The Path Forward for Biofuels and Biomaterials, 311 SCIENCE 484, 484 (2006).
18 See ROBERT E. BLANKENSHIP, MOLECULAR MECHANISMS OF PHOTOSYNTHESIS (1st ed. 2002).
for example, by entropy-driven “depletion-attraction”\textsuperscript{24} as well as physical forces such as hydrogen bonding.\textsuperscript{25}

One of the most exciting prospects in the area of light capture is that the excitation energies of each nanoscale arranged pigment chromophore (excitons) in the antenna array will have been mapped in terms of protein spatial, orientational and energetic factors, facilitating the construction of artificial photosynthetic electron pathways to the reaction center that perform a single quantum computation, sensing many states simultaneously and so enhancing the efficiency of the energy capture and transfer at physiological temperatures.\textsuperscript{26} The premise is that this ideally would allow a future nanotechnological artificial photosynthesis antenna system to sample all the potential electron pathways instantaneously and “choose” the most efficient.

Nanostructured light harvesting antenna systems may interface at high energy transfer efficiency with fully characterised artificial versions of the reaction centers proteins known as PSII and PSI that are central to the photosynthetic process.\textsuperscript{27} A nanotechnological version of a fully characterized PSII may not be limited to using four successive charge-separation reactions in four manganese ions and a calcium ion to oxidize two water molecules (stored by the oxygen-evolving complex (OEC)) to yield a molecule of diatomic oxygen, four hydrogen ions and electrons (then siphoned off for storage in chemical bonds).

PSII in plants is a complex protein with 27 subunits and 32 cofactors involved in electron transfer and light harvesting. Any synthetic mimic of this protein (maquette) must be simpler.\textsuperscript{28} The ultimately successful GAP model of PSII is likely to involve significantly more efficient versions of the chlorophyll complex, redox-active tyrosine and tetra-nuclear manganese/calcium cluster (Mn\textsubscript{4}CaO\textsubscript{5}).\textsuperscript{29} Higher structural resolution and computation analysis (now down to 1.9 ångströms or 1.9×10\textsuperscript{-10} m) will

\begin{thebibliography}{99}
\bibitem{27} See generally Devens Gust et al., \textit{Solar Fuels via Artificial Photosynthesis}, 42(12) \textit{ACCT. CHEM. RES.} 1890 (2009); Henry N. Chapman et al., \textit{Femtosecond X-ray Protein Nanocrystallography}, 470 \textit{NATURE} 73 (2011).
\bibitem{28} Ronald L. Koder et al., \textit{Design and Engineering of an O\textsubscript{2} Transport Protein}, 458(7236) \textit{NATURE} 305, 308 (2009).
\bibitem{29} Brendon Conlan, \textit{Designing Photosystem II: Molecular Engineering of Photo-catalytic Proteins}, 98(1-3) \textit{PHOTOSYNTH. RES.} 687, 690 (2008).
\end{thebibliography}
have clarified the water substrate binding sites. Research in photochemical conversion will have discovered ways to decrease entropy by imposing constraints on the spatial relations among the pigments, donors and acceptors.

Household artificial photosynthesis systems will incorporate designer molecules (or maquettes) that prolong the charge separation necessary to generate electron flow. These will probably apply one or either of two strategies: chemical bonds in supramolecular structures, or supports such as polymers, zeolites, sol-gel glasses, lipid membranes and self-assembled films.

The perfected AP catalysts for oxidation of water and for the reduction of CO$_2$ will be based on detailed understanding of multi-electron and multi-step catalytic events. The quantum yield will have increased to near unity and the turnover number to $\sim 10^7$ perhaps by exploiting the capacity of the built-in electric field of nanoscale and microscale semiconductor p-n junctions to add photovoltages in series. The most globally widespread water catalytic system will involve inexpensive and self-repairing components that operate under ambient conditions at neutral pH with non-pure (salty or bacterially and chemically contaminated) water. Such a novel water oxidation center will also be stable to a variety of exposure conditions in air, water and heat.

The water-splitting sections of AP devices in widespread use may involve metal complexes and molecular assemblies on surfaces and in rigid media. A variety of other approaches may also have proven successful. A major challenge overcome will have been to optimize the free energy

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30 Hillier & Wydrzynski, supra note 11, at 316.
31 See generally Devens Gust & Thomas A. Moore, Mimicking Photosynthesis, 244 SCIENCE 35 (1989).
37 See generally Qiushi Yin et al., A Fast Soluble Carbon-free Molecular Water Oxidation Catalyst Based on Abundant Metals, 328 SCIENCE 342 (2010).
38 See generally James H. Alstrum-Acevedo et al., Chemical Approaches to Artificial Photosynthesis, 2, 44(20) INORG. CHEM. 6802 (2005).
New catalysts for H₂ production and methods for efficient H₂ storage are being built. Nanotechnology is likely to have made smaller and more efficient components that are less susceptible to oxygen induced free-radical damage than H₂ – evolving bacteria genetically modified with less oxygen-sensitive hydrogenases, or even wholly synthetic photosynthetic bacteria with electron flow directed towards the H₂-producing enzymes and away from competing pathways.  

