Apocalypse, Technofix Future, or Back to Nature?

A Reflection on the Future of Technology in Environmental & Energy Policy

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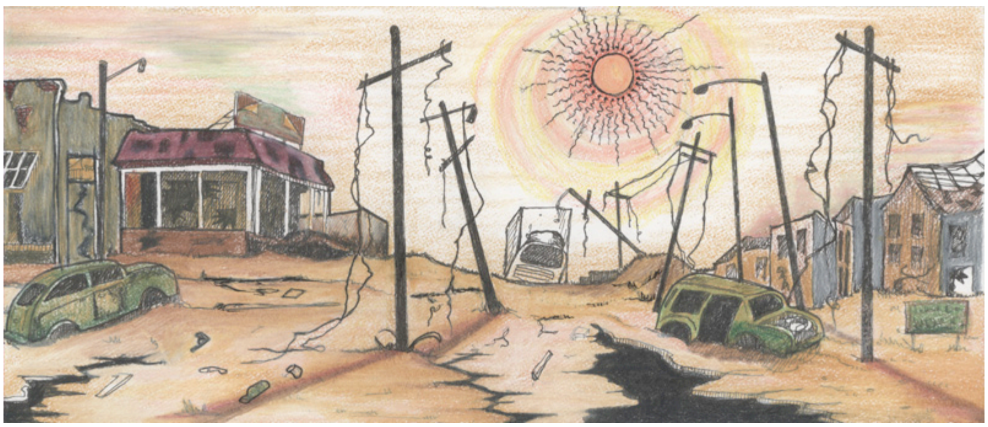
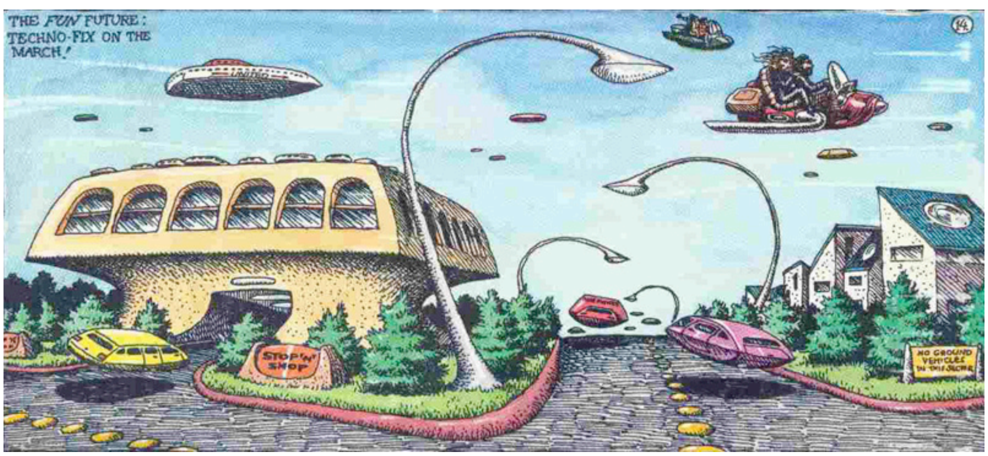




I. Introduction

This paper aims to discuss some of the key issues surrounding technological change in the context of unfolding environmental and energy challenges, with a view to asking whether supporting and/or directing such change is an appropriate keystone in policy looking to address these challenges. Much has been written on the relative effectiveness of different policy mechanisms towards encouraging technology (e.g., Jaffe et al., 2002; Requate, 2005; Verbruggen and Lauber, 2009; Verbruggen et al., 2010), and it is not my intention to rewrite any of it. Rather, I ask the question upon which much of the usefulness of this ongoing work would seem to depend: *should policy-makers look primarily to technology in the face of these challenges, or is greater focus on alternate mitigation and adaptation strategies called for?*

To bring focus to the issues, it will be necessary to constrain the domain of our enquiry as tightly as possible. What is meant by 'technological change', and what shall we understand by policy that falls under the auspice of 'environmental and energy'? What constitutes a 'long-term environmental problem', and what criteria must a policy response meet to justifiably be called a 'solution' to such a problem?

