Hydrocarbon Hysteria: Differentiating Approaches to Consumption and Contamination in Regulatory Frameworks Governing Unconventional Hydrocarbon Extraction

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A variety of methods of extracting natural resources and, in particular, those utilised to produce energy from hydrocarbons,[1] provide facts and statistics (of both questionable and acclaimed origin) which shock and appal, or garner considerable support. However, as more research and consideration is given to these, the more realism inevitably emerges in relation to their regulation. In an interesting study of risk it was submitted by Jaeger that, "There can be little doubt that the world economy presently is locked into a path involving a large array of quite serious risks", and that this path is heavily determined by "its dependency on increasing energy use" at the risk of "ecosystem destruction".[2] It is likely that projects seeking to extract previously unconsidered hydrocarbon resources to quench our undeniable thirst for energy will inevitably continue in some form and to some degree. This means regulation will be increasingly difficult and it must be accepted that certain factors cannot be changed.

This article will concentrate, for the purposes of illustration ,on two examples of hydrocarbon extraction below their "peak"[3] in the eyes of scientists to illustrate the theoretical and regulatory issues. The first is the extraction of the so-called oil or tar sands[4] in Alberta, Canada.[5] The material is a partially liquid and partially solid material constituting a mixture primarily of bitumen, water and sand, amongst other elements, often frozen solid during winter owing to its water content. Once extracted from the mixture, the bitumen can be distilled to produce more widely used fuels. The raw material is extracted either by conventional open cast mining,[6] or a number of methods involving the injection of either heated fluid mixtures or steam at high pressure to liquefy the mixture underground, allowing it to be pumped out in a manner akin to conventional crude oil. The second extraction of hydrocarbons is that of "fracking" or hydraulic fracturing. This is the extraction of natural gas through the process of injecting mixtures of water, sand and other chemicals into formations of shale, other rocks, and even coal to allow gas trapped within the seams to flow out and be collected at the well head. The same process is also used to obtain "tight oil" where oil rather than gas is trapped in such a fashion.

[1] For the purposes of the piece, hydrocarbons will largely be confined to the definition afforded in the Hydrocarbon Oil Duties Act 1979 c.5 of "petroleum oil, coal tar, and oil produced from coal, shale, peat or any other bituminous substance, and all liquid hydrocarbons". However, the piece will also consider substances which although hydrocarbons are exempt from the Act, namely gaseous hydrocarbons, and in particular shale gas.

[2] C. Jaeger, R. Ortwinn, E. Rosa and T. Webler, *Risk, Uncertainty and Rational Action* (London: Earthscan, 2001), p.287.

[3] The concept of peak oil was first conceived by petroleum geologist M. Hubbert, who was mocked for his suggestion in a presentation to the Shell Oil Exploration and Production Research Division at Houston, Texas in June 1956. See *http://www.hubbertpeak.com/hubbert/1956/1956.pdf* [Accessed October 15, 2014].

[4] The presence of sand and various minerals in the mixture gives its thick consistency, akin to tar, and hence the colloquial name, tar sands.

[5] Note should be made that tar sands projects exist in numerous other states internationally, however at present, the Canadian industry is by far the most developed and extracts some of the largest known deposits in the world which can be accessed and refined using current technologies.

[6] This approach could be used to source around 10 per cent of known deposits in Alberta.

The first step is accepting you have a problem

The reliance of the modern world on hydrocarbons, including both oil and gas, is undeniable and with conventional oil reserves dwindling, the allure of unconventional sources of energy continues to grow, regardless of negative consequences.[7] Our daily lives are so reliant on oil, gas and their derivatives that to deny our inextricable connection to them for the foreseeable future is unrealistic. Progress towards alternative sources continues unabated, but to expect all such developments in the production of energy and secondary outputs[8] to come to fruition to "rescue" us from our need for hydrocarbons and the resulting production of energy and materials we use constantly would be naïve to say the least.[9] As such the regulatory framework managing the extraction of these substances must reflect that large scale oil and gas extraction is inevitably to continue for the foreseeable future; indeed it is essential that it does. Quite simply we are not yet ready or indeed able to give up our addiction to hydrocarbons.[10]

Extractors, whether nationalised, private or of a hybrid nature are not subject to the same incentives as individuals. There is little or no moral compulsion inherent within them to avoid causing environmental damage through excessive consumption or contamination, or to provide for the needs of future generations. The raison d'etre of companies is to survive, succeed, and to produce and maximise profit.[11] Whilst something of a generalisation, such attitudes are undeniably prevalent in the extraction industry, and none more so than amongst hydrocarbon extractors.[12] The most basic element of these alternate driving factors and aspirations is self-perpetuation. Concepts of intergenerational equity[13] espoused as a moral and ethical basis for environmental protection simply do not apply to corporations; they have no future generations. They are a legal person, an entity created by law to maintain a system predicated in part upon their recognition as being able to bear certain legal rights. As a result, instead of maintaining those of a like nature, regulation should reflect that they are driven to continue to extract, to survive, and instead of preserving, to eliminate those akin to themselves. Were it not for competition regulation, the optimal condition for any production company would surely be as the sole actor within a monopoly.[14]

Similarly, ethical inclinations towards precaution embodied in regulatory theory by the precautionary principle are less applicable to corporate entities than to ourselves. There is an inherent degree of separation from the caution we would apply ourselves, were we extracting the resource.[15] We would not pollute or over-consume the immediate environment around us owing to an inextricable connection thereto for the most basic of needs such as water and food.[16] Companies, for the most part, would not consider such concerns unless forced to do so by regulation or social and media pressure.

[7] See in this regard: A. R. Brandt and A. E. Farrell, "Scraping the Botton of the Barrel: Greenhouse Gas Emission Consequences of a Transition to Low-Quality and Synthetic Petroleum Resources" (2007) 84 *Climate Change* 3.

[8] Materials which do not occur naturally, though consume primary (extracted) outputs in their manufacture.

[9] T. Trainer, *Renewable Energy Cannot Sustain a Consumer Society* (London: Springer, 2007).

[10] In 2012 alone almost 67 per cent of the energy produced in the UK was sourced from hydrocarbons. See *https://www.gov.uk/government/publications/uk-energy-in-brief-2013* [Accessed October 15, 2014].

[11] Matten and Moon call this the "core profit-making responsibility" of companies which drives any action in accordance with standards of corporate social responsibility; D. Matten and J. Moon, "'Implicit' and 'explicit' CSR: A conceptual framework for a comparative understanding of corporate social responsibility" (2008) 33 *Academy of Management Review* 404, 405.