In the AP “dark reaction” ATP and NADPH as well as carbon dioxide (CO₂) will be used in an enhanced version of the Calvin-Benson cycle to make locally usable food or fuel (for domestic, heating, cooking, light and transport) in the form of carbohydrate via the enzyme RuBiSCO (Ribulose-1,5-bisphosphate carboxylase oxygenase). Redox-active CO₂ carriers will recover the necessary CO₂ directly from the atmosphere and pump it over significant concentration ranges. CO₂ reduction and H₂O oxidation half-reactions may have been coupled to remove the need for a sacrificial electron donor. Photochemical methods coupled with time-resolved spectroscopy will have identified and monitored intermediates and rate-limiting processes in the reaction cycle leading to H₂ evolution, aiding the development of photosensitizers and electron relays that are not inhibited

(ΔG) required for the overall water splitting process. New generation semiconducting oxide photoelectrodes may have been perfected. Multiwalled carbon nanotubes and singlewalled carbon nanotubes might have produced the critical breakthrough. Water oxidation systems utilizing photosensitive components grafted by core-shell nanowires to a genetically engineered virus may have proven important. So may the role of carotenoid polyenes in providing protection from singlet oxygen damage.

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42 Woong Kim et al., Interfacing Silicon Nanowires with Mammalian Cells, 129(23) J. AM. CHEM. SOC., 7228-29 (2007).
43 See generally Sgobba & Guidi, supra note 20.
44 See generally Yoon Sung Nam et al., Biologically Templated Photocatalytic Nanostructures for Sustained Light-driven Water Oxidation, 5(5) NATURE NANOTECHNOLOGY 340 (2010).
45 Gust et al., supra note 27, at 3.
46 Ann Magnuson et al., Biomimetic and Microbial Approaches to Solar Fuel Generation, 42(12) ACCT. CHEM. RES. 1899, 1907-08 (2009).
47 Gust & Moore, supra note 31.
by acids. 50 Multiple photoinduced charge separation pathways will accumulate several redox equivalents at a single redox site to improve the efficiency of CO\textsubscript{2} reduction and bio-inspired self-repair strategies will have ensured this aspect of GAP survives damage from repeated cycles of thermodynamically demanding reactions. 51

**IV. WHY ARTIFICIAL PHOTOSYNTHESIS WILL BECOME A MAJOR AREA OF INTERNATIONAL TRADE AND INVESTMENT?**

Artificially enhanced photosynthesis, if applied equitably, could produce tradable products that assist crop production on marginal lands, reduce atmospheric CO\textsubscript{2} levels, lower geopolitical and military tensions over fossil fuel, food and water scarcity and create carbon-neutral hydrogen fuel for domestic, community and industrial storage. 52 One Global Artificial Photosynthesis (GAP) model involves bio-mimetic polymer photovoltaic generators plugged in to the national electricity grid to power hydrogen fuel and waterless agriculture, chemical feedstocks and polymers for fibre production. 53 This model has the advantage of the “light” and “dark” reactions being uncoupled in relation not only to energy/material flow balance, but also to the requirement to be co-located in space. Such an uncoupling will vastly extend the area for capturing light over otherwise barren land, and also allow the elimination or reduction of molecular oxygen in GAP reactions, enhancing longevity of the components.

Another model emphasizes the greater potential for individual and community economic autonomy implicit in micro or local generation of fuel and food through GAP products installed as a policy priority on domestic dwellings and vehicles. Large GAP facilities providing fuel for industry or backup supply can still be preferentially located under such a model near large sources of seawater, CO\textsubscript{2}, waste heat, high solar irradiation and proximity to end use facilities.

Global promotion of AP (through its potential to reduce carbon dioxide) is directly relevant to the 2009 Copenhagen Accord – a non-binding political agreement that recognized the critical impacts of population growth and fossil fuel-driven climate change as well as the need to establish a comprehensive adaptation program including international support for those countries most vulnerable to its adverse effects. 54 For the
first time, all major CO₂-emitting countries agreed to a target of keeping global warming to less than 2°C above pre-industrial levels. It contained important undertakings concerning mitigation including the Copenhagen Green Climate Fund and establishing a mechanism to accelerate renewable energy technology development and transfer. 55 Other important internationally agreed targets to reduce poverty and lack of necessary fuel and food as expressed in the United Nations Millennium Development Goals. 56 These critical survival issues for the poor will be exacerbated as global population grows towards 10 billion by 2050 and energy consumption rises over 600 EJ/yr.

Many observers have derided such so-called “soft-norm” (unenforceable and non-legally binding) agreements as facilitating a model for business-as-usual by the fossil fuel-related industries that are so central to energy supply and anthropogenic climate change. What if, however, science could provide in the next 20 years a means by which such goals and principles could be satisfied without compromising the capacity of people to obtain sufficient energy for survival and flourishing?