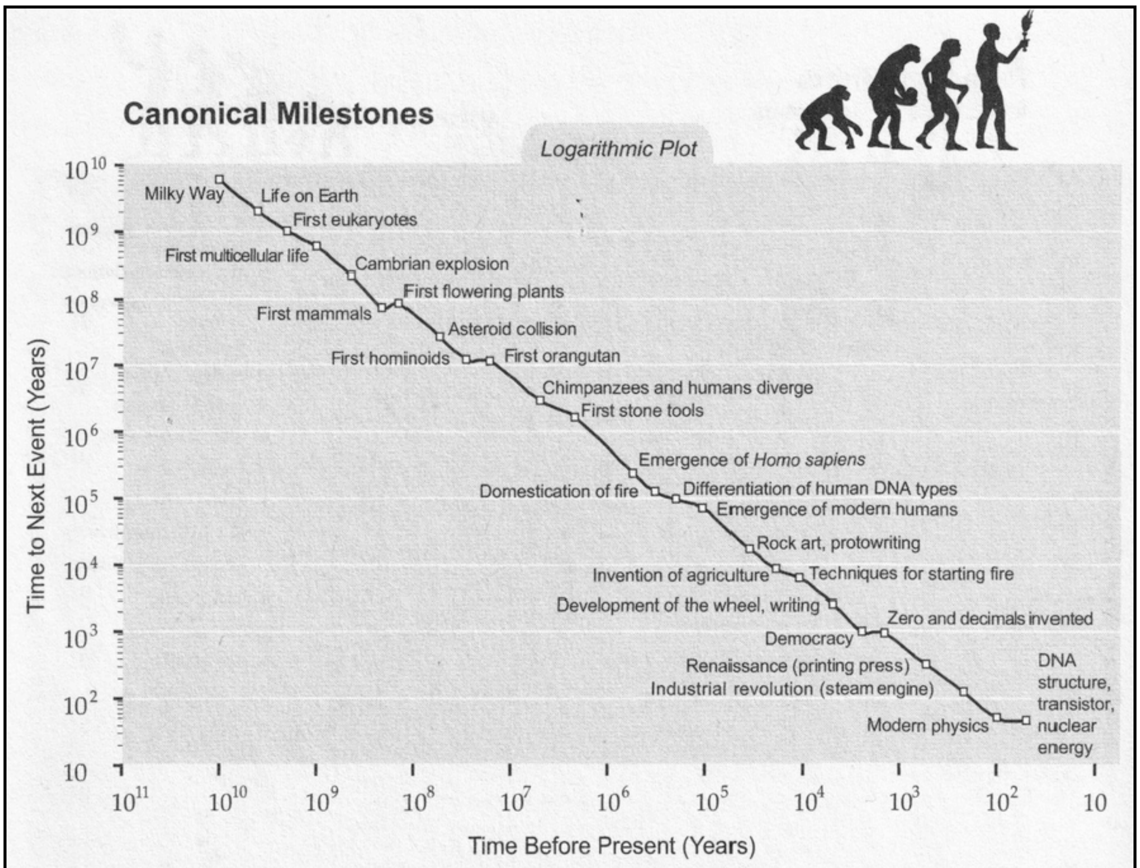
Firstly, it will be important to untwine two strands of technological change, which may be termed *innovation* and *adoption*. Under the former, we understand activities leading up to the discovery of novel technology, such as research and development. Under the latter, we understand subsequent activities involving its diffusion and actual implementation. Here, it is important to be clear on the circumstances under which a policy targeting behavioural (cultural) change should be viewed as 'technological policy'. The distinction between behaviour and technology is, in fact, a nuanced one. Particularly in the case of decentralized technologies - those tending to bear on the life of the individual and/or community - behavioural change is often a highly visible manifestation of a technological innovation's influence. Furthermore, some technologies remain impotent in the absence of *cultural adoption*, requiring changes in behaviour before bearing fruit: novel types of heating systems, insulation and energy sources provide topical examples. Much of the technological adoption prescribed in recent environmental policy papers (e.g. ECOFYS, 2011) implicitly calls for far-reaching and rapid changes in the way individuals and groups use resources. To make sense of the question before us, therefore, policies seeking to influence behaviour in parallel with the introduction of abatement technology must be taken into the fold. To recap: the notion of 'technological change' (through policy) will be treated as two-stranded, with *innovation* on the one hand, and *adoption* on the other. The latter is understood to include policy that targets technological change indirectly, by seeking to influence human behaviour.