[12] The discussion of corporate responsibility in the oil and gas sector being driven by the implications of a negative corporate image upon success and investment is a well-researched area though for recent discussion in this regard see; D. Spence, "Corporate Social Responsibility in the Oil and Gas Industry: The Importance of Reputational Risk" (2011) 86 *Chicago Kent Law Review* 59.

[13] Rio Declaration on Environment and Development, June 14, 1992, 33 I.L.M. 874 (1992) Principle 3.

[14] This is admittedly somewhat of a generalisation and fails to account for a plethora of external factors to mere output and price control which could make a non-competitive monopoly in production less profitable than an open market. However, the implication here is merely one of little or no inherent ethical or social motivations in many corporate decisions. Analysis of decisions is predominantly on a cost-benefit basis it is argued, and only where the cost of extraction outweighs benefit is this likely to result in it cession. For a more in depth discussion of this issue consider; L. Bossi V. and Petkov, "Monopoly, Time Consistency, and Dynamic Demands" (2012) 13 *Journal of Industrial Competition and Trade* 339 and E. Thompson, "Why World Oil Monopolization Lowers Oil Prices: A Theory of Involuntary Cartelization" (2000) 7(1) *International Journal of the Economics of Business* 63.

[15] D. Spence, "Corporate Social Responsibility in the Oil and Gas Industry: The Importance of Reputational Risk" (2011) 86 *Chicago Kent Law Review* 59.

[16] Donnelly succinctly illustrates this point in his discussion of Markets and Economic and Social Rights, stating "Markets are social institutions designed to produce economic efficiency"; J. Donnelly, *Universal Human Rights In Theory and Practice* (New York: Cornell University Press, 2003), p.200.

Of course, other factors are undeniably present. Markets and their forces are far more complex than this illustration of the compulsion to produce could ever hope to portray. However, the point remains that extraction companies want to, and must, extract hydrocarbons to some degree. Thus to apply the precautionary principle to them based upon traditional conceptions of precaution focused on individual morality is a flawed approach. Instead imposing or exploiting other risks to them in order to initiate precaution is necessary.

Barrett, in his book on the Environment and Statecraft, considers some of the real-world issues faced in situations akin to that of extraction companies by states in their negotiations of international agreements on pollution. They are ultimately competitive entities, driven by the need for profit. As such they not only must extract but are also driven to extract first or in a manner producing the best competitive advantage. Barrett considers what he terms the "first mover advantage", in basic terms, the ability to be able to ensure an outcome based upon acting first and knowing the result of that action.[17] Whilst companies cannot fully predict the ramifications of every action, the "first move" is an advantage they retain in relation to regulation, and exploit where possible. In order to avoid, or at least limit, this impact, regulation must reflect it. One option is to ban the substance extracted or utilised in its entirety. A noble idea and certainly possessing environmental merits, especially in relation to the combustion of hydrocarbons to produce energy, but one as discussed above, inherently utopian. However, the Montreal Protocol has often been cited as an example of its practical application.[18] The provisions of the text, in effect, impose such an approach in relation to chlorofluorocarbons ("CFCS") and is widely regarded as one of the most successful examples of environmental regulation in international environmental law. By requiring all companies to cease the use of these substances, they were forced not only to utilise alternatives available to them, driving their cost down as a consequence, but also to seek economic advantage by developing cheaper and less environmentally damaging alternatives. Such an approach would not, however, be possible in relation to hydrocarbons used to produce energy. Coal, natural gas and oil simply do not have readily available alternatives to which we could switch in spite of their cost and with almost immediate effect and without crippling existing infrastructures globally.[19]

The traditional conception of the precautionary principle,[20] to halt development of a resource in the face of reasonably anticipated or likely environmental impacts, is therefore less easily applied to hydrocarbons.[21] As a society, nationally, regionally and globally, we are as yet incapable of immediate withdrawal from their widespread utilisation. This is not to say that the ultimate goal of regulation should not be to deter the use of hydrocarbons altogether. Indeed such aspirational aims are needed to drive the progression of regulation. Stagnation in the face of ever-evolving industry is arguably as dangerous as absolute inaction. However, these are undeniably long-term goals. Thus focus in the shorter term ought to be directed to goals which can be achieved within that same timeframe. Key concerns which can be placed within this group in relation to the oil sands, hydraulic fracturing, and indeed many other industries can be divided into two broad categories. The first is the consumption of other resources in order to access hydrocarbons, and second is the contamination and adverse effects of the methods adopted to access those hydrocarbons.[22] This distinction between concerns illustrates a considerable regulatory challenge as these two distinct categories necessitate two equally distinct approaches to control and reduction.

[17] S. Barrett, *Environment and Statecraft: The Strategy of Environmental Treaty-Making* (Oxford: OUP, 2003), p.88.

[18] Montreal Protocol on Substances That Deplete the Ozone Layer, art.2.9(c), September 16, 1987, 1522 UNTS 28, 33 (entered into force January 1, 1989).

[19] See *https://www.gov.uk/government/publications/uk-energy-in-brief-2013*. [Accessed October 15, 2014.]

[20] Rio Declaration on Environment and Development, June 14, 1992, 33 I.L.M. 874 (1992) Principle 15.

[21] "The threat of harm and the duty to act need to be linked with some plausible causal hypothesis as the basis for decisions that protect the public health and welfare, including financial resources"; P. L. de Fur and M. Kaszuba, "Implementing the Precautionary Principle" 288 *Science of the Total Environment* 155, 157.

[22] Note should be made that there is, as with all such projects considerable debate between activists and policy makers as the intensity and even existence of some impacts. Those discussed within the piece are the commonly accepted challenges facing the two extraction industries considered.

Assessing the scale

The concerns with regard to the consumption of other resources in the case of the oil sands centre on the usage of water by extraction projects. Vast amounts of water are utilised in the extraction of the raw material from the earth and the necessary post-extraction refinement processes. Estimates as to the volume of water consumed to facilitate the obtaining and processing of the bituminous oil sands range from one to three barrels of water to each barrel of synthetic crude oil produced.[23] To most, such a ratio is perplexing and indeed appears almost ridiculous. Similarly, to fracture deep rock formations to release the natural gas sought by hydraulic fracturing copious amounts of water and other fluids are used to increase pressure in existing faults to expand them. In both, the oil sands and hydraulic fracturing industries, however, there are substantial positive incentives to increase recycling of the water used in this regard. Such consumption of water is, it should be conceded, capable of being reduced. Indeed companies are investing considerable amounts of capital into researching methods of doing so, whether through recycling or the use of alternatives. These actions often actively go beyond government regulations imposed upon them.