What if the global economy’s energy dependence on fossil fuels could be reduced as GAP products allowed buildings, cars, planes and ships became producers of their own fuel? Economies would restructure to emphasize smaller locally-powered and controlled units, minimizing energy use in transportation (much present-day energy consumption is dedicated to gathering raw materials and low-cost labor to make and transport goods for use in other countries). Nanotechnology-based artificial photosynthesis systems might be programmed to remove carbon dioxide from the atmosphere in proportion as it was used in the burning of the produced ethanol, or help coastal industrial plants split sea water using sunlight to produce carbon-neutral hydrogen-based fuels.

Such thought experiments involve a future perspective in which solar fuels created though humanity’s capacity to fully understand the principles and enhance (particularly through nanotechnology) the operation of photosynthesis, have become the predominant form of energy generation on the planet. Such micro or local generation of food and fuel will challenge the present paradigm of centralized fossil-fuel oriented power generation controlled by multinational corporations. It may not be an easy transition for them to manage and they may resist or try to delay the change to a GAP-fuelled world. International trade and investment law may provide them with a particularly useful mechanism in this regard.

55 Id.
Establishing the principles for dissemination of GAP technology under international trade and investment law will be equally important with facilitating the scientific collaborations that will allow it to take place in time to address the major societal and environmental challenges that the expanding human population and its dependence on fossil fuels are currently creating.

Societies, just as individuals, acquire virtues or character traits through the consistent application of principles in the face of obstacles. In the past those principles were predominantly a matter of philosophic and religious, as well as legislative and judicial debate. One hypothesis is that it should be statements on bioethics and human rights by international organizations such as the United Nations or UNESCO instead of international trade and investment law that consensually shape the principles applied in globally rolling out new technologies such as artificial photosynthesis.

“Soft-law” norms, the United Nations Millennium Development Goals, for instance, may be particularly valuable in this context as they have a high global symbolic resonance and democratic acceptance and are particularly focused on issues of energy storage, production and conversion, agricultural productivity enhancement, water treatment and remediation and experts have encouraged nanotechnology to systematically contribute to their achievement. Principles supporting similar goals (and directed to individuals, communities and private corporations as well as States (Article 1)) appear in the UNESCO Universal Declaration on Bioethics and Human Rights (particularly the social responsibility principle in Article 14(b) – “access to adequate nutrition and water,” 14(c) – “improvement in living conditions and the environment” and 14(e) – “reduction in poverty and illiteracy”).

V. GOVERNANCE OF GLOBAL ARTIFICIAL PHOTOSYNTHESIS AND INTERNATIONAL TRADE LAW

There are high stakes for supranational corporations should the nanotechnology revolution begin to develop global artificial photosynthesis (GAP). Many global corporate entities may be concerned that GAP products will take financial and political power from their hands and return it to individuals and communities. Studies such as the Limits to Growth report confirm how the process of corporate profit-driven economic growth

utilizing the structures of international trade and investment law is undermining the capacity of the biosphere to support the human species.

International trade, and more particularly international trade and investment law, lies at the heart of the corporate globalisation process by which foreign capital takes advantage of abundant natural resources (particularly timber, oil, coal and minerals) or cheap labor, to manufacture products for distribution and profitable sale throughout the world using road, rail, sea and air freight transport, reduced tariffs and mass marketing techniques. If international trade in GAP products is to make a successful contribution to public and environmental benefit, then established thinking suggests it must be rolled out utilising this “free trade” and corporate globalisation process.

International trade and investment law, which provides the rules governing the system of corporate globalisation, does not sit easily within established social contract, rule of law, or science-based natural law thinking. There are many reasons for this. One is that international trade and investment law is a normative scheme with a limited range of corporate-focused interests that do not cover the full range of human societal and environmental concerns. The second is that it represents law at the service of private corporate interests that has never emerged from protracted social contract thinking – its democratic legitimacy rests chiefly on an indirect link to the representatives of nation states who have rarely if ever sought a democratic mandate about its activities. The third is that its governance mechanisms are not transparent or accountable to international civil society or the rule of law. The discussion that follows highlights some important ways in which international trade and investment law may create obstacles to the successful international trade of GAP products.

The World Trade Organisation (WTO) is headquartered in Geneva near many of the United Nations human rights organisations with which it normatively has so little in common. The WTO is comprised of a secretariat and public officials from nation states who have been involved in agreements by which those states agree to not merely reduce various trade barriers, but to allow supranational corporations to take control of major national assets (such as intellectual property, hospital and health services, water, agriculture, power-generation and manufacturing) in a way that is very hard to undo (due to the compensation to corporate stakeholders that must be paid by taxpayers). What has been created in other words is a supranational corporation-controlled legal system that is pushing global governance in directions different to those of democratic-based community and civil society institutions committed to societal virtues such as justice, equity and, increasingly, environmental sustainability.

