Climate Change: What it means in terms of energy

Ian T Dunlop
Member, The Club of Rome

Abstract

As population rises from 7 billion today toward 9 billion by 2050, the inevitable logic of exponential growth in both population and consumption is now hitting the limits of global ecosystems and resource availability. The immediate pressure points are climate change, energy security, biodiversity loss, water and food availability, issues which are converging rapidly in an unprecedented manner, in the process contributing substantially to current financial instability.

Climate change is arguably the most intractable of these issues, due to its complexity, inherent uncertainties and the inertia of the climatic system. However, there is now unprecedented evidence that human carbon emissions from fossil-fuel consumption and land degradation are, on the balance of probabilities, warming the planet at an accelerating rate. Historic emissions have probably already locked in a temperature increase of around 2^0C relative to pre-industrial conditions, sufficient in due course to melt large parts of the Greenland and West Antarctic ice sheets, leading to a 6-7 metre sea level rise once a thermal equilibrium point is reached. Even if current climate policies are fully implemented, the likely temperature increase will probably be in excess of 4^0C, leading in due course to a 70 metre sea level increase. Empirical evidence suggests that climate modelling has probably badly underestimated both the speed and the extent of climate change.

The implication is that the official target of limiting temperature increase to below 2^0C is inadequate if dangerous climate change is to be avoided, a more realistic target being below 1.5^0C. This requires the reduction of atmospheric carbon concentrations from 391ppm CO_2 currently to below 350ppm CO_2. Even to achieve the current 2^0C official target requires global emissions to peak immediately and decline rapidly.

Despite two decades of negotiation, virtually nothing has been done to constrain emissions and there is no sign of this changing in the short term if current attitudes prevail. Adaptation to a 4^0C temperature rise is talked about glibly in policy circles as a realistic strategy if required. Such an outcome would be catastrophic, with a possible reduction in global population to less than 1 billion people from the current 7 billion. If the global community is serious about addressing climate change, prudent risk management dictates that action must be elevated to an emergency footing, outside the arena of adversarial politics, as time for a graduated incremental response has run out. The cost of taking action now if the science turns out to be wrong is vastly outweighed by the catastrophic cost of inaction if the science is right.

The implications for energy are diabolical. Changes to the energy system take decades to implement, but fossil-fuel emissions must be cut rapidly and there is no sign that sequestration methods, such as carbon capture and storage, will contribute to a solution either at the scale, or in the time, now required. Official forecasts of expanding fossil-fuel use, used to justify continued investment with concepts such as "carbon-ready" power stations, are irresponsible. To have a reasonable chance of remaining below even the inadequate 2^0C official target, only 30-40% of current proven fossil-fuel reserves can be burnt. Unfortunately alternative energy sources all have lower power densities than fossil-fuels, hence far greater spatial requirements with attendant environmental implications.

Energy policy must focus on integrated solutions to both climate, energy and global sustainability, taking an objective view of technical realities. Differing policies are required for the developed and developing world, with no "silver bullet " for either, rather a multitude of "silver buckshot". Global carbon pricing and emission reduction targets are essential.

Developed world policy must achieve a significant reduction in energy demand, strong and consistent support for the introduction of renewable energies, serious consideration of new nuclear technology and biofuels with gas as a transition fuel, albeit coal seam and shale gas may be environmentally unacceptable. High emission unconventional oil and tar sands development must halt. Developing world policy must re-focus on low emission pathways, avoiding lock-in of fossil fuels. Above all, economies must be placed on the equivalent of a war-footing to meet these objectives. History has demonstrated that market solutions alone, whilst important, will not avoid dangerous climate change. Indeed concepts of markets and economic growth need to be re-thought. The enormous scale of energy investment now required will provide the stimulus to move beyond current financial instability.

From Global Drivers to Strategic Risks

Since the Industrial Revolution the world has undergone an unprecedented transformation, largely a result of human activity. To the point, as proposed by Paul Crutzen, that we are now arguably in a new geological epoch – the Anthropocene [1], where humanity is a dominant, if not the dominant force in world evolution.

The changes have been particularly marked since WW11 as the developed world has enjoyed rapidly rising standards of living and wealth creation. But in the euphoria created by this good fortune, we fail to recognize that the global drivers behind it have gradually turned into major strategic risks; that is risks which pose existential threats to humanity. In essence, they reflect an increasing gulf between narrow self-interest and the common good.

As population rises from 7 billion today toward 9 billion by 2050, and possibly 10 billion by 2100 [2], the inevitable logic of exponential growth in both population and consumption is now hitting the limits of global ecosystems and resource availability. The immediate pressure points are climate change, energy security, biodiversity loss, water and food availability, issues which are converging rapidly in an unprecedented manner as China and India in particular move up the growth escalator. They are also contributing substantially to current financial instability.

This situation is not unexpected; it has been anticipated for decades going back before the 1972 publication of "The Limits to Growth" [3]. In the meantime the developed world has created a political system which has proved incapable, so far, of recognising that the most important factor for its own survival is the preservation of a biosphere fit for human habitation.