Secondly, 'environmental and energy' is disarmingly broad, and adequately constrains the ranges of neither technologies, nor challenges, nor policies. To sharpen our focus, I will concentrate on technology-policy concerned with addressing either or both of two key sets of challenges associated with the use of traditional hydrocarbon resources (coal, oil, gas and their geological precursors). The first are challenges posed by the emission of the greenhouse gas, carbon dioxide (CO_2), which has steadily risen to infamy over the past two decades as a result of them. The second are challenges associated with the (still controversial) looming limitations on hydrocarbon availability, in the context of the role their supply plays in economic growth and development. Since the question before us treats the existence of pertinent 'long-term environmental problems' as a given, I will leave aside questions to do with the detailed nature of - and uncertainties surrounding - these challenges. With regards to the types of technologies under consideration, I will have renewable energy generation foremost in mind, as it has an important and dual role to play in simultaneously meeting both the environmental and energy challenges. Nevertheless, many of the arguments presented should apply more broadly, to abatement technologies in general.

Thirdly, granting that confrontation with the twin environmental and energy challenges will mount, when can a policy be termed a solution? Here, brevity forces us to fall back on orthodox microeconomic foundations, with welfare terms measured through changes in individual utility.

II. Predicting and Explaining Technology

Shamans, scientists nor Schumpeterians have ever been very good at foretelling how technology would unfold, or explaining how it does so. When it comes to *prediction*, little progress has been booked beyond inductive 'laws' that extrapolate from trends within particular sectors (e.g., 'Moore's law') or broader 'canonical milestones' (**Fig. 1**). From the perspective of the question at hand, such approaches[1] obviously arrive at optimistic projections, and would endorse a 21st Century policy strongly focused on technological abatement.



Canonical milestones based on clusters of events from thirteen lists.

Fig. 1: One technologist's deterministic outlook on the past and future state of technology (Kurzweil, 2005).

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[1] It is worth noting that Kurzweil's ontology embeds the market *within* the swoop of technology, rather than the other way round – market capitalism is but a milepost on the long technological march, rather than the very system that enables, drives and directs it.

Traditional attempts to actually *explain* technology have tended to find appeal in the principles of Darwinian rather than Walrasian competition (e.g. Arthur, 2010). It is telling that ‘exogenous technological progress’, in the form of a factor-augmenting multiplier, has been invoked in macroeconomic models since the days of Swan (1956) and Solow (1957), and still enjoys widespread credence (e.g., Easterly and Levine, 2001). It has been hard enough for economists to account for the very possibility of technical progress in competitive markets in the first place, let alone have useful things to say about its future course. Part of their vexation has stemmed from the marginal cost and hence rental price of supplying an item of knowledge to an additional user being zero in a fully competitive market, thereby nullifying the incentive for R&D. Even with the rather ‘pas laissez-faire’ introduction of ‘excludability’ - through patents and other forms of intellectual property - it has proven difficult to comfortably situate technological progress within economic orthodoxy.

Many have endeavoured to endogenize technological growth by tying it into factor accumulation (e.g. Arrow, 1962; Mankiw et al., 1992; Barro and Sala-I-Martin, 1995; Mankiw, 1995). However, it has proven hard to convincingly reconcile these endogenous models with empirical data (Easterly and Levine, 2001), although allowance must be made for methodological difficulties in measuring things like ‘technology’, ‘human capital’ and ‘knowledge’. It would appear, then, that if economists have anything to say about the merits and potency of abatement technology policy for the ensuing century, their message is at best an ambiguous one. So what do others say?

III. A Triad of Stylized Outlooks

Outlooks on the role that technology will, should or must come to play in the coming century can be divided into three stylized 'camps'. These are not intended to exhaust the spectrum of possible positions on the matter, but they do a better job of triangulating my position on the prospects for technology (and hence technology–policy) than do more formal conceptual frameworks (c.f. van den Bergh and de Mooij, 1997). I will also use them to sketch pertinent facets of the environmental and energy challenges ahead.