One example of a WTO agreement that may create particular problems for the global roll-out of output from a macroscience NES project is the
Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). TRIPS is a pro-patent agreement likely to increase the price paid by governments, communities and citizens for nanotechnology-based products, by requiring increased patent terms and enhanced protection of patent monopolies under threat of trade sanctions. Its norms can be relied upon by corporate lobbyists to restrict the capacity for governments to issues compulsory licenses and mass-produce cheaper versions of patented GAP products in public health emergencies. The WTO General Agreement on Trade in Services (GATS) likewise allows small cliques of government trade officials (many of whom have been appointed from, and/or will subsequently be rewarded with, lucrative private sector employment) to “liberalise” various health-related service areas (such as hospitals, electricity and water utilities) where GAP technology might be prioritized by governments. That privatization process is likely to diminish the likelihood that GAP technology will be speedily implemented in those sectors, even if that is in the global public interest, if such a course would undermine the relevant corporate profits.

“Liberalise” is a word which draws on liberal ideologies of individual freedom, but in this WTO usage it appears to represent pro-corporate “spin” to disguise a process that in effect facilitates the ownership of such services by foreign-based private corporations with little local accountability or motivation to reduce costs to citizens. Such WTO agreements arose despite considerable evidence against the public benefit of applying pro-privatisation, neo-classical economic theory to the health and environment sectors. Missing from such sectors, for example, are a genuinely competitive market, government capacity to regulate the market to prevent market failure, or the ability to accurately place a financial value interests such a good health or a pristine environment in financial terms.

Other WTO multilateral agreements potentially likely to create obstacles for GAP products include the Agreement on Agriculture (AoA), the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) and the Agreement on Technical Barriers to Trade (TBT). In the period 1970-2000, in order to obtain leniency on national debt repayments, many less developed nations were coerced into removing trade barriers via the Structural Adjustment Policies (SAPs) of the International Monetary Fund (IMF) and World Bank. SAPs were a practical manifestation of the so-called “neoliberal political-economic consensus” that recommended deregulation of financial institutions and government technology regulators, so that free market forces could operate in more lucrative pro-monopolistic conditions.

In practice, neoliberal economic policy and SAPs entailed reductions of government expenditure on health, welfare, education and other public services; privatization of government enterprises and utilities; reducing
government tax revenues; elimination of tariffs and subsidies (in practice for developing nations but not for protected agricultural industries in developed nations); undermining laws for minimum wages, collective bargaining, unfair dismissal and improved employment conditions, opening of capital and currency markets; removing barriers to foreign direct investment; and promotion of private property rights over natural resources and public goods. Such WTO policies, in other words cut across and even opposed policy initiatives and domestic legislation emerging out of established social contact understandings predicated on foundational social virtues such as justice, equity and environmental sustainability. To the extent that GAP products may have a profound impact of developing nations economic situations and debt levels SAPs could have a major impact in either facilitating or inhibiting their roll-out.

WTO agreements do contain some recognition of public health and environmental norms that are likely to assist global roll-out of GAP products. Article 27.2 of TRIPS for example provides: “Members may exclude from patentability inventions, the prevention within their territory of the commercial exploitation of which is necessary to protect public order or morality, including to protect human, animal or plant life or health or to avoid serious prejudice to the environment.”

Likewise Article XIV of GATS provides: “[N]othing in this Agreement shall be construed to prevent the adoption or enforcement by any Member of measures: (a) necessary to protect public morals or to maintain public order; (b) necessary to protect human, animal or plant life or health; (c) necessary to secure compliance with laws or regulations which are not inconsistent with the provisions of this Agreement including those relating to: (i) the prevention of deceptive and fraudulent practices . . . .”

Article XXb of the GATT (adopted in 1947 and incorporated into WTO Agreements in 1994) similarly allows an exception to GATT corporate privatisation rules when that is necessary “to protect human, animal, or plant life or health.” Exceptions along these lines are now found in the Agreements on Application of Sanitary and Phytosanitary Measures (SPS agreements) and the Technical Barriers to Trade (TBT) agreement. The problem is that such considerations exist as difficult to justify exceptions, rather than equally important considerations with core international trade law concepts such as “liberalization” (which can be translated as “open-access to social control by supranational corporations”).

To give an example, in 1988 the European Union (EU) imposed a ban on the sale of beef from cattle fed with artificial hormones following the precautionary principle and evidence that this could cause cancer or nerve disorders. The U.S. challenged the decision in 1996 and a WTO panel of trade lawyers ruled the ban was illegal, (against the restricted set of WTO
norms they apply) chiefly because it was inconsistent with the SPS agreement and its risk-assessment procedures.

More recently United States-based corporations have been instrumental in inducing the U.S. Trade Representative (USTR) to negotiate a series of regional and bilateral Free Trade Agreements (FTAs) in which provisions are included increasing intellectual monopoly privileges (IMPs), promoting investor-state dispute settlement mechanisms and pressuring health-technology cost-effectiveness assessment systems in ways not possible in the WTO (where the bargaining power of the U.S. is countered by opposing blocks of developing countries). These mechanisms too could become obstacles to global roll-out of GAP products.