Increasing prosperity has bred complacency; the assumption that growth within a finite system can continue indefinitely. Hardly surprising, given that power and influence accrue to those who prosper under the existing system, and that technology until recently has enabled us to push back or ignore physical constraints. Our institutions have become predominantly short-term focused; politically due to electoral cycles and corruption of the democratic process; corporately due to perverse subsidies and incentives. As a result, enormous political and personal capital is now vested in preserving the status quo and we are ill-equipped to address the existential challenges which confront us.

The limits we now face are global, rather than regional, and cannot be circumvented as we have done in the past. What was workable in a relatively empty world of 2-3 billion people post-WWII is not workable in today's full world of 7 billion, let alone a world of 9 or 10 billion. Our preoccupation with an unregulated market economy is rapidly leading toward an uninhabitable planet, as sustainability issues of theoretical concern for decades manifest themselves physically, particularly in regard to climate and energy:

Climate Change

Climate change is arguably the most intractable of these issues, due to its complexity, inherent uncertainties and the inertia of the climatic system.

There is now unprecedented evidence that human carbon emissions from fossil-fuel consumption and land degradation are, on the balance of probabilities, warming the planet at an accelerating rate [4] [5] [6] [7] [8] [9]. The impact is clearly seen in record global surface and ocean temperatures [10] [11] [12], rapid Arctic and Antarctic ice volume loss [13] [14] [15] [16], increasing permafrost carbon and methane emissions [17] [18] [19] [20], ocean acidification [21] [22], potential reversal of carbon sinks into sources, for example in the Amazon [23] and escalating extreme weather events [24] [25]. These major changes are happening at the 0.8°C temperature increase we have already experienced relative to pre-industrial conditions, let alone the additional 0.6°C to 3.5°C [26] to which we may already be committed as the full effect of historic emissions is felt.

The inertia of the climate system, particularly the slow warming of the oceans, means that the results of our emissions today only become evident decades hence. Paleoclimate analysis suggests that current global average temperature is around 0.6^{0}C above the peak temperature of the Holocene period of the 10,000 years prior to 1900, during which time humanity as we know it developed. The thermal inertia of historic emissions is likely to translate, in due course, into a 2^{0}C mean temperature increase relative to pre-industrial conditions, subject to the uncertainty band above. Once equilibrium is reached, this will be sufficient for large parts of the Greenland and West Antarctic ice sheets to melt, leading to sea level rises of 6-7 metres over time.

Even if current climate policies were to be fully implemented, rather than regarded as "aspirational", it is likely the temperature increase would be in excess of 4⁰C [27], sufficient over time to melt all ice sheets, leading to a sea level rise of around 70 metres [28] [29]. It is unclear how rapidly these changes might occur, but the empirical evidence of Arctic sea ice and ice sheet melt suggests it is happening far faster than expected [30]. Thus unless we take real action now, we may well be locking in irreversible climate change of catastrophic proportions for future generations; indeed we may have already done so [31] [32]. Difficulties in gaining acceptance of this thesis include the denialist mindset of vested interests and key institutions, plus the fact that conventional economics ignores such possibilities.

Other scientific analysis notes that the speed of atmospheric CO_2 build-up is faster that at any time in recent geological history [33], and the risk that climate modelling may have badly underestimated the speed of climate change impact, with current climate policies having virtually no chance of constraining global temperature increase below the "official" UNFCCC target of 2⁰C, leading to increases in excess of 4⁰C [34] [35] [36]. A particular concern is the triggering of non-linear climatic tipping points, especially the Arctic permafrost, which move global or regional climate to a different equilibrium state, for far less favourable to human development [37].

The appropriate method of handling high impact, low probability events such as tipping points, the conundrum of the so-called "fat tail" of probability distributions, has been well explored by Harvard's Martin Weitzman [38], arguing that conventional cost benefit analysis is entirely inappropriate in such circumstances, and that insurance against catastrophe should be the dominant consideration. Unfortunately the latest science suggests that the supposed low probability of these events has increased significantly in recent time.

A 4°C World

Unless there is a radical change in global attitudes toward climate change in the near future, a 4⁰C temperature rise will probably become inevitable. A 4°C world is talked about glibly in policy circles, often to justify greater concentration on the supposedly "politically easier" task of adaptation as opposed to mitigation, but the real implications seem to be little understood outside the scientific community. The outcome would be catastrophic. Large parts of the world would be subject to extreme drought, whilst other parts experience intense rainfall [39]. Mean temperature rises around 4°C would mask substantial global variations, with for example far larger increases, 10-16°C, occurring in the Arctic [40]. Global carrying capacity would probably fall dramatically as food and water availability declines, with a possible reduction in global population to less than 1 billion people from the current 7 billion [41].

As the Royal Society put it January 2011, *"In such a 4°C world, the limits for human adaptation are likely to be exceeded in many parts of the world, while the limits for adaptation for natural systems would largely be exceeded throughout the world"* [42].