In the case of Alberta, Canada, extractors are eminently aware of the need to regulate and reduce their water consumption and are driven by the strict licensing of water consumption.[24] The oil sands licensing system in the province of Alberta is in fact designed to perpetually reduce consumption. This is achieved by reducing the volume allowed to be removed from natural water bodies if the initial quota allocated is not used in full by a firm within a given period. The cost of extracting and transporting water to where it is required and the cost of licenses for such usage are prohibitive. In the case of those costs controlled or imposed by the regulatory authorities this is intentional. Firms are incentivised into reducing potentially environmentally damaging water consumption by a regulatory system which promotes and adds to existing economic motivation to consume responsibly. In essence, the system exploits market forces common to all firms to promote good environmental practice, essentially making the decision to act in a responsible manner "good business sense".

The second category of impact, that of contamination, is, by contrast, not as easily managed. In relation to contamination arising from the oil sands, the focus of consideration will be on the effects of the "tailings ponds". These are vast man made pools of by-products from the extraction and refinement processes which are, in some instances, toxic.[25] They have caused considerable bird deaths and are suggested as leaking significant volumes of the fluid contained therein into the surrounding ecosystem. Discussion of the impacts of hydraulic fracturing will centre upon the controversy over the seismic consequences of the practice and the seepage of the fluid mixture used to cause the fractures exposing the gas sought.

In both the case of contamination and consumption the true extent of the adverse effects of the practices are not known. Such an accusation could be levelled and is indeed conceded in relation to the consumption of water by the oil sands industry of Alberta. Alberta Environment, the government agency tasked with monitoring the impacts of oil sands developments has stated that:

> "Methods for directly determining the impact of reduced water availability on the aquatic ecosystem are not available … and to our knowledge are rare in the international scientific literature."[26]

Whilst the impact of the water removed is not fully known, the volume used is strictly controlled and monitored. These restrictions are based upon existing studies, similar instances, and the breadth of knowledge available and obtained regarding the ecosystems affected, using models and research constructed upon a single recognisable impact which can be recreated for the purposes of analysis. Such an approach

[23] The figures are progressively being reduced by concerted efforts on the part of extractors and refiners to curb water usage. The figures utilised here are provided by the Canadian Association of Petroleum Producers. See *http://www.capp.ca/getdoc.aspx?Docid=193756*.

[24] The regulation of water extraction and recycling is contained within the Alberta Water Act RSA 2000 Chapter W-3 (CAN).

[25] See *http://www.energy.alberta.ca/OilSands/1708.asp#T*. [Accessed October 15, 2014.]

[26] Alberta Environment Fisheries and Oceans Canada, *Water Management Framework: Instream Flow Needs and Water Management System for the Lower Athabasca River* pp.31 at *http://environment.alberta.ca/documents/Athabasca_RWMF_Technical.pdf*. [Accessed October 15, 2014.]

is not available with regard to the impacts of the contamination. Predictability and recreation are simply not possible in relation to contamination impacts owing to the composite nature of contaminants and the innumerable other variable factors which are not in themselves accurately ascertainable. In essence, the lack of knowledge with regard to contamination impacts dwarves that in relation consumption impacts. As a result the management of consumption is based upon far more reliable scientific groundings.

Consumption impacts can be measured with incredible accuracy by both regulator and extractor. Most regulatory systems require periodic reporting of the extraction of water, especially in relation to that removed from natural sources.[27] The degree of contamination by contrast is not as easily ascertained. Such impacts can vary in terms of form, severity, and duration before being able to be either accurately monitored or expunged by naturally occurring processes, if at all. As a result imposing targets in relation to contamination with any certainty as to effectiveness is extremely difficult.[28] In relation to hydraulic fracturing, the fluid mixture utilised to expose and expand fractures in bedrock is different for each operator and indeed, in some cases, varies between wells. Thus to measure the level of contamination from them is fraught with difficulty. Management of this issue varies by jurisdiction. In the United States, many federal jurisdictions protect the composition of the fluid mixture injected from disclosure as trade secrets.[29] Some jurisdictions, and most recently Florida, have however taken steps to make this information publicly accessible.[30]

Similarly the volume of seepage from tailings ponds created by oil sands extraction would vary from pond to pond, as indeed would the concentration and composition of the contents. Again whilst contents of the ponds have to be declared following the decision in *Great Lakes United v Canada (Minister of the Environment)*,[31] the varying nature of their composition makes predictions as to the impact of any seepage fraught with difficulty. Indeed the exact impacts of contamination vary wildly in response to innumerable factors, both from the extraction process itself and the constituent elements of the material extracted and the location from which it is being taken. Taking, for example, just the tailings ponds themselves, the size, location, rainfall, and particular construction of a single pond, and all smaller factors within each of these, as well as their contents, can vary the level of seepage and therefore the impacts of said material once it enters the indigenous ecosystem in which the pond is situated. The very state of tailings is also unpredictable. One of the most challenging issues in relation to the tailings ponds and their reclamation, and as a result the focus of much of the research into them, has been the length of time taken for the initially liquid tailings to settle and dry. The duration of the drying process differs again according to composition, but also in relation to the methods employed to assist or accelerate the transition. As a result companies are only "required to … provide target dates for closure and reclamation of ponds".[32]

Similar issues arise owing to the varied location of wells and hydraulic fracturing fluid used in each instance by companies attempting to extract natural gas. Variances in the composition and density of the overburden material above the shale, coal or other rock formation in which the natural gas is contained will influence the potential for extensive fractures beyond the size of those forecast, or the seepage of gas from well heads or fractures reaching permeable material. Regulating and monitoring the level of contamination potentially caused by both hydraulic fracturing and oil sands extraction is, therefore, liable to being plagued by inefficacy. Lavelle indicated that in order to measure effectively the response of any animal to exposure to a substance not usually present in its environment a number of pieces of data must

[27] See in this regard for Canada at *http://esrd.alberta.ca/air/legislation/compulsory-industry-monitoring-and-albertas-environmental-regulatory-program.aspx*. [Accessed October 15, 2014.] Also for the UK at *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296716/geho0511bttl-e-e.pdf*. [Accessed October 15, 2014.]