The United States has a long history of using trade law to influence health and environmental policies in other countries to the benefit of its corporations. In 1988, for example, amendment called “Special 301” was made to a section of the Trade Act 1974. This became the principal statutory authority under which the U.S. investigated and, if need be, threatened trade sanctions against foreign countries that maintained acts, policies and practices that its corporations considered violated, or denied their rights or benefits under trade agreements, or, through otherwise being justifiable, reasonable or non-discriminatory, nonetheless burdened or restricted U.S. commerce. The USTR was required under the Trade Act 1974, to create, in its annual review, a Special 301 Report Priority Watch List. Using this mechanism corporations could petition the USTR to investigate and, ultimately, threaten trade sanctions against what they perceive to be an unjustifiable, unreasonable or discriminatory policy related to utilization of GAP products by a foreign country (for example a subsidy for GAP products that were competing in the market against existing patented products).

The capacity of U.S. bilateral trade agreements to undermine global marketing of GAP products is highlighted by their use to attempt to alter public-focused regulatory processes such as quarantine, blood fractionation, safety and cost-effectiveness assessment of health technologies. A World Health Organization (WHO) commission and numerous civil society publications have documented the contradictory relationship of such provisions with the Doha Declaration on TRIPS and Public Health and their potentially deleterious impacts on public health.

The tactics that might be employed by supranational companies in connection with trade agreements to preferentially alter domestic governance arrangements concerning GAP products, are both multitudinous and morally questionable – for not being capable of universal application and lacking coherence with global or domestic social contracts. Apart from specific provisions increasing intellectual monopoly privileges they may include revolving door appointments (between private interest
lobby groups and the USTR trade offices) and “working groups” established under bilateral and regional trade agreements to lobby for and block domestic governance changes in the other signatory nations.

VI. GLOBAL ARTIFICIAL PHOTOSYNTHESIS AND INVESTOR-STATE PROVISIONS

Another tactic of particular concern as a potential obstacle to global roll-out of GAP products are attempts by supranational corporations to influence global governance regimes by means of so-called “investor state” dispute settlement provisions. In the 1990’s civil society prevented the creation of a supranational investment protection agreement (the Multilateral Agreement on Investment or MIA) that would have allowed the global implementation of such provisions, but they have nonetheless proliferated in a series of bilateral and regional arrangements. Basically they allow supranational corporations to sue (before small panels of commercial arbitration lawyers with little understanding of or desire to apply international public law) other countries who have imposed governance requirements (even when in the public health and environmental interest based on good scientific evidence) if their commercial interests are thereby impeded.

Investor-state provisions surfaced in the failed Multilateral Investment Treaty (MAI) in the 1990’s and in the 1994 North American Free Trade Agreement (NAFTA) between the United States (the U.S.), Canada and Mexico.60 They are now part of over 2000 bilateral investment treaties (BITs).61 They grant investors covered by them a right to initiate dispute settlement proceedings (before a panel of trade lawyers known as commercial arbiters) for damages against foreign governments in their own right.62

The lawyers officiating on such arbitral proceedings are view such investment agreements as private contracts, are paid by the parties and do not necessarily take account of domestic public health and environment protections – creating a pro-investor jurisprudence. It should be of concern to those supporting marketing of GAP products that investor state


challenges have occurred in relation to a broad spectrum of public health and the environment legislation and policies. Supranational corporations could use this mechanism to claim compensation where a global NES project was subsidized by a government on the basis that its products were more environmentally friendly, or safe from a public health point of view. For example, statutes on water protection, waste disposal and waste treatment as well as universal health care or access to affordable medicines have been challenged by supranational corporations under investor-state mechanisms.

Should GAP products begin to look as if they are likely to replace those upon which supranational corporations have substantial investments (in say old photosynthesis fuels or electricity distribution networks), then those corporations may well resort to investor state mechanisms to protect their profits and inhibit the roll-out.

The investor state legal mechanism sits in a twilight zone between international public law (including international human rights law) and commercial arbitration. In Philip Morris’s investor state claim against Australia, one of the lawyers on the dispute resolution panel will be chosen by Philip Morris. That company will undoubtedly chose a commercial arbitrator who views the issues through the narrow vision of contractual rights. Such a tribunal member is unlikely to view sovereign states as having, for example, capacity to issue interpretive declarations of their intentions under the treaty for instance though legislation (as would normally be the case under international public law). The United States has never lost an investor-state dispute settlement claim.63

Australia can chose another member of the panel, but this might often be done through the agency of a private legal firm that doesn’t appreciate the importance of ensuring a lawyer is appointed with public law expertise. Each party then chooses the president of the panel who has the deciding vote. It will be important but very difficult for Australia to get a lawyer with a public law background into that role.

Investor state provisions have been criticized as allowing foreign investors leverage to undermine government legislation promoting, for example, sustainable development, environmental protection, and public health policy.64 Investor state dispute settlement claims have challenged attempts by nation states to regulate against chemicals proven to cause developmental disability,65 neurotoxins,66 hazardous lawn pesticides67 and

63 See generally HUMAN RIGHTS IN INTERNATIONAL INVESTMENT LAW AND ARBITRATION, (Pierre-Marie Dupuy et al. eds., 2010).
carcinogenic gasoline additives. The mechanism has also been used by foreign corporations to attempt to overturn legislation on water security, waste disposal, waste treatment and a U.S. ban on cattle with suspected bovine spongiform encephalopathy (BSE or mad cow disease).