When asked at the Melbourne 4 Degree Conference in July 2011 to explain the difference between a 2°C and a 4°C world, Hans Joachim Schellnhuber, Director of the Potsdam Institute for Climate Impact Research replied simply: *"human civilisation"*.

In short, if we have any sense of responsibility to current and future generations, a 4°C world is to be avoided at all costs.

Risk Management on a Global Scale

There will always be scientific uncertainties on an issue this complex, with year-to-year climatic variations continuing to be used selectively by deniers to discredit the mainstream science; but the underlying trends are clear and unfortunately they are all moving in the wrong direction. The world is undoubtedly warming and human carbon emissions are almost certainly a major cause; the uncertainty relates more to the outcome this will produce – whether, over time, it will be 2⁰C or 7⁰C. It is tempting to believe the deniers are right, but faced with the science, the mounting empirical evidence and the implications of a 4°C world, prudent risk management dictates we should not risk inaction.

After two decades of negotiation, despite rapidly improving scientific knowledge and the evidence, virtually nothing has been done to address the problem, with human emissions accelerating on a worst-case pathway [43].

However, the 2009 Copenhagen and 2010 Cancun UNFCCC meetings were not the failures generally portrayed, albeit the outcome was not what many had hoped for. For the first time the real issues came to the negotiating table:

- the impossibility of getting agreement among 193 countries via the UN process,
- the necessity for the top 6-12 emitting countries to take the lead in framing solutions; but based on current, not outdated, science.
- The prospect that the real objective might be to limit temperature increase to 1.5°C or less, relative to pre-industrial levels, rather than the "official" 2° C,
- the beginnings of a technology transfer and financing package for the developing world

Certainly, legal binding undertakings were missing, but this was a forgone conclusion given that the developed world has yet to put forward any serious proposals to encourage developing country action, and that their own targets and policies are hopelessly inadequate and compromised in the light of the real problem that has to be addressed.

There is a long way to go, but it is dawning on global leaders that the size of the challenge is far greater and more urgent than is being officially acknowledged. Unfortunately it may take some further natural disasters to drive the point home; although that may occur more rapidly than expected if the latest evidence can be believed.

Gradually, the world is starting to understand that, if catastrophic outcomes and climatic tipping points are to be avoided, on the balance of probabilities the real target to restore a safe climate is to reduce atmospheric carbon concentrations back toward the pre-industrial levels below 350ppm CO_2 from the current 392 ppm CO_2. This will require emission reductions of the order of 50% by 2020, almost complete de-carbonisation by 2050 and continuing efforts to draw down legacy carbon from the atmosphere [44] [45] [46] [47]. Already total greenhouse gas concentrations are around 470ppm CO_2equivalent, in excess of the official UNFCCC and International Energy Agency (IEA) 450ppm CO_2e stabilization target, which supposedly corresponds to the 2°C temperature target.

Looked at from a total carbon budget perspective, to have a less than 25% chance of exceeding the 2°C target, the world can only emit a further 800 Gigatonnes CO_2 in toto from today, a budget which would be used up in less than 20 years. Accepting a 50/50 chance allows the budget to increase to 1,200 $GtCO_2$, used up in less than 30 years. If the temperature target has to be less than 2°C, as seems likely, the budgets are considerably lower [48]. This requires global emissions to peak in the next year or so, certainly no later than 2020 and then fall in the 4-9% pa range depending on the peak year. An equitable approach would require developed world emissions to fall rapidly, while developing world emissions continued to rise for a period before also falling.

The cost of this degree of change is probably in the range 3-5% of global GDP, rising the longer real action is delayed. This is a manageable amount even if the mainstream science were, in time, found to be wrong and climate change turned out to be benign – the investment would not be wasted as a cleaner environment would result, which is desirable from many other perspectives. However, the potentially catastrophic cost of continuing inaction if the science is right, would be in excess of 20% of GDP, equivalent to the costs of WWI, WWII and the Great Depression combined, let alone the human suffering involved. We only play the fossil-fuel emissions game once, there is no trial run; in this context, responsible risk managers would have taken action long ago.

Climate change risk management is increasingly discussed [49], but rarely in the context of the catastrophic risk to which we are now exposed. The science on an issue this complex will not be settled for a long time, but that requires even greater prudence in managing risk and uncertainty, particularly when climatic changes may be sudden and irreversible.

The Implications for Energy

The risks of climate change pose a diabolical problem for global energy supply and demand. Cheap energy has been the cornerstone of successful societies for centuries. Today, just as economic growth for the bulk of the world's population is accelerating, the days of cheap fossil–fuel energy are ending, triggered by the peaking of global oil supply and the need to reduce carbon emissions to combat climate change. After years of denial, these realities are finally being partially acknowledged by official bodies such as the IEA [50], the International Monetary Fund [51]and some industry leaders [52] [53] [54] [55] [56] [57] [58]. Unfortunately the full implications of the message have yet to penetrated the "official future" of many national governments.