- Outlook 1: 'Camp Apocalypse' -

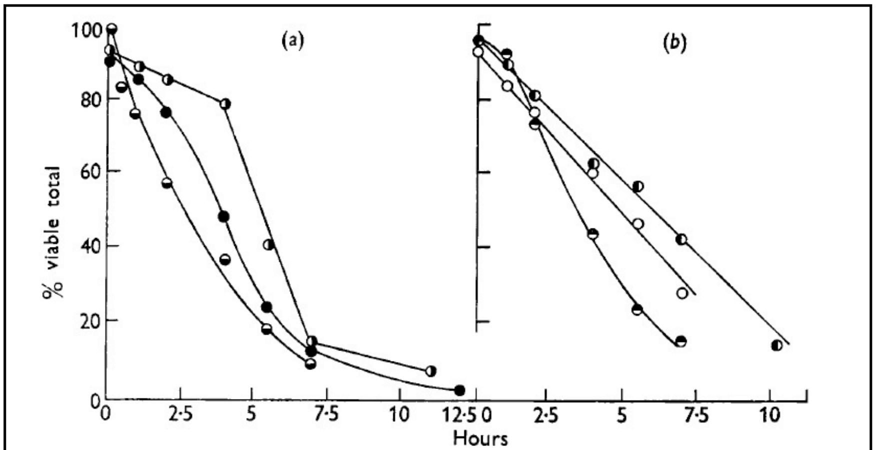

Fig. 12. Effect of nutritional state on death of *Aerobacter aerogenes*. *A. aerogenes* was grown in continuous culture at a dilution rate of 0·25 hr.$^{-1}$ with different components of the medium limiting the growth of the organisms. Survival curves of 20 μg./ml. populations in saline-tris buffer aerated at 40° and pH 7·00 ± 0·05 were obtained (see text). Part (*a*): ●: limited by S; ◑: by N; ◒: by Mg. Part (*b*): ◐: by O; ◓: by P; ○: by C.

Fig. 2: Prokaryote population decline under different nutrient-limiting conditions (Postgate and Hunter, 1962).

The first outlook comes from the 'Apocalypse' camp. Adherents regard *Homo sapiens'* current growth trajectory as lying on a Malthusian collision course with finite resources (**Fig. 2**). Technologies won't save us because their discovery and implementation rest upon – have been enabled and made possible by – a surging flux of energy and material from a finite, shrinking and forever more intractable reservoir (see also **Fig. 5**). In a sense, this view regards technological 'progress' as a higher-order phenomenon that is ultimately grounded on lower-order material conditions - hard constraints set by natural laws operating on initial endowments. Extending this line of reasoning, the collapse of island civilizations (Easter, Henderson, Malden, Pitcairn, …)[2] provide foreboding analogues for humanity's fate on Earth – an island-planet in space. Adherence to the status quo amounts to single-minded faith in technology. In line with historical precedent, this would see the gradual demise or abrupt collapse of Western-style industrial society.

And then there's the destabilisation of Earth's climate. Evidence is mounting, most recently through careful study of Pleistocene deglaciation (**Fig**. **3**), that CO_2 emissions anticipate future temperature rises. In other words, *today's* temperatures are correlated with *past* CO_2 emissions – the worst is yet to come. Furthermore, CO_2-induced surface warming is roughly irreversible (Solomon et al., 2009).

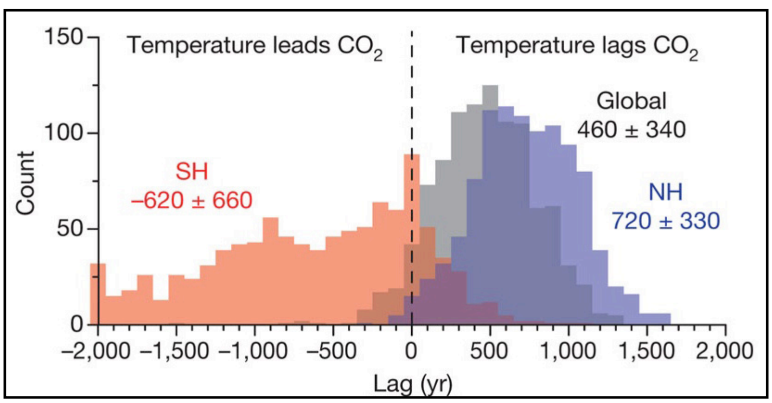

Fig. 3: Phasing of CO_2 concentrations and temperature in global (grey), Northern Hemisphere (blue) and Southern Hemisphere (red) 20–10 kyr datasets (Shakun et al., 2012). Global CO_2 changes lead temperature on the order of centuries (Shakun et al., 2012).

Meanwhile, the pathway marking a Luddite retreat to pre-industrial times has been irrevocably trampled underfoot by a human population far in excess of the Earth's carrying capacity – where this overshot capacity must now be measured without the benefit of an eons-deep 'Carboniferous cushion' of accumulated coal, oil and gas. In the words of Ted 'Unabomber' Kaczynski, an extreme example of the apocalypse's flag-bearer, "there is not enough nature to return to."