The Australian Productivity Commission’s final report in December 2010 recommended that the government should seek to avoid the inclusion of investor state dispute settlement provisions in its trade agreements. The Commission found against the need for such provisions because in most instances the desire on the part of governments to retain a good reputation with foreign investors, the lack of systematic regulatory bias against foreign investors, the availability of insurance and investor-state contracts as well as the “considerable policy and financial risks” arising from them.

The Australian government signaled that it did agree with the inclusion of investor state dispute settlement provisions in the TPPA, though this was probably one of the main reasons the TPPA was initiated by the U.S. In a published letter responding to an opinion editorial piece (by the author and a colleague) about the inclusion of investor state provisions in TPPA, Australian Trade Minister Simon Crean wrote: “Let me say we have serious reservations about the inclusion of investor-state dispute settlement provision in this agreement. We do not want new layers of red tape under the guise of trade liberalization. Australian negotiators will make this clear at the Melbourne meeting which concludes today.”

In 2011 the Australian Government went further and announced in a Trade Policy Statement:

Some countries have sought to insert investor-state dispute resolution clauses into trade agreements. Typically these clauses empower businesses from one country to take international legal
action against the government of another country for alleged breaches of the agreement, such as for policies that allegedly discriminate against those businesses and in favor of the country’s domestic businesses . . . . The Gillard Government supports the principle of national treatment – that foreign and domestic businesses are treated equally under the law. However, the Government does not support provisions that would confer greater legal rights on foreign businesses than those available to domestic businesses. Nor will the Government support provisions that would constrain the ability of Australian governments to make laws on social, environmental and economic matters in circumstances where those laws do not discriminate between domestic and foreign businesses. The Government has not and will not accept provisions that limit its capacity to put health warnings or plain packaging requirements on tobacco products or its ability to continue the Pharmaceutical Benefits Scheme.

In the past, Australian Governments have sought the inclusion of investor-state dispute resolution procedures in trade agreements with developing countries at the behest of Australian businesses. The Gillard Government will discontinue this practice. If Australian businesses are concerned about sovereign risk in Australian trading partner countries, they will need to make their own assessments about whether they want to commit to investing in those countries.

Foreign businesses investing in Australia will be entitled to the same legal protections as domestic businesses, but the Gillard Government will not confer greater rights on foreign businesses through investor-state dispute resolution provisions.75

VII. GLOBAL ARTIFICIAL PHOTOSYNTHESIS AND NON-VIOLATION NULLIFICATION OF BENEFITS

Another tactic by which international trade agreements may create obstacles for marketing of GAP products is the non-violation nullification of benefits (NVNB) provision. Highly secretive and poorly understood, NVNB clauses further heighten the suspicion that what has been created in the WTO dispute resolution process is not law emerging from a social contract, but law at the service of large scale private corporate interests.

NVNB claims are directly referred to in Article 26 of the WTO *Dispute Settlement Understanding* (DSU), in the GATT, Article XXIII of GATS and Article 64 of TRIPS. Under such NVNB provisions, the full range of dispute resolution mechanisms may be invoked whether or not a breach of any specific provision in a trade agreement is alleged or substantiated. The precondition is that a “reasonably expected” “benefit” accruing under the relevant trade agreement, has been “nullified or impaired” by a “measure” applied by a WTO Member. NVNB provisions thus cut across two of the foundational social virtues underpinning the rule of law under domestic or global social contracts – certainty and predictability.

Both the United States and European Economic Community have argued before a GATT 1994 panel that recourse to NVNB claims should remain “exceptional” otherwise “the trading world would be plunged into a state of precariousness and uncertainty.” Nevertheless, contemporary controversy over NVNB claims and proceedings arises in large part from their potential to allow a WTO Member to tactically exploit a trade agreement’s textual “constructive ambiguities” and threaten a dispute if a wide and largely undefined range of domestic regulatory components are not altered, or compensation organized use of NVNB provisions may facilitate a WTO dispute settlement process involving deliberate diplomatic “gaming” of trade “rules”, from what had otherwise been viewed as finely balanced textual truces (such as between the advertising and scientific definitions of “innovation” in Annex 2C of the AUSFTA), where uncertainty is deliberate and inherent and dispute panel interpretation more an act of ongoing negotiation, than judicial analysis.

Article 3.2 of the DSU requires panels to clarify existing provisions of agreements in accordance with customary rules of interpretation of public international law. This leads to consideration of how the NVNB principle interacts with Article 26 of the *Vienna Convention on the Law of Treaties*, incorporating the principle of *pacta sunt servanda*: “Every treaty in force is binding upon the parties to it and must be performed by them in good faith.” NVNB claims appear to undermine this fundamental principle of international law by subsequent reinterpretations based on the “spirit” of the agreement. At the WTO meeting in Hong Kong in December 2005, the United States delegation pushed hard behind the scenes for trade concessions in return for its acquiescence to the moratorium on the use of NVNB provisions under TRIPS. The resultant Ministerial Declaration left the position of NVNB claims under TRIPS extremely uncertain.