Depending on the acceptable risk to restore a safe climate, the global carbon emission reduction targets above will only allow around 30 - 40% respectively of existing fossil-fuel reserves (reserves recoverable with existing technology and prices) to be consumed [59]. Which removes any justification for expanding reserves of oil, gas and coal with increasingly risky, costly and environmentally damaging ventures, such as deepwater oil exploration and tar sands, unless those emissions can be safely sequestered long-term. Looking at our traditional fossil-fuel mainstays in this context:

Peak Oil

Peak oil is not primarily an economic issue, but a reflection of the physical barriers to energy supply we now face. We are not running out of either oil, gas or coal resources. The issue is how to convert those resources in the ground into flows to the market in an environmentally and economically acceptable manner.

Peak oil is the point at which it is no longer possible to increase oil production to meet demand, notwithstanding increasing prices, as evidenced by the stagnation of global oil supply since 2005 [60] [61]. It results from the discovery rate of new oilfields falling far behind our escalating use of oil, and the fact that production from long established oilfields is depleting at faster rates than anticipated. As a result, we are forced to explore in more difficult conditions, with ever increasing risk and cost, as witnessed by the BP Deepwater Horizon blowout in the Gulf of Mexico [62] and controversy over tar sands production in Canada [63] [64] [65]. Recent estimates indicate the need to bring on stream the equivalent oil production of four Saudi Arabia's over the next 10-15 years just to maintain current supply, let alone meet increasing demand [66] [67]. Highly unlikely in current circumstances.

Peak oil, due to the immediacy of it's impact, is likely to be the trigger which forces serious action on climate and energy security. The oil price spike to US$147 per barrel in July 2008 gave warning of the tightrope we are walking, as well as probably triggering the first stage of the Global Financial Crisis (GFC) as it broke the financial back of debt-laden, gasoline-dependent consumers on the fringe of US cities. Prices subsequently dropped as the GFC destroyed oil demand, but have recovered close to US$100 per barrel currently. Further increases can be expected if economic activity strengthens, which in turn will have a temporary dampening effect, leading to an undulating plateau of price and supply volatility, possibly for some time.

Opinions vary widely on the evolution of global oil supply, and much will depend on the speed of economic recovery globally [68]. It may well be that global supply by 2030 is 20-30% below current levels [69] a traumatic change for a world wedded to oil, particularly in sectors where substitution options are limited, for example for private transport and aviation [70]

Coal

Coal is the most critical factor in solving the energy security and climate change dilemma. It is the largest, cheapest and most widely available fossil-fuel resource, but has the worst environmental impact, with emissions double that of gas per unit of energy. Unless means can be found to capture and store those emissions securely, the coal industry worldwide will have to shut down rapidly if catastrophic climate change is to be avoided. Clean Coal Technology (CCT) and geological Carbon Capture and Storage (CCS) are seen as the means of securing coal's long-term future, to the point where they have become unquestioned articles of faith on the part of industry and government. Substantial research and development for both CCT and CCS has been initiated, with high emission facilities, such as power stations, being built "carbon-ready" so that CCS technology can, in theory, be added as soon as it is available.

Unfortunately that faith looks increasingly misplaced. CCS is established technology in the oil and gas industry where it has been practiced safely for decades by storing carbon dioxide in the reservoirs from which it was originally extracted with the oil and gas. However, sequestering carbon emissions on the scale now required by the climate science means the establishment of an industry larger than the world oil industry, storage in geological formations that have never demonstrated the security and stability of oil and gas reservoirs, solving substantial reservoir engineering problems and, unlike oil and gas practice, transporting the material large distances from source to storage for no economic benefit. This has to be done at scale in less than two decades to have any real impact on the climate problem. At present there are only five commercial scale projects worldwide, none in the critical power generation area, and technical progress is painfully slow. The IEA have highlighted the need for 100 projects by 2020, 800 projects by 2030, and 3,400 projects by 2050 [71]; an extremely demanding target representing an investment to 2050 of around US$3 trillion.

CCT, as distinct from CCS, refers to a range of technologies, such as Integrated Combined Cycle Gasification and Supercritical Pulverised Coal Plants, aimed at reducing the environmental impact of coal. However, it is an oxymoron in that coal does not become clean, rather emissions are reduced typically by 20-40% and efficiency is increased; all of which is valuable, but it does not solve the underlying problem of coal's high emissions.

Gas

Much store is placed on the future role of gas, whether as Liquified Natural Gas (LNG), Coal Seam Gas (CSG) or unconventional gas from shale beds, as a transition fuel to the low-carbon economy in replacing coal, the rationale being that carbon emissions from gas burning supposedly have roughly half the warming potential of coal. However extensive use of gas has some unexpected consequences given current climate change risks.

Coal burning emits not just carbon, but also aerosols, tiny particles which are suspended in the atmosphere and have a cooling effect. Cleaner-burning gas does not emit aerosols, so if coal use drops, to be replaced by gas, the level of aerosols drops correspondingly and hence the cooling effect reduces. So one unintended consequence of the use of gas may be a relative increase in global temperature in the medium term due to the removal of aerosols which are currently holding global temperature at a lower level than would otherwise be the case.