[28] "Presently, we cannot quantitatively apportion contaminant levels into natural and industrial sources" K. P. Timoney and P. Lee, "Does the Alberta Tar Sands Industry Pollute? The Scientific Evidence" 3 *The Open Conservation Biology Journal* 65, 78.

[29] See J. Craven, "Fracking Secrets: The Limitations of Trade Secret Protection in Hydraulic Fracturing Law" (2014) 16 *Vanderbilt Journal of Entertainment and Technology* 395.

[30] See *http://www.myfloridahouse.gov/Sections/Committees/billvote.aspx?VoteId=30275&IsPCB=0&BillId=5126&* [Accessed October 15, 2014].

[31] *Great Lakes United v Canada (Minister of the Environment)* [2010] 2 F.C.R. 515; 2009 FC 408 (April 23, 2009).

[32] See *http://oilsands.alberta.ca/tailings.html* [Accessed October 15, 2014].

be available. These are the "identity of the toxicant", "identity of the target organ", "dose-response" (the ability to measure the scale of the response according to the dose applied), and "temporal aspects" (knowledge of whether the exposure resulting in impact is a single instance or chronic in nature).[33]

In the case of the potential contaminant pathways[34] of oil sands and hydraulic fracturing, this data is not readily available. Such a lack of knowledge with regard to the impacts of contamination is, however, not reserved to the relatively recently developed approaches to hydrocarbon extraction, but is a common factor in established forms also. This is even true in the context of drilling for oil on offshore rigs, a method with which the industry has considerably more experience and has made far greater investment in research and technological developments than most. The American Congressional Research Service, in detailing the developments with regards to the "clean up" of the Deepwater Horizon incident conceded that in relation to the 100 million barrels spilt and not "evaporated, dissolved, or … effectively removed from the Gulf environment through human activities", it was "debatable whether the fate of the remaining oil will ever be established conclusively".[35]

Recognising the consequences

The second distinction between consumption and contamination impacts is in the assessment of the adverse consequences which result from both. Consumption has immediate or quantifiable effects, such as the withdrawal of a particular volume from a water course or body. The resultant secondary impacts of such consumption are therefore, as mentioned, measurable in themselves. They can be attributed, largely incontrovertibly, to that action and develop within a timeframe and on a schedule which can be relatively accurately predicted. Whilst there are exceptions to this assertion, we undeniably have a greater knowledge of the potential manifestations of excessive consumption of resources to facilitate extraction.[36] The consumption of water is a clear example of this, seasonal variances in water levels in reservoirs, rivers, and lakes from which extraction occurs are already widely monitored and a litany of literature and research discusses the possible ramifications of excess in this regard.[37] Similarly many impacts of extraction would be progressive, and noticeable for the local populace of regions where consumption of water occurred allowing for the inclusion, to some degree, of contextual evidence of negative effects where appropriate. As such the accuracy and breadth of indicators of adverse impacts potentially stemming from consumption are considerable. Such indicators are commonly referred to by scientists as "biomarkers", which are defined as being:

> "A characteristic of a biological system that can be measured in an objective manner and used as a metric of the behaviour of such a system."[38]

In the case of contamination, however, such attribution is not as easily achieved. As well as the variance in factors potentially influencing contamination impacts outlined above, the duration of their development to quantifiable and assessable levels is also unpredictable and subject to innumerable influences. Often the impacts of consumption of natural resources by extraction projects, although long lasting, begin and

[33] K. S. Lavelle, A. R. Schnatter, K. Z. Travis, G. M. H. Swaen, D. Pallapies, C. Money, P. Priem and H. Vrijhof, "Framework for integrating human and animal data in chemical risk assessment" (2012) 62 *Regulatory Toxicology and Pharmacology* 302, 306.

[34] Lavelle discusses "mechanistic pathways", or the process by which contaminants (referred to as "chemical agents") and highlights that being able to identify this progression from source to the locus of the contaminant impact is key in addressing the issues raised by them and avoiding them in the future.

[35] American Congressional Research Service, *Deepwater Horizon* Oil Spill: Recent Activities and Ongoing Developments (2013), pp.2. See *http://www.fas.org/sgp/crs/misc/R42942.pdf* [Accessed October 15, 2014].

[36] This is also true in other industries such as in the use of geological surveys to assess the impacts of the extraction of minerals and ores. The knowledge of such impacts also facilitates safety assessments with regards to workers involved in the extraction of the resources, and as such not only improves methods but also allows companies to meet other legal obligations.

[37] Note that this is only in relation to some particular aspects of an ecosystem, but this is still more than is available for even specifically researched contamination impacts.

[38] R. L. Lundblad, *Development and Application of Biomarkers* (Boca Raton, FL: CRC Press, 2011), p.13.

can be seen within a relatively short timeframe. For example, the effects of the extraction of large quantities of water from rivers and streams are often apparent, even if not fully developed, within a seasonal cycle. The effect of the various components of tailings by contrast can take much greater periods of time to take effect or be identified. Similarly the long-term impacts of injecting vast quantities of hydraulic fracturing fluid into the ground, or the inevitable leaks from some well heads should they seep into the water table as has potentially occurred in the United States,[39] are unknown and not always attributable directly to the extraction processes owing to a similar temporal disconnect from the original action. The concerns with regard to the lack of knowledge as to the impacts any such contamination might have are exacerbated by another gap in understanding.

As has been highlighted, some aspects of the impacts of excessive consumption of natural resources to extract hydrocarbons are hard to predict in full. The biomarkers of their impacts are, however, known, such as low flow levels in rivers, high water marks of lakes, and structural integrity of land surrounding mining sites all of which can be measured with a high degree of accuracy. As a result a "traffic light system" for river flow rates has been developed in Alberta to monitor and manage the extraction of water from rivers in the province.[40] Under the system, a series of flow rate barriers give rise to corresponding restrictions once breached. Under "green" conditions no restrictions are placed upon the licensed level of extraction for companies and "amber" conditions place restrictions upon those levels until the status has been lifted, and the monitoring authority permits the resumption of consumption or imposes further restrictions. Finally under "red" conditions no extraction of water is permitted until the status is lifted.