[2] Controversial claims for Malthusian collapse have also been made for Sumer, Mycenaean Greece, Classical Greece, the Han-, Chin-, Sung- and Tang- Dynasties and Mongol- and Manchu- China, the Indus Valley, Izapa, the Etruscans, the Olmec, Ancient Egypt, the Norse colony on Greenland, the Hittites, Munhumutapa, Ancient Levant, Cahokia, the Tokugawa Shogunate, Hindu- and Moghul- India, Babylonia, the Anasazi, the Incas, the Mayans, Angkor Wat and the Roman Empire (Tainter, 1989). Even if neither climate change nor scarcity killed them, Archaeologists are presumably agreed that technology did not save them.

Under this alarmist scenario, the role of 21st Century technology is not just moot. Locked in inseparable dependence, it is the very vehicle driving us towards the edge. The implication would be that more radical policy intervention, beyond technology, is called for.

- Outlook 2: 'Technofix Future' -

If, in the face of more expensive hydrocarbons (Hotelling, 1931) and climate destabilisation, the task of upholding our welfare does indeed fall to technology, then technology would appear to have its work cut out for it. The second camp holds technology up to the task, foreseeing a 'Technofix Future'.

Modern western civilization can already boast an impressive track record on transformative technologies, making it natural to look for further fixes in the face of anticipated challenges. Analogies to bygone civilizations can be dismissed as inappropriate, because modern resource allocation lies in the capable hands of the market, ably assisted by policy-makers armed with market-based instruments. Concerns about fossil-fuel shortages are ill-founded, as is amply demonstrated by the explosive growth in the exploration, extraction and processing of unconventional fossil-fuels (e.g., 'deep oil', 'heavy oil', 'shale oil', 'shale gas', 'tar (or oil) sands'). These developments have allowed the United States, for example, to terminate many of its import contracts for Middle-Eastern gas and to build its first liquid natural gas (LNG) export facility in over forty years (Crooks, 2012).

Furthermore, known technological solutions already exist for a slew of anticipated problems. 'Renewable energy' already ranks amongst the world's fastest growing industries (Bloomberg New Energy Finance, 2011), with hydro-, solar- (both photovoltaic and thermal) and wind- already regarded mature generation technologies, while conversion efficiency gains continue to accrue in the promising fields of wave- and tidal- generation, and biofuels. Low-hanging fruit is increasingly being picked, meanwhile, through the implementation of energy efficiency measures in the commercial, household and industrial sectors (Yudelson and Fedrizzi, 2008). Several theoretical studies demonstrate that extant technologies such as these, widely implemented, are already adequate to the task of stabilizing CO_2 at 'permissible' concentrations (e.g., ECOFYS, 2011).

Finally, policy-makers have no shortage of measures to choose from, including market-based instruments (emission taxes, abatement subsidies and tradable permits) and command & control instruments (technological-, emission- and so-called generation performance- standards). Chill out, and let the market and government do its' business.

- Outlook 3: 'Back to Nature' -

The third and final camp favours a reversion 'Back to Nature'. Adherents share in the belief that mounting separation, isolation and alienation from 'nature' is unsustainable (in at least the economic sense), and include 'closed-loop' and 'zero-growth' economists that advocate forgoing some measure of economic growth (**Fig. 4**) in exchange for a gentler ecological footprint.