CSG and unconventional shale-gas also have complications. They rely on fracturing geological formations with fluids to release gas trapped in the coal seam or rock pores. Depending on the geological strata, this may result in a rapid production build-up, but an equally rapid production decline, necessitating many wells being drilled over an extensive surface area using large amounts of water. Potential risks to acquifers and agricultural land use include water contamination, water table depletion and increased fugitive gas emissions if water tables fall. All of which requires high standards of regulation and compliance, with associated costs, if these new industries are to operate responsibly. A very different operation from conventional oil and gas production, which is relatively localized. This is causing significant conflict between the energy and agricultural industries in rural Australia.

The most important factor is the leakage of gas prior to combustion. Whilst gas when burnt has roughly half the emissions of coal, if gas is leaked to atmosphere pre-combustion, it has a warming potential around 25 times that of CO_2 over a 100 year time frame. A leakage rate of around 3% negates the advantage gas has over coal from an equivalent warming perspective - typical leakage rates appear to be in the 1.5 – 2.5% range [72] [73].

Recent analysis suggests that extensive use of gas will actually increase warming for several decades ahead, the period depending on success in limiting leakage [74] [75]. As Noburu Tanaka, Executive Director of the IEA put it: *"While natural gas is the cleanest fossil fuel, it is still a fossil fuel. Its increased use could muscle–out low carbon fuels such as renewables and nuclear, particularly in the wake of Fukushima. An expansion of gas use alone is no panacea for climate change".*

So gas is not the solution to emissions reduction which is generally assumed and its extended use needs to be treated with caution. It also emphasizes the need for high standards of performance to prevent leakage if the use of gas increases. On the positive side, gas-fired power generation facilities can be built on both large and small scale, and fired up very quickly to meet peaking power demand, in contrast to base-load coal-fired power generation. In this context, gas can be valuable as a back-up to intermittent renewable energy generation.

If dangerous warming is to be avoided, CCS will be equally necessary for gas as well as for emissions from other industrial processes such as steel and cement manufacture. But objectivity is essential in developing these proposed solutions. Whilst research on CCS and CCT should be accelerated to determine the realistic role these technologies can play, and they will undoubtedly work in specific situations, it is extremely unlikely they will provide the hoped-for panacea for coal or gas. To sequester just 20% of current CO_2 emitted from global fossil-fuel combustion would require an industry 70% larger than the world oil industry, which has itself taken decades to establish [76]. Given the climate change risks now emerging, it is an extremely dangerous strategy, and morally reprehensible, to place most of our eggs in these baskets, as fossil-fuel rich countries are doing, and to lock-in the construction of new high-emission facilities, "carbon-ready" or not, before the viability of the technology is assured.

Given that CCS is an existential technology for both coal and gas, it is of particular concern that fossil-fuel industry players do not seem committed to invest in the technology at the speed required, simultaneously attempting to prevent the introduction of carbon pricing which would speed its commercialization and passing off risk to the public sector. Which suggests that those players do not yet understand – or want to understand - the climate change risks to which we are now exposed. Similarily with the lack of continuity and consistency in government policy. There is clear evidence of moral hazard in the attitude of both the fossil-fuel industries and governments to CCS, as their supposed commitment to CCS research erodes their preparedness to reduce emissions. As The Economist put it:: *"The world's leaders are counting on a fix for climate change that is at best uncertain and at worst unworkable"* [77].

Concerns have also been expressed over the peaking of both coal and gas supplies, albeit at longer time frames than the peaking of oil.

The implication of the climate change / energy conundrum is that the world has to halt the use of all fossil-fuels as rapidly as possible, except to the extent that CCS, and possibly some other genuinely long term sequestration techniques can safely store emissions, which is likely to be a relatively minor part of total fossil fuel use. Even for that to happen, industry and governments will have to demonstrate far greater commitment that has been forthcoming thus far. A massive challenge, far beyond anything being acknowledged politically, with far reaching implications across the global economy, not least for financial markets as the value of fossil fuel companies is re-assessed [78]

The Alternatives to Fossil-Fuels

The alternatives to our traditional energy supply mainstays of oil, gas and coal range from nuclear power to numerous renewable energy options. There is no "silver bullet" to solve escalating energy security concerns as fossil-fuels are phased out, but much "silver buckshot" whose development must be accelerated, ideally by a combination of regulatory and market mechanisms, to meet future needs. The critical policy requirement is that each option is assessed in the light of its true cost, benefits and risks. Externalities such as carbon pollution must be fully internalized, inter alia removing the enormous subsidy the fossil-fuel industries have enjoyed since the Industrial Revolution, and which continues to distort investment decision-making [79]. The competitive ranking of the new alternatives will only emerge gradually, hence the need to accelerate the overall innovation process but avoid picking winners.

Particular emphasis must be placed on demand management to reduce demand through a combination of efficiency improvement and conservation, inter alia using smart grids and distributed energy systems

A critical factor is the "Energy Return on Energy Invested"(EROEI); how many energy units are produced for the energy invested in producing it. Historically, from an energy production perspective, this ratio has been 100:1 or more for large onshore oilfields; it is now declining below 5:1 in many new offshore oil provinces and tar sands operations, and may fall below 1:1 when the true environmental impact is internalized. There is little point in continuing operations when EROEI ratios fall much below 3:1 [80] [81] [82].