NVNB claims, in other words, may become another tactic whereby supranational corporations whose interests are allegedly adversely impacted, may attempt to inhibit governments from passing legislative subsidies or other measures supporting a global NES project even where that involves no direct violation of any WTO or bilateral trade agreement.
VIII. GLOBAL ARTIFICIAL PHOTOSYNTHESIS AND THE OPEN-ACCESS MODEL

An open-access model for research and marketing of GAP products involves 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 GAP partnership model might facilitate members’ access to non-exclusive licenses over IMPs. Many of the debates that will impact on GAP here are already being played out in relation to synthetic biology. Intellectual monopoly privileges (IMPS) claimed over GAP components (such as antenna systems, reaction centers and water catalysts) will be hard to identify, fragmented across many owners and sometimes overly broad. These factors may make it harder for would-be GAP innovators to get licenses and patents as GAP research advances.

As GAP research progresses towards the mass-production and distribution phase, the need for common standards may promote a “tipping dynamic” in which one solution owned by a single corporation quickly comes to dominate the field. GAP will probably benefit not from following the “dog-eat-dog” patent wars of pharmaceutical research and development, but from examples such as the mobile telephone industry where no single manufacturer owns every patent that covers its product – forcing sharing arrangements. The number of licensing transactions that GAP firms face could be reduced by facilitating limited or unlimited open-access the core, widely used parts of GAP technology.

Patent pools between the public-private sectors with zero royalties could be used to promote GAP collaboration, but contributors will have to ensure the terms they agree on don’t violate anti-monopoly laws by excluding competitors. The complex technologies involved in GAP may cause researchers competing in this rapidly advancing area to unintentionally infringe IMPs, especially when patents are allowed to be broad and numerous or vaguely written. Companies called “patent trolls” may infest the GAP area as they have in that of biotechnology. Such firms will acquire patents (for example form bankrupt GAP-related firms) simply to parasitically profit from the evolving research needs of GAP researchers. In another field (the software industry), the Open Innovation Network gets

77 See also Geertui Van Overwalle et al., Models for Facilitating Access to Patents on Genetic Inventions, 7(2) NAT. REV. GENET. 143, 143-47 (2006).
around this by buying up Linux-related patents.\textsuperscript{80}

A further issue is that GAP firms and their researchers will tend to become locked into researching parts of artificial photosynthesis with which they have become familiar, have ready legal access, or are already widely used across the industry and less likely to be the subject of IMP challenges. The important point is that if the most widely used GAP components parts are subject to some form of open-access permission then the research will proceed faster. This effect can be enhanced if GAP researchers are encouraged to deliberately choose “open” rather than “closed (patented)” parts. GAP-involved firms and universities (given incentives such as raising profile, obtaining reciprocal access and building a user base) could donate part of their data to open source projects.\textsuperscript{81} Additionally, companies involved in public-private linkage projects with GAP researchers might 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 would then provide a powerful incentive for voluntarily limiting the patent duration claimed in such a submission.\textsuperscript{82}

Many specific open-source models exist that the governance structures of a GAP Project might draw upon. Cambia’s Bioforge initiative \textit{BiOS} (Biological Open Source), for instance, is a legally enforceable framework to enable the sharing of the capability to use patented and non-patented technology materials and methods, within a dynamically expanding group whose entry was conditional upon consent to the same principles of responsible sharing, in a “protected commons.” Those who join a BiOS “concordance” agree not to assert IMP rights against other members’ use of the technology to do research or develop products (whether for profit or public good).\textsuperscript{83} Similarly, the \textit{Initiative for Open Innovation} (IOI) is a new global facility, funded through grants from the Bill & Melinda Gates Foundation and The Lemelson Foundation.\textsuperscript{84} The \textit{BioBricks Foundation} (BBF), likewise, is a not-for-profit organization founded by engineers and scientists from MIT, Harvard, and UCSF with significant experience in both non-profit and commercial biotechnology research. BBF encourages the development and responsible use of technologies based on BioBrick\textsuperscript{TM}


\textsuperscript{82} Henkel & Maurer, \textit{supra} note 79.

\textsuperscript{83} BiOS, \textit{About BiOS (Biological Open Source) License and MTAs}, http://www.bios.net/daisy/bios/mta.html (last visited Sept. 25, 2011).

standard DNA parts that encode basic biological functions.85

Members who join an open-source-structured GAP Project collaboration might be contractually granted brief periods of exclusive ownership (much less than 20y patent terms) in return for a promise to afterwards share data and 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 – as happens with the Merck Gene Index (MGIP). The MGIP promotes the unrestricted exchange of human genomic data, and facilitates progress in biomedical research by reducing duplication of efforts did, speeding the identification of disease-related genes.86

One example of how open-source governance may assist to speed up that pace of GAP research derives from how multinational pharmaceutical companies have supported the SNP Consortium.87 The SNP Consortium was established in 1999 as a collaboration of several companies and institutions to produce a public resource of single nucleotide polymorphisms (SNPs) in the human genome. The initial goal was to discover 300,000 SNPs in two years, but by 2001, 1.4 million SNPs had been released to the public domain.88