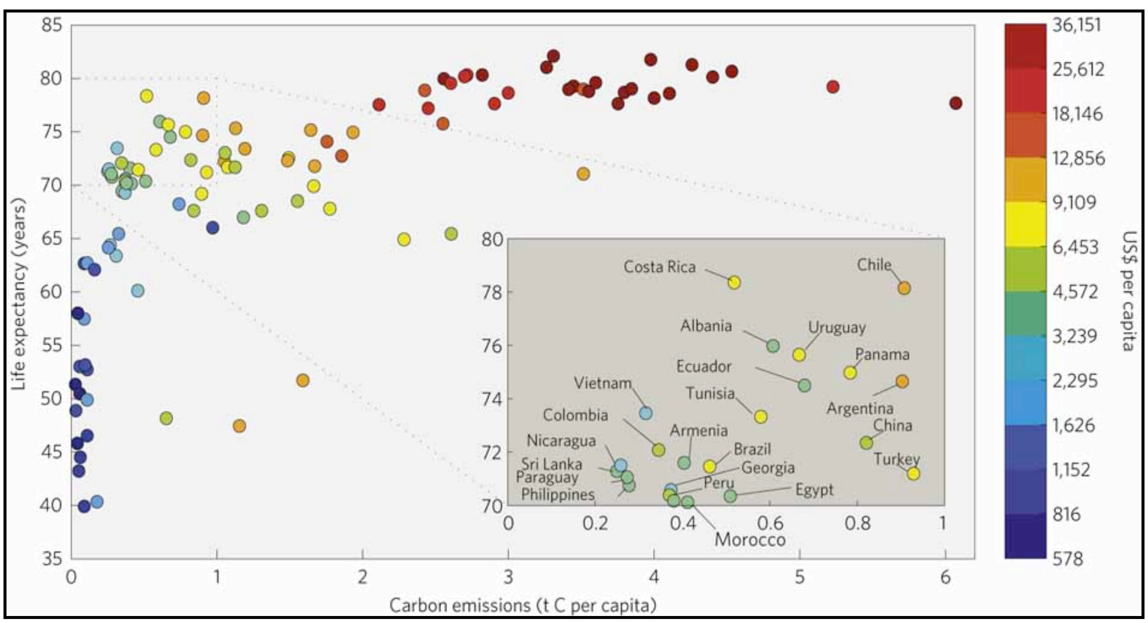

Fig. 4: Life expectancy, carbon emissions and income for different countries (Steinberger et al., 2012). Carbon emissions take into account embodied carbon in imports.

It is a mistake to bet on the silver bullet of future technologies, either because they are *Fata Morganas*, or else bullets to the head. The technofixer's unconventional fossil-fuels and allied technologies fail on both these counts, because they yield progressively less net energy and carry unacceptable environmental costs – not least through their implicated emissions (**Figs. 5 & 6**).

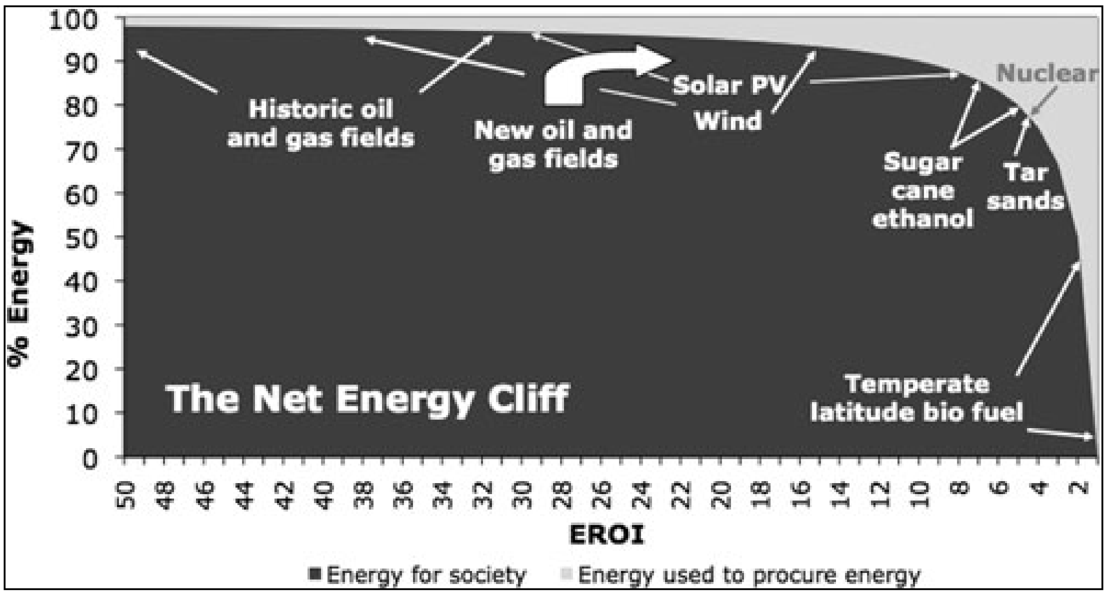

Fig. 5: Futuristic energy supplies (e.g., 'deep oil', 'heavy oil', 'shale oil', 'shale gas', 'tar sands') and technologies (e.g., coal liquefaction, directional drilling, 'fracking', 'gas-to-liquids') are progressively coming on-line, but yield less net energy and incur significant environmental cost (Murphy and Hall, 2010). EROI = Energy Released ÷ Energy Invested.