The alternatives encompass:

- demand reduction via efficiency & conservation
- hydro
- wind
- solar PV
- concentrating solar thermal
- passive solar
- geothermal
- wave
- tidal
- new generation nuclear
- biomass
- biofuels (albeit these may be excluded on low EROEI grounds)
- the unknown unknowns ?

Each alternative currently contributes a minor amount to global supply relative to fossil fuels, albeit some are growing rapidly. With the exception of nuclear, they also have far greater spatial requirements and lower power densities than fossil fuels, raising issues of potentially conflicting land use and declining EROEI. The latter has major implications for economic growth, as less energy becomes available to society relative to the amount required to access it. To be effective, these sources also require major innovation in for example carrier mechanisms (eg electricity or hydrogen?), storage and transmission. Whether other forms of cheap energy will emerge, or energy will remain expensive, is unclear, but there is little doubt that energy prices in the medium term will be volatile as the new order unfolds.

History has demonstrated that major innovations in the energy arena can take at least 30 years to reach "materiality", based on conventional commercialization processes [83]. This only serves to underline the enormity of the transition ahead.

Nuclear warrants special mention, as any renaissance of the nuclear industry engenders strong emotion, both for and against, in the light of historical accidents such as Chernobyl and Three Mile Island, along with the risk of nuclear weapons proliferation. Those concerns have been amplified by the accident at the Fukushima nuclear plant in Japan in March 2011, resulting from the major earthquake and tsunami.

Investment in nuclear energy has stagnated for many years, albeit 66 new nuclear plants are now under construction worldwide, particularly in China and elsewhere in the developing world, primarily government-funded [84]. It is too soon to judge the impact the Fukushima accident will have on these and other future nuclear programmes, given that Fukushima was old technology, and that the full extent of the accident remains unclear. But undoubtedly it will result in a major review of safety standards and procedures at the very least.

Newer nuclear technologies, such as Generation III (advanced) & IV reactors, promise greater safety and less proliferation risk than existing plants, including possibly the ability to use up existing nuclear waste. However these technologies are still in the embryonic stage and far from commercial application.

Nonetheless, given the enormous scale of the climate and energy challenge ahead, it would be most unwise to exclude nuclear options from the possible solutions. Therefore nuclear should be considered, provided the full life-cycle and environmental costs and risks are taken into account.

What is rarely acknowledged is that decisions made today about energy systems, urban design, housing and infrastructure generally, lock in patterns of consumption and emissions which last for decades to come, which is why those decisions must be taken with a clear understanding of their long term implications, and not based on short-term political expediency. It is why the concept of "carbon ready" power stations makes no sense in a world probably already in the climate danger zone.

An Emergency Response is Essential

Governments and corporations globally, including major players in the fossil-fuel industries, acknowledge that climate change is a serious issue requiring urgent action. In making that acknowledgment, it is reasonable to assume that these key players have studied and understood the science. They will be aware that every major Academy of Science and credible scientific organization around the world urges far more extensive and rapid action than currently contemplated officially. "Knowledge is responsibility" and the continued procrastination of global leaders, refusal to accept the risks, and obstruction of realistic climate policy is a fundamental breach of their fiduciary responsibilities to the global community. Yet it has to be assumed that those leaders, in the final analysis, do wish to avoid catastrophic outcomes.

On that basis, it is clear on the balance of probabilities, that we have little time to take serious action to reduce carbon emissions if catastrophic climate change, in excess of a 4°C temperature rise, is to be avoided.

It is also clear that serious action to transform energy systems will not be achieved using the incremental change to "business-as-usual" approach which has typified the corporate response to date, or if process-driven UNFCCC and national government initiatives are allowed to continue at their current pace.

The extent of change is enormous. The technical solutions, whilst complex, are within our grasp; the major risk is a failure of leadership to implement them in time to be effective. In reality, given the time frame within which substantial change has to be achieved, say the next two decades, and the time wasted over the last two decades, there is no alternative but to mount an emergency response, akin to placing economies on a war-footing where rapid, fundamental re-direction of economic activity is mandated. In essence this is the direction in which China may be heading. Alternatively it can be viewed as an industrial revolution, as proposed in Germany.

Whatever the branding adopted, the change must be rapid and effective, ideally coordinated globally. It is unlikely that this can be achieved with the current adversarial politics in many developed countries, which may require issues relating to the global "common good", such as climate change and resource depletion, to be set outside conventional politics. Idealistic possibly, but that is the reality of climate change risk. A pre-requisite is honesty about the challenge we face. If this is not forthcoming, it is impossible to implement realistic solutions.

Continuation of business–as-usual in the energy arena is not a realistic option. But the energy transformation now required presents enormous opportunity to overcome current financial instability. The investment stimulus it implies holds the promise of setting the world on a genuinely sustainable development path.