This system is based not on an absolute understanding of the prevailing impacts of excessive water consumption within that ecosystem, but upon knowledge of the biomarkers of potential impacts and a precautious approach. The same knowledge is not available in relation to indicators for contamination impacts. Besides the death or considerable deterioration in health of flora and fauna, the presence of high levels of particular substances in groundwater or rivers, or soil samples might be touted as such biomarkers. However, such a suggestion is remiss as at that point the impact has not only occurred, but may also have reached a degree beyond restitution. Many such biomarkers are not backed by scientific consensus either. For example, the argument that the presence of high levels of methane in water sources proximal to hydraulic fracturing projects in the United States is caused by those projects has been met with derision.[41] Officials representing both the governmental authorities and the extractors have suggested that such levels could be naturally occurring, or as a result of the use of poorly maintained or developed boreholes to source water in a region in which mains water supplies are not readily available to all.[42] Measuring contamination using such inadequate biomarkers therefore fundamentally undermines the function of monitoring them, to practice precaution in the extraction of the materials sought, in this case hydrocarbons. Indeed in many instances the original source of contamination will have abated or become less severe by the time the true extent of damage incurred is realised as hydrocarbons are found in seams or concentrated pockets, and as such extraction facilities are often both mobile and multiple in nature.

As a result of the difficulty in identifying and attributing the impacts of contamination caused by such projects, measures to regulate industries such as the oil sands and hydraulic fracturing extractors are based upon precaution. The precautionary principle is a mainstay of environmental protection and enshrines a

[39] See D. T. Allen, V. M. Torres, J. Thomas, D. W. Sullivan, M. Harrison, A. Hendler, S. C. Herndon, C. E. Kolb, M. P. Fraser, A. D. Hill, B. K. Lamb, J. Miskimins, R. F. Sawyer and J. H. Seinfeld, "Measurements of methane emissions at natural gas production sites in the United States" (2013) *Proceedings of the National Academy of Sciences of the United States of America* (early edn).

[40] See *http://www.environment.alberta.ca/apps/OSEM/* [Accessed October 15, 2014].

[41] Allen, "Measurements of methane emissions at natural gas production sites in the United States" (2013) *Proceedings of the National Academy of Sciences of the United States of America* (early edn).

[42] Allen, "Measurements of methane emissions at natural gas production sites in the United States" (2013) *Proceedings of the National Academy of Sciences of the United States of America* (early edn) contrasted to S. M. Miller, S. C. Wofsy, A. M. Michalak, E. A. Kort, A. E. Andrews, S. C. Biraud, E. J. Dlugokencky, J. Eluszkiewicz, M. L. Fischer, G. Janssens-Maenhout, B. R. Miller, J B Miller, S. A. Montzka, T. Nekrkorn, and C. Sweeney, C. "Anthropogenic Emissions of Methane in the United States" (2013) *Proceedings of the National Academy of Sciences of the United States of America* (early edn).

number of basic principles. First, any damage reasonably perceived as potentially arising from an action should be mitigated to the greatest degree possible. Secondly, such potential damage ought to be balanced against the benefit gained. Finally, the principle is underpinned by the notion that the burden of proof in suggesting an action is not harmful, or that the balance favours continuing in spite of potential risks, lies with those wishing to pursue said action.[43]

Under the principle, regulatory policy and action should be applied in spite of uncertainties regarding impact of an action upon the environment where there is any reasonable expectation of harm. The principle does not require all risks to be considered, or that a project cease on the basis of any potential damage. Although the burden lies with the actor to prove that the action is harmless or relatively undamaging, equally if no or very little damage can be shown to occur preventing permits being granted is considerably difficult. Certainly this has been the case in relation to the oil sands and hydraulic fracturing industries. In simple terms, the burden of proof of risk is not easily breached. Herein lies arguably the greatest challenge facing the regulation of emerging hydrocarbon extraction industries and where the distinction between consumption and contamination impacts is most stark.

The unknown nature of the impacts of contamination, both in terms of form and extent, severely inhibits the possibility of regulation which effectively mitigates or eliminates said damage or "stressors" upon ecosystems. Stressors are defined as, "a chemical, material, organism, radiation temperature change, or activity that stresses human health, the environment, or quality of life".[44] Gentile highlights two key aspects to environmental risk assessments of the ramifications of stressors on an ecosystem.[45] First, the characterisation of the stressor and, secondly, the characterisation of how ecosystems respond to, and recover from, one or more stressors.[46] In the case of consumption impacts both the stressor, the lack or reduction of a natural resource such as water in an ecosystem, and the response of that ecosystem to the stressor can be characterised, facilitating an "increasingly important tool for ranking, assessing, reducing, and managing environmental risks"[47] represented by an ecological risk assessment. Contamination impacts, by contrast, do not have fully ascertainable stressors beyond knowledge of the form and possibly concentration of contaminants in which they went into the ecosystem, though this varies by project as has been discussed. The monitoring of the dispersal, and impacts of contaminants released whether this is with knowledge or accidentally, is also all but impossible logistically given the aforementioned variances in mixtures of both tailings and fracturing fluid mixtures. As a result the response and recovery of said ecosystems, often equally as variable as the contaminants themselves, cannot be ascertained either. Precaution, in any manner akin to that espoused by the precautionary principle—a fundamental aspect of regulation under the auspices of environmental law of such projects—is therefore not effective in relation to their contamination impacts.

There is undeniably a potential for harm from the contaminants of said projects. Despite this, little, and in some instances no, environmental policy has been afforded beyond monitoring of a handful of biomarkers. The creation of a uniform single approach as in relation to water consumption is impossible owing to the aforementioned variances. Jaeger suggests in relation to the principle that "risk minimisation is warranted when consequences are highly uncertain and effects are either not known or only suspected".[48] This suggestion, however, fails to account for the inextricable social and economic ties to hydrocarbons underpinning everyday life which drive a degree of ignorance towards said impacts. Instead, the approach

[43] Rio Declaration Principle 15.

[44] K. Sexton, "Setting Environmental Priorities: Is Comparative Risk Assessment the Answer?" in K. Sexton (ed), *Better Environmental Decisions: Strategies for Governments, Businesses and Communities* (Washington DC: Island Press, 1999), p.209.

[45] J. H. Gentile, M. A. Harwell, W. H. van der Schalie, S. B. Norton and D. J. Rodier, "Ecological Risk Assessment: A Scientific Perspective" (1993) 35 *Journal of Hazardous Materials* 241.

[46] 46 J. H. Gentile, M. A. Harwell, W. H. van der Schalie, S. B. Norton and D. J. Rodier, "Ecological Risk Assessment: A Scientific Perspective" (1993) 35 *Journal of Hazardous Materials* 241, 243.