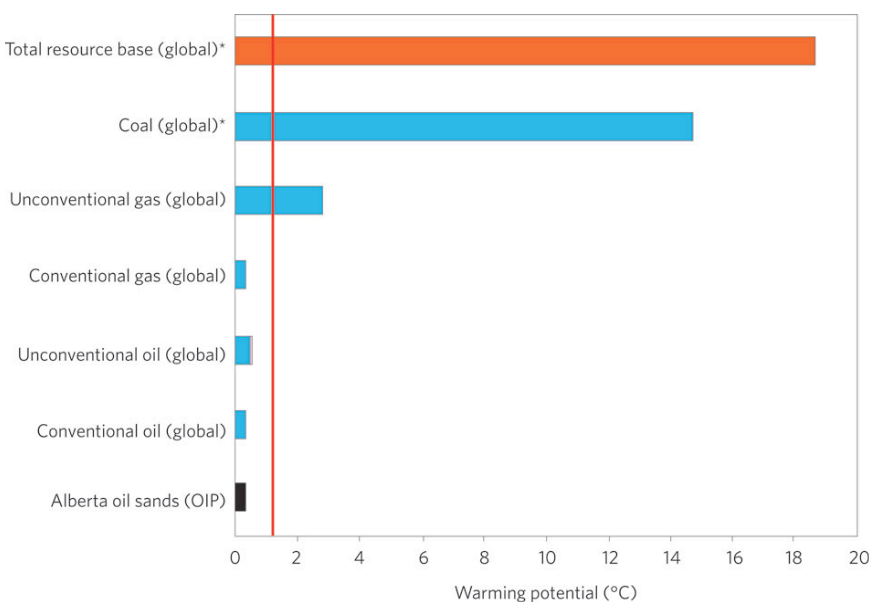

Fig. 6: Estimates of the warming potential of different fossil-fuel resources (Swart and Weaver, 2012). Red line indicates level agreed to under the Copenhagen Accord. OIP = Oil In Place.

Renewables technologies are highly necessary, but being flow rather than stock resources, their efficacy is frustrated by intermittent demand and supply, and hampered by a dearth of energy storage solutions (Rogers et al., 2008). The emphasis should rest on cultural and institutional shifts framing technological change, rather than the inception of new technologies.

IV. Synopsis & Conclusion

There is little doubt that technologies will play an important part in confronting the energy and environmental challenges ahead, and that there is much room for well-crafted technology policy. The question being asked, though, is how much room? As we have seen, the forward trajectory of technology is highly uncertain. So is its' capability to harmlessly and affordably augment our atmosphere (CO_2 management – 'COM', which includes attempts at carbon capture & storage – 'CCS'), modulate incoming solar radiation (solar radiation management – 'SRM'), or provide us with a steady supply of clean energy (fusion reactors, second- and third- generation biofuels in high latitude belts, and so forth). What *can* safely be said about these and other proposed geo- and bio-engineering interventions is that great uncertainty surrounds their adverse and beneficial effects alike (Smith, 2010; Irvine et al., 2012; Pongratz et al., 2012; Ricke et al., 2012) - the scale and complexity of the systems involved make these propositions highly risky. In addition to imbuing our forecasts with a much-needed measure of humility, today's lack of consensus about tomorrow's technological capability should encourage prudence – rather than outright reliance - in respect of its role in policy.

What's more, once discovered, energy technologies evidently take a long time to implement. Wood, coal, oil and gas (in that order) each took about a century to outdo their predecessor (Marchetti, 1977), and today's renewables are on a similar trajectory.

Even if technological solutions *were* readily at hand, there is only so much technology-focused democratic policymaking appears capable of achieving. In much of the world, renewable energy will remain dependent on some sort of subsidy scheme for the foreseeable future. However, the levels and types of support wax and wane at the whim of political agendas, which are at the intermittent mercy of an idiosyncratic beast known as 'the periodic election cycle' (topical UK examples include Feed-in Tariffs - 'FITs', Renewable Obligation Certificates – 'ROCs', and the fledgling Renewable Heat Incentive – 'RHI'). Few things corrode investor confidence like uncertainty (Ulph and Ulph, submitted 2012), which in the renewables industry is further amplified by expensive initial outlays and long payback periods determined by the price of 'green' electricity. China's command economy, uninhibited by the handicap of this 'democratic uncertainty', commits a proportion of GDP to renewables beyond that of most 'developed' nations (**Fig. 7**). A string of failed attempts at international collaboration on CO_2 targets and the near-collapse of the European carbon market experiment, meanwhile, do not exactly engender confidence in the future of a rigorous and consistent global emissions policy. All this serves to discourage private-sector investment into renewables.