References

---

[1] "Geology of Mankind – The Anthropocene", Paul J Crutzen, Nature, January 2002: http://academics.eckerd.edu/instructor/carlsopr/Papers/Anthropocene.pdf

[2] World Population Projections – 2010 Revision". UN Population Division, May 2011: http://esa.un.org/unpd/wpp/Other-Information/Press_Release_WPP2010.pdf

[3] "The Limits to Growth", A Report to the Club of Rome, 1972

[4] "The Physical Science Basis", Fourth Assessment Report, International Panel on Climate Change, 2007: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

[5] "Synthesis Report", Richardson et al, Copenhagen Climate Conference March 2009. http://climatecongress.ku.dk/pdf/synthesisreport

[6] "The Copenhagen Diagnosis" Climate Change Research Centre, UNSW, November 2009. http://www.copenhagendiagnosis.com/

[7] "Climate Change – A Summary of the Science", Royal Society, London, September 2010: http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2010/4294972962.pdf

[8] "The Critical Decade: Climate Science, Risks, Responses", Climate Commission Australia,May 2011: http://www.acci.asn.au/getattachment/e9ae9b51-a39b-486d-99dd-f006286f28df/Climate-Commission-Report-23-May-2011.aspx

[9] "America's Climate Choices", National Academy of Sciences, May 2011: http://dels.nas.edu/Report/Americas-Climate-Choices/12781

[10] Goddard Institute for Space Science, NASA: http://www.nasa.gov/topics/earth/features/2010-warmest-year.html

[11] "State of the Climate, Global Analysis 2010", NOAA, January 2011: http://www.ncdc.noaa.gov/sotc/global/

[12] World Meteorological Organisation, 20th January 2010: http://www.wmo.int/pages/mediacentre/press_releases/pr_906_en.html

[13] "Is Antarctica Melting?", NASA, January 2010. http://www.nasa.gov/topics/earth/features/20100108_Is_Antarctica_Melting.html

[14] Polar Science Centre, University of Washington: http://psc.apl.washington.edu/ArcticSeaiceVolume/IceVolume.php

[15] "Arctic Report Card", NOAA, October 2010: http://www.arctic.noaa.gov/reportcard/ArcticReportCard_full_report.pdf

[16] Ice-Sheet Disintegration, Veligcogna/Hansen, 2010. http://www.columbia.edu/~mhs119/IceSheet/

[17] "Modelling Permafrost on the East Siberian Arctic Shelf", Nickolsky/Shakhova, April 2010. http://iopscience.iop.org/1748-9326/5/1/015006/fulltext

[18] "East Siberian Arctic Shelf De-stabilising and Venting, Climate progress, March 2010. http://climateprogress.org/2010/03/04/science-nsf-tundra-permafrost-methane-east-siberian-arctic-shelf-venting/

[19] "Thawing permafrost will accelerate global warming in decades to come", US National Snow & Ice Data Centre (NSIDC), 16th February 2011: http://nsidc.org/news/press/20110216_permafrost.html

[20] "Permafrost Carbon-Climate Feedbacks Accelerate Global Warming", Charles D. Koven et al, PNAS July 2011: http://www.pnas.org/content/early/2011/08/17/1103910108.abstract

[21] "Oceans are Acidifying Ten Times faster today ----" Climate Progress: http://climateprogress.org/2010/02/18/ocean-acidification-study-mass-extinction-of-marine-life-nature-geoscience/

[22] "Effects of Ocean Acidification", Ridgwell/Schmidt, environment360, February 2010. http://www.e360.yale.edu/content/feature.msp?id=2241

[23] "The 2010 Amazon Drought", Lewis et al, University of Leeds: http://www.leeds.ac.uk/news/article/1466/

[24] "Natural Catastrophes in 2010", Munich Re, January 2011. http://www.munichre.com/en/media_relations/press_releases/2011/2011_01_03_press_release.aspx

[25] "Shaping Climate-Resilient Development", ECA 2009. http://www.mckinsey.com/App_Media/Images/Page_Images/Offices/SocialSector/PDF/ECA_Shaping_Climate%20Resilent_Development.pdf

[26] "On Avoiding Dangerous Anthropogenic Interference with the Climate System"' Ramanathan & Feng, PNAS 2008. http://www.pnas.org/content/105/38/14245.full.pdf+html

[27] "Climate Scoreboard", Climateinteractive, September 2011: http://climateinteractive.org/scoreboard

[28] "Paleoclimate Implications for Human-made Climate Change", Hansen & Sato, NASA GISS & Columbia University Earth Institute, July 2011: http://arxiv.org/pdf/1105.0968v3

[29] "Earth Energy Imbalance and Implications", Hansen, Sato, Kharecha & von Schuckmann, NASA GISS & Columbia University Earth Institute, August 2011: http://www.columbia.edu/~jeh1/mailings/2011/20110826_EnergyImbalancePaper.pdf

[30] "Arctic Sea Ice Volume", Neven, Polar Science Center, Applied Physics Laboratory, University of Washington: http://neven1.typepad.com/blog/2011/09/piomas-august-2011.html