[47] 47 J. H. Gentile, M. A. Harwell, W. H. van der Schalie, S. B. Norton and D. J. Rodier, "Ecological Risk Assessment: A Scientific Perspective" (1993) 35 *Journal of Hazardous Materials* 241, 252.

[48] Jaeger, *Risk, Uncertainty and Rational Action* (London: Earthscan, 2001), p.115.

presented by economists and suggested by Jaeger as a potential solution to these failings of the precautionary principle is that "even if uncertainties are high, it is more prudent to estimate or guess the probabilities of harmful effects than treating all potential risks as equal".[49] Such an approach incorporates an element of subjective judgement "but this is still superior to the assumption that all uncertain outcomes have the same probability and magnitude of negative outcomes",[50] or indeed that they will occur.

This explanation of the approach, a variation on cost-benefit analysis, is somewhat opposed to the environmental underpinnings of regulation of the extractive industries generally. The approach, however, is reflective of the reality of the importance at present, and for the foreseeable future, of hydrocarbons as a source of energy. Thus, the analysis is not one of cost versus benefit as it is in the case of consumption impacts, where the cost of extraction and impact, potential or otherwise, can be ascertained with an acceptable degree of accuracy in the emerging hydrocarbon industries as the risks are relatively uniform in nature.

The simplest way to illustrate this issue is in the contrast with consumption-based impacts. The consumption of any resource to produce a product for an end user, in the case of the two industries considered here, natural gas and synthetic crude oil, bears inherent costs. These may take the form of regulatory charges, equipment to access those resources, transportation, or simply the purchase price of said resource. As such there are constant pressures upon extractors, both to reduce their own costs, but also to remain competitive within the industry. This often results in reduced consumption, or more efficient practices, and "green" or environmentally-minded appearance in their operations. When coupled with a desire to reduce costs, this is a relatively effective and self-perpetuating method of ensuring persistent efforts to reduce consumption and by extension its impacts for the most part. This is not to suggest that increases in economic efficiency and environmental standards and safety always coincide. Indeed, the opposite is often as true. However, the combination of pressures to reduce costs in search of a competitive advantage in the market place, and regulation enforcing and promoting[51] better environmental practices has been shown to be one of the most effective methods of reducing risk and raising standards where these two aims can be applied in a reciprocal nature.[52]

Attributing responsibility

Contamination impacts however, once mitigated to a degree sufficient to meet existing regulatory requirements, are of little or no cost to the extractor.[53] Therefore, from an ecological perspective they are arguably of the greatest concern. The exception to this is where further foreseeable or avoidable impacts can be attributed to the specific process used by them, or they are so severe as to potentially give rise to a viable basis for a private legal action against either the licensing authority or industry itself.[54] Leakage from tailings ponds, for example, is regarded as unavoidable in its totality.[55] However, unless impacts which could reasonably have been foreseen are attributed to the pond of a specific extractor, and are on the balance of probabilities[56] causing the impact alleged, no action is likely to succeed. Similarly, the

[49] Jaeger, *Risk, Uncertainty and Rational Action* (London: Earthscan, 2001).

[50] Jaeger, *Risk, Uncertainty and Rational Action* (London: Earthscan, 2001).

[51] An action most often achieved through the imposition of greater actual or potential costs to the extractor.

[52] The most clear example of such success is the Montreal Protocol which banned the use of chlorofluorocarbons ("CFCS") as a refrigerant and thus required private bodies to seek out viable alternatives to remain competitive. Former Secretary General to the United Nations Kofi Annan is widely quoted as having said that "Perhaps the single most successful international agreement to date has been the Montreal Protocol".

[53] See H. Coman, "Balancing the Need for Energy and Clean Water: The Case for Applying Strict Liability in Hydraulic Fracturing Suits" (2012) 39 *Environmental Affairs Law Review* 131.

[54] Such actions are also limited by a number of other factors. These might include prohibitive costs of litigation, dispersed effects felt communally rather than individually or at a distance from the source great enough to cast reasonable doubt regarding their attribution and the analysis of impacts against considerable positive economic impacts of the presence of such large industrial activity in proximity to a community.

[55] Instead groundwater collection systems returning detected leaked material to the ponds are necessitated at *http://environment.alberta.ca/apps/OSIPDL/Content/Posters/Tailings.pdf* [Accessed October 15, 2014].

[56] For a discussion of the issues regarding proving liability in unconventional hydrocarbon extraction industries, see H. Coman, "Balancing the Need for Energy and Clean Water: The Case for Applying Strict Liability in Hydraulic Fracturing Suits" (2012) 39 *Environmental Affairs Law Review* 131.

impacts of hydraulic fracturing on seismic activity on the Fylde Coast of the United Kingdom halted testing of potential sites for the extraction process until a review into said impacts was completed. The review, however, does not consider halting the projects on the basis of induced seismicity. Instead, the review of hydraulic fracturing allowed the resumption of testing and proposed a traffic light system of perpetual monitoring akin to that utilised in relation to water consumption from natural courses in Alberta by extractors of the oil sands.[57]

The nature of impact reporting outside of the regulatory context by the mass media results in only dramatic, large scale and immediate instances receiving the degree of the widespread opposition necessary to force significant increases in regulatory action or considerable evaluations of existing frameworks. Examples of this include notable major oil spills, such as the Exxon Valdez[58] and Deepwater Horizon[59] events, bird deaths on the tailings ponds of the oil sands extraction industry, and the occurrence of irregularly frequent tremors off the North West coast of the United Kingdom. All of these occurrences have led to reforms of the regulatory frameworks governing extractors involved in the processes which led to their occurrence. However, the difficulties already highlighted in terms of attribution, and the long period between extraction and impact common in many extraction industries, and certainly in the case of the oil sands and hydraulic fracturing, indisputably reduce the viability of any such reforms in the regulation of contamination impacts. This is because punitive measures which might stem from them remain difficult to apply without the evidence demanded in a legal context.