IX. INTERNATIONAL PUBLIC LAW AND PHOTOSYNTHESIS AS PLANETARY COMMON HERITAGE

A GAP Project governance structure emphasizing international law might protect photosynthesis from excessive patents promoting inequitable or unsustainable use within the class of United Nations treaties involved with protecting the common heritage of humanity (such provisions cover, for instance, outer space,89 the moon,90 deep sea bed,91 Antarctica92 and world natural heritage sites93). Five core components are generally regarded

87 Henkel & Maurer, supra note 79.
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.94

The claim for GAP and its core components to common heritage status would likely be at an inchoate stage initially. Probably the closest analogies involve claims that genetic diversity of agricultural crops,95 plant genetic resources in general,96 biodiversity or the atmosphere97 should be treated as not just areas of common concern but subject to common heritage requirements under international law. The non-binding UNESCO Universal Declaration on the Human Genome and Human Rights, for example, only goes so far as to declare in Article 1 that: “The human genome underlies the fundamental unity of all members of the human family, as well as the recognition of their inherent dignity and diversity. In a symbolic sense, it is the heritage of humanity.” Article 4 states: “The human genome in its natural state shall not give rise to financial gains.”99 Other international law concepts that could be influential are those that may declare GAP a global public good,100 an aspect of technology sharing obligations,101 or those

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95 See generally GREEN GLOBE YEARBOOK 1993: AN INDEPENDENT PUBLICATION ON ENVIRONMENT AND DEVELOPMENT FROM THE FRIDTJOF NANSSEN INSTITUTE, NORWAY 33 (Helge Ole Bergesen & Georg Parmann eds., 1993).
100 Inge Kaul, Financing Global Public Goods: Challenges, in LIMITS TO PRIVATIZATION: HOW TO AVOID TOO MUCH OF A GOOD THING 311 (Ernst Ulrich et al. eds., 2005).
101 See generally Thomas Alured Faunce & Hitoshi Nasu, Three Proposals for Rewarding Novel Health Technologies Benefiting People Living in Poverty. A Comparative Analysis of Prize Funds,
arising under the international right to health (set out for example in Article 12 of the United Nations International Covenant on Civil and Political Rights). The UNESCO Declaration on the Responsibilities of the Present Generations Towards Future Generations expresses a concept of planetary common heritage that could encompass GAP in Article 4: “The present generations have the responsibility to bequeath to future generations an Earth which will not one day be irreversibly damaged by human activity. Each generation inheriting the Earth temporarily should take care to use natural resources reasonably and ensure that life is not prejudiced by harmful modifications of the ecosystems and that scientific and technological progress in all fields does not harm life on Earth.”

Planetary medicine is now a growing field in which the expertise of medical professionals in directed towards issues of global health and environmental protection, particularly including climate change. A GAP Project could well be promoted through domestic and international media as a defining symbolic endeavour of planetary nanomedicine. One significance of this for artificial photosynthesis researchers is that funding agencies respond indirectly to public and governmental national interest concerns and nanotechnology, despite its great promise, still has a problematic place in the popular imagination owing to safety issues. A GAP Project therefore represents an excellent opportunity to create a high profile awareness of nanotechnology as a positive contributor to overcoming major contemporary public health and environmental problems.

The process of photosynthesis is as central to life on earth as DNA; thus there are likely to be similar major debates over whether patents should be allowed over any part of the photosynthetic process. Such a debate will be unlikely to inhibit patents being taken out over many aspects of GAP. The U.S. Supreme Court, for example, has ruled that genes (despite the symbolic importance of DNA to human heritage) can be patentable if they are isolated and purified.

GAP research and development will also face major issues about

whether patents should cover GAP products as well as processes and functions. 107 It is likely that in the U.S. the “utility” for a GAP patent (as is the case for DNA) will be that it must be specific, substantial and credible. 108 If GAP IMP ownership becomes fragmented, researchers in the field may find their “follow-on” research hampered by the high cost and difficulty in negotiating contracts with large numbers of GAP IMP owners. Each individual GAP patent owner, for example, without some prior licensing and sharing arrangement, will have an incentive to overcharge other researchers requiring access. 109

X. CONCLUSION

This article has set out to explain why the development of marketable products from artificial photosynthesis research is likely to pose considerable challenges to international trade and investment laws, particularly if a Global Artificial Photosynthesis (GAP) project succeeds in rolling out this technology. It is possible that international public law and trade and investment law will come into conflict with initiatives to declare aspects of photosynthesis common heritage of humanity and so open to restricted claims of intellectual monopoly privilege. It is important that efforts are made to reduce the potential for such conflicts, particularly by increasing the breadth of normative considerations, the democratic legitimacy, transparency and accountability of international trade and investment dispute resolution processes.

107 Jane Calvert, Patenting Genomic Objects: Genes, Genomes, Function and Information, 16(2) SCIENCE AS CULTURE 207, 207-221 (2007).
109 Henkel & Maurer, supra note 79.
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