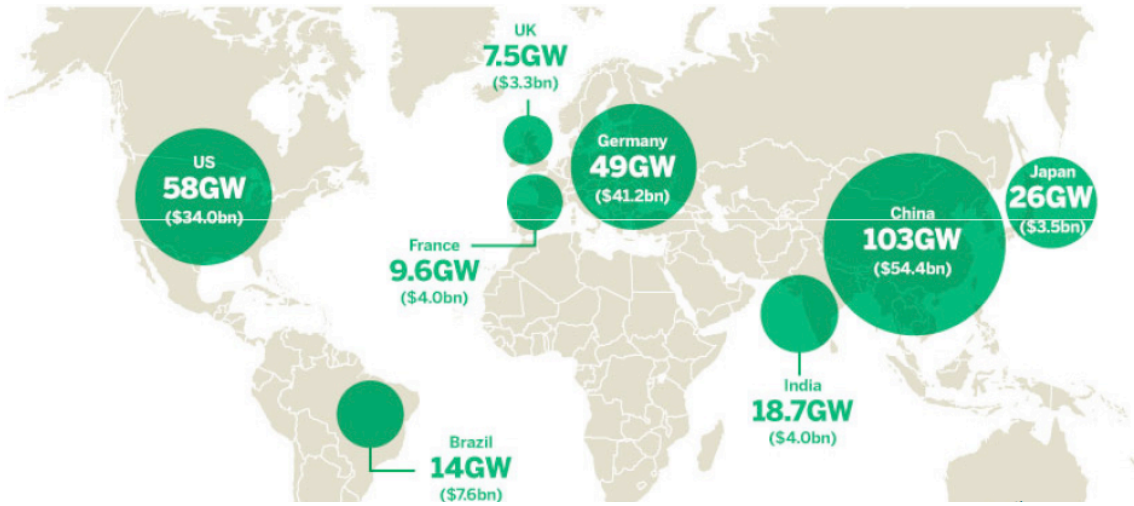

Fig. 7: Commitment to all renewables amongst major players in 2010 in terms of total capacity (GW), and total investment (2010 US$) (Hook and Crooks, 2011).

In the face of reigning scientific projections on the future state of our planet, are technology-focused environmental and energy policies an appropriate course of action? The balanced response seems to be that they are necessary, but not sufficient. So what's missing?

To arrive at an answer, it is first necessary to appreciate just how fundamentally different renewable energy generation is, in terms of its underlying *economics*, from the fossil-fuel technologies that have dominated the preceding century. Fossil-fueled power enjoys economy of scale: all other things being equal, a 2 GW coal-fired power plant is less than twice as expensive as a 1 GW plant. Renewable power production, in contrast, exhibits a diseconomy of scale of sorts: the patchy distribution of renewable resources *in space as well as in time*, in principle, favours dispersed production.

Leveraging this insight, my answer is that more focus needs to be placed on building community resilience and bringing about demand-side reductions in our use of and dependence on fossil-fuels and other non-renewable resources, in parallel with multi-level governmental support for both the innovation and adoption of renewables technology. How could this be brought about? In many countries and regions, the appropriate policy measures are already within grasp. Policy-makers need to more actively emulate the emblematic Danish and German examples, by aggressively facilitating the *ownership* (decentralization) of renewable generation technologies at household, community and municipal levels. Local ownership of energy production changes everything. It stymies societal opposition to wind-farms and other renewables development (Warren and Birnie, 2009; Warren and McFadyen, 2010; Musall and Kuik, 2011). It induces a more dispersed and hence more resilient energy supply (Rogers et al., 2008). Where the option exists to sell excess production to the grid, it instils a culture of efficient energy usage. Moreover, it has shown itself a strong force for community (socio-)economic revitalization (Munday et al., 2011).

As harbinger of doom and salvation alike, technology has always required human accompaniment. The question has always been what *form* this accompaniment should take – *how* and *for whom* technology is harnessed. The profound changes that are increasingly called of us fall beyond the means of mere technological *possibility*. Rather, it is by changing the way energy is owned and controlled that we can begin to catalyze the more profound societal shifts upon which our collective welfare will depend. This would see institutional change setting the stage for technological adoption, rather than the other way round. Policy, from the level of the village gathering to the General Assembly, should harmonize accordingly.

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