In contrast, the impact of consumption by volume would be reduced from the outset, with the endeavour for profits promoting the reduction in costs by industry. Whilst this does not account for rises in output or demand, in that such reductions might be outweighed by increased extraction, meaning the net consumption would not fall, progress would undoubtedly be made at a greater rate than if this were not the case. Contamination impacts beyond storage or disposal of by-products such as the construction of tailings ponds themselves cost the industry relatively little unless adverse effects are proven to standards demanded by the law. Research into improving the reclamation of the tailings ponds is on-going and, indeed, is subject to some cumulative efforts by extractors.[60] However, the licensing and leasing processes on which they are reliant do not stipulate requirements in this regard beyond a broad and non-committal suggestion in policy documents to return land to a state of "equivalent capacity".[61] The issue in relation to equivalence of land is of particular interest in relation to the impacts to the indigenous populace of the regions exploited for their resources owing to the inimitable connection they have to that particular ecosystem.[62]

The result will be one of the nature of a race to the bottom. Extractors are incentivised merely to find the lowest cost equivalent ecosystem to that which once dominated the locations utilised for the construction of tailings ponds. This is illustrated by the focus on the time taken for reclamation in the oil sands industry rather than its form. As a result of this broad approach to restoration requirements, the financial incentive to reduce contamination is somewhat neutered. Thus arguably one of the most potent methods to ensure compliance or action on the part of private commercial actors in such projects is lost. The consistent reductions in water consumption by the oil sands industry reflect this reality. Where pressured by the

[57] Report of the Royal Academy of Engineering and the Royal Society, "Shale Gas Extraction in the UK: A Review of Hydraulic Fracturing" (June 2012), p.6. See *http://www.raeng.org.uk/news/publications/list/reports/Shale_Gas.pdf* [Accessed October 15, 2014].

[58] The Exxon Valdez oil tanker ran aground off the coast of Alaska on March 24, 1989 and caused the second largest oil spill in American history.

[59] A well blowout on the ultra-deepwater drilling rig Deepwater Horizon in April 2010 led to the deaths of 11 crew members and the largest oil spill in American history.

[60] See, e.g. the Oil Sands Tailing Consortium at *http://www.capp.ca/energySupply/innovationStories/Land/Pages/OSTC.aspx* [Accessed October 15, 2014].

[61] The Lower Athabasca Regional Plan, described as a roadmap for development makes this stipulation (at p.26) at *https://www.landuse.alberta.ca/LandUse%20Documents/Lower%20Athabasca%20Regional%20Plan%202012-2022%20Approved%202012-08.pdf* [Accessed October 15, 2014].

[62] This issue is too broad to afford its deserved consideration here. The need to include more stringent constraints on the utility of land once reclaimed in regulatory frameworks is however considered in relation to slate mining in; R. Paradelo, A. B. Moldes and M. T. Barral, "Characterisation of Slate Processing Fines According to Parameters of Relevance for Mine Spoil Reclamation" (2008) 41 *Applied Clay Science* 172.

media, regulatory frameworks and crucially also the economic necessity of remaining competitive within a rapidly developing industry, there has been considerable progress on reducing water consumption both in the oil sands industry, and also in the emerging hydraulic fracturing sector.

In Alberta, the use of recycled water from processes is becoming ever more commonplace, as well as the use of brackish water,[63] unfit for many other purposes owing to its high salt content as a result of such pressures.[64] Within the hydraulic fracturing industry research into formulas for more efficient and less costly fluid mixes have, and will continue to, reduce water consumption.[65] The development and utilisation of silicon beads to maintain fractures once initially induced and avoid the need for repeat fracturing, reducing in turn fluid use, has also become more commonplace.[66] Such developments bear significant costs in terms of research and implementation, and as such to suggest that they are undertaken initially based solely upon an overriding moral compulsion on the part of extractors to reduce their environmental impact would be naïve. Again, therefore, it is apparent that economic influence is the most effective means of influencing extractors in this regard.

A relative response

Thus the challenge is in accepting that the use of ever more extreme methods to obtain oil and gas resources is to some extent inevitable. The hydraulic fracturing and oil sands industries are not going to cease their operations by choice, or through regulation in the foreseeable future. Conversely, States are also reluctant to regulate the hydrocarbon extraction industry excessively owing to the economic benefits in relation to fiscal revenues and foreign investment, as well as potential political liability having in many cases promoted these industries as sources of economic growth on a national scale as part of political campaigns.[67] Also in some cases, and this has certainly been prevalent throughout the history of oil sands extraction in Alberta, the Government[68] itself has tangible financial investments in hydrocarbon extraction. These issues are not exclusive to the hydrocarbon industry, however, and are noted as issues facing environmental law generally.[69] The effect of said reluctance is, however, no more relevant than to this sector owing to the immense global, regional and national implications of energy security both in terms of commerce and politics. Having accepted that this status quo is unlikely to alter significantly in the near future however, regulation must reflect this reality.

The existence of regulations concerning consumption, as well as the free market induced financial incentives has proved more effective than any activism has mustered thus far. This is not to say activism is ineffective or without its place; more that it should be directed to areas where there is less inherent incentive for industry to act in a manner respectful of environmental concerns. Economics in the form of the free market has, throughout history, proved to be one of the most effective means of promoting particular actions on the part of private actors and extreme energy projects have thus far proved no exception to this prevalence. Whether regulation could emulate or mimic the impacts of the economic incentives to

[63] Brackish water is the term given to water of a higher salt content than fresh water (i.e. that generally found in inland surface waterways) but over a lower salinity than sea water.

[64] See *http://www.capp.ca/environmentCommunity/water/Pages/UsingWater.aspx* [Accessed October 15, 2014].

[65] See *http://www.cuadrillaresources.com/protecting-our-environment/water/water-sourcing/* [Accessed October 15, 2014].

[66] As has been discussed, rarely do firms act responsibly without a degree of benefit to themselves. In the case of silicon beads, the technology also increases the productivity of wells once fracturing has occurred. As such the action reducing water consumption was developed for this amongst a plethora of other reasons and benefits. This further adds weight to the contention that it is economic incentives in the forms of costs which offer one of the most effective tools for reducing contamination impacts.

[67] In particular, the Canadian Conservative Party have been strong advocates of the role of the oil sands in future Canadian economic prosperity at *http://www.conservative.ca/?p=4178* [Accessed October 15, 2014].

[68] In the case of the oil sands the provincial government of Alberta and the federal government of Canada historically had significant public investments in this industry and even owned majority stakes in extraction companies.

[69] These are highlighted as "The Short Comings of Traditional Legal Solutions" in E. Morgera, *Corporate Accountability in International Environmental Law* (Oxford: OUP, 2009), p.28.

reduce consumption is up for debate itself, but certainly the attentions of activists, regulators and lawyers alike should be upon contamination if they are suggesting reform.

The unknown nature of both cause and effect of impacts which could be said to stem from contamination make them a far more pressing concern than those which are subject already to concerted efforts to be reduced, and the extent of which can be assessed. As such, in the context of attempts to restrict and, as an aspiration, cease the exploitation of sources of extreme energy the focus of contention should be on that for which precaution cannot be exercised and there is no considerable incentive to reduce. Free market economics has been in existence far longer than environmental impact assessments and risk analysis and to ignore its inimitable influence upon the "unnatural" legal persons to which it arguably gave birth would be remiss. The pressure that costs can place upon a company's actions are undeniable. In the context of consumption-based impacts their effect is clear, rapid developments in technology in the hydrocarbon extraction industries emerging to supplement conventional oil reserves follow the most costly or potentially most costly by-products and actions for which they are responsible and this is too prevalent a trend to deny. Companies wish to survive in the same manner all life does and so for them to invest in something with no inherent benefit to themselves is foolhardy. There are exceptions to this observation undeniably, but the number of exceptions to the observation that companies strive to avoid and reduce costs would be far less. As Lin-Hi and Muller illustrate:

> "Although CSR [Corporate Social Responsibility] has both normative and an instrumental dimension, a potential business case for the assumption of social responsibility is a precondition for implanting CSR in practice. If CSR leads to a competitive disadvantage, responsible corporations risk being driven out of the market by irresponsible competitors."[70]

Where appropriate and feasible therefore the utilisation of this reality should be increased in regulatory frameworks.

Conclusion

Traditional regulatory methods, as has been highlighted, are only successful in relation to equally familiar, and therefore predictable, impacts. New advances in hydrocarbon extraction bring new challenges and risks and with them a need for new regulatory approaches not to replace, but to supplement existing examples.

In relation to contamination, the construction of an unavoidable incentive to reduce waste is the most obvious and, in the short term, one of the most effective methods of achieving this. The established mechanisms of free market economics should, therefore, be not just used, but trusted, as a basis for regulation. In the same way that responses of ecosystems to most consumption-based impacts are predictable, so too are company responses to costs. Regulatory frameworks should, therefore, exploit that predictability where they can. As such, punitive financial measures for levels of by-production above set parameters would be a viable basis for such a proposal.

In order to supplement this, an overriding imposition of the polluter pays principle in relation to any contaminations would further pressure extractors to both limit and control their waste output. Such an approach would reduce the social responsibility element of maintaining low or non-existent levels of contamination on the part of extractors. Essentially their actions would be based on necessity rather than any form of overbearing moral compulsion. Lin and Muller highlight this as the difference between, "avoiding bad" and "doing good"[71] and discuss the merits of both. However, in relation to the impact of

[70] N. Lin-Hi and K. Muller, "The CSR Bottom Line: Preventing Corporate Social Irresponsibility" (2013) 66 *Journal of Business Research* 1928, 1929.

[71] N. Lin-Hi and K. Muller, "The CSR Bottom Line: Preventing Corporate Social Irresponsibility" (2013) 66 *Journal of Business Research* 1928, 1932.

contaminants, the key would be the improvement in attribution of contamination to extractors. Whilst this assertion is outside the realm of law, and highly dependent upon on-going scientific research, a better relationship between the legal and scientific spheres could be achieved. The desire for certainty within the law does not marry with the data which science can at present afford. There exists, therefore, a necessity to rectify this void between that which science can afford and that which the law requires. Without such a progression in knowledge, the regulation of contamination impacts in these contexts, and in environmental law generally, will not develop to meet the specific demands the ever-evolving industries place upon them, leading to wholesale inefficacy.

The use of biomarkers for particular ecosystems and contaminants affords both a specific and quantifiable means of assessing the risks and impacts of extraction techniques and associated processes present. Thus it represents a promising development in this regard. The method, however, brings with it an undeniable issue in relation to the selection and monitoring of those biomarkers. In relation to their use, Owen suggests that the approach of the US Food and Drug Agency of imposing its own qualification and review process for biomarkers would "facilitate and accelerate acceptance of biomarkers in a regulatory context".[72] This assertion is based on the observation of Goodsaid and Frueh that in relation to medical biomarkers the "validity of preclinical and clinical biomarkers has been traditionally settled by debate, consensus and the passage of time".[73] However, in relation to the use of biomarkers in environmental risk assessment such a progression towards a single set of agreed biomarkers is neither likely, owing to the variance between ecosystems, nor therefore appropriate in many instances. This is especially true of hydrocarbon extraction owing to the pace and largely mobile nature of the industry. By defining and prescribing biomarkers at a regulatory level a uniform monitoring system relative to each ecosystem could be established, offering both improved scientific and legal validity. This would also afford a base onto which regulatory authorities would be able to base punitive financial measures to promote good practice. Viable legislative measures to enforce them which would withstand the rigours of litigation could also be drafted as a result.

One objection to this suggested framework might be based on the existing academic criticisms levelled at carbon trading mechanisms.[74] The proposition here though is a different one, based not on the creation of a new market in by-products, but the utilisation of the existing one. Such an approach is suggested based upon two realisations. First, that the use of hydrocarbons is highly unlikely to abate, certainly in its entirety, at any point within the lifetime of most current inhabitants of the planet. Secondly, that consumption- and contamination-based impacts of the emerging methods of extraction of those hydrocarbons are different in terms of both cause and effect, and as a result their regulation must reflect and address those differences in itself. This overall economically underpinned approach must be accompanied by the science on which to base such a system. In terms of the philosophical analogy utilised in the introduction therefore, we must; accept that we cannot change, the demand for such projects in the short term and their ever-decreasing consumption of resources; have the courage to change that which we can, contamination; and the wisdom to do so based upon acceptance of that difference. Without accepting these differences and tailoring relative regulatory frameworks accordingly, their success will be continually limited in relation to contamination based impacts.

[72] R. Owen, T. S. Galloway, J. Hagger, M. B. Jones and M. H. Depledge, "Biomarkers and Environmental Risk Assessment: Guiding Principles from the Human Health Field" (2008) 56 *Marine Pollution Bulletin* 613, 619.

[73] F. Goodsaid and F. Frueh, "Biomarker qualification pilot process at the US food and drug administration" (2007) 9 *American Association of Pharmaceutical Scientists Journal* E105.

[74] A useful overall review of such mechanisms is provided in S. Perdan and A. Azapagic, "Carbon Trading: Current Schemes and Future Developments" (2011) 39 *Energy Policy* 6040.