[31] "Irreversible climate change due to carbon dioxide emissions", Solomon et al, NOAA, PNAS December 2008: http://www.pnas.org/content/early/2009/01/28/0812721106.abstract

[32] "Rethinking a Safe Climate - have we already gone too far?", David Spratt, 23 January 2011: http://climatecodered.blogspot.com/2011/01/rethinking-safe-climate-have-we-already.html

[33] "The Last Great Global Warming", Lee R Kump, Scientific American, July 2011: http://www.scientificamerican.com/article.cfm?id=the-last-great-global-warming

[34] "Models Guiding Climate Policy are Dangerously Optimistic", Kevin Anderson, The Guardian, 24th February 2011: http://www.guardian.co.uk/environment/2011/feb/24/models-climate-policy-optimistic/print

[35] " Reframing the Climate Change Challenge in the Light of Post-2000 emission Trends", Anderson & Bows, Royal Society UK, 2008: http://rsta.royalsocietypublishing.org/content/366/1882/3863.full.pdf+html

[36], "Beyond dangerous climate change: emission scenarios for a new world", Anderson & Bows, Royal Society UK 2011: http://rsta.royalsocietypublishing.org/content/369/1934

[37] "Tipping Elements in the Earth's Climate System", Lenton et al., PNAS 2008. http://www.pnas.org/content/105/6/1786.full.pdf+html

[38] "On Modeling and Interpreting the Economics of Catastrophic Climate Change", Martin Weitzman, Harvard University,May 2008. http://www.economics.harvard.edu/faculty/weitzman/files/REStatModeling.pdf

[39] "Climate Change: Drought may threaten much of globe within decades", Aiguo Dai, NCAR, October 2010: http://www2.ucar.edu/news/2904/climate-change-drought-may-threaten-much-globe-within-decades

---

[40] "4°C Global Warming: regional patterns and timing", Richard Betts et al, Hadley Centre, UK Met Office, Oxford 4 Deg Conference, September 2009: http://www.eci.ox.ac.uk/4degrees/ppt/1-2betts.pdf

[41] "4 Degrees Hotter", Climate Action Centre Primer, David Spratt , 14th February 2011: http://www.climateactioncentre.org/sites/default/files/4-degrees-hotter.pdf

[42] "Four Degrees and Beyond – the potential for a global temperature increase of four degrees and its implications", Royal Society Transactions, January 2011: http://rsta.royalsocietypublishing.org/content/369/1934.toc

[43] "Global Carbon Budget 2009", Global Carbon Project, November 2010. http://www.globalcarbonproject.org/carbonbudget/09/hl-full.htm

[44] "Target Atmospheric CO_2 – Where Should Humanity Aim?, Goddard Institute for Space Studies, NASA, December 2008. http://www.giss.nasa.gov/research/briefs/hansen_13/

[45] Hans Joachin Schellnhuber, Potsdam Institute for Climate Research, Guardian 15th September 2008. http://www.guardian.co.uk/environment/2008/sep/15/climatechange.carbonemissions

[46] "Climate Code Red", 2008. http://www.climatecodered.net/

[47] "Transition Plan Strategic Framework", Safe Climate Australia, November 2009. http://www.safeclimateaustralia.org/wp-content/uploads/2009/05/Transition.Framework.01B.pdf

[48] "Greenhouse gas emission targets for limiting global warming to 2°C", Meinhausen et al, Nature, April 2009. http://www.nature.com/nature/journal/v458/n7242/abs/nature08017.html

[49] "Degrees of Risk: Defining a Risk Management Framework for Climate Security", N.Mabey et al, E3G, February 2011: http://www.e3g.org/images/uploads/Degrees%20of%20Risk_Defining%20a%20Risk%20Management%20Framework%20for%20Climate%20Security_Full%20Report.pdf

[50] "World Energy Outlook", 2008, 2009 & 2010, International Energy Agency, OECD, Paris: http://www.worldenergyoutlook.org/

[51] "World Economic Outlook", International Monetary Fund, April 2011: http://www.imf.org/external/pubs/ft/weo/2011/01/pdf/text.pdf

[52] Association for the Study of Peak Oil (ASPO). http://www.peakoil.net/

[53] "Status of Conventional World Oil Reserves – Hype or cause for concern?", Owen/Inderwildi/King, Smith School, University of Oxford. March 2010. http://www.telegraph.co.uk/finance/newsbysector/energy/oilandgas/7500669/Oil-reserves-exaggerated-by-one-third.html

[54] "The Oil Crunch", UK Industry Task Force on Peak Oil & Energy Security, February 2010. http://peakoiltaskforce.net/download-the-report/2010-peak-oil-report/

[55] "The Big Oil Picture", Macquarie Bank, September 2009. http://www.aspo-australia.org.au/References/Bruce/Macq7-Oil-Sept-09-Iain-Reid-NY.pdf

[56] "The End of Easy Oil", Jeroen van de Veer, Shell, Council for Foreign Relations, April 2008. http://www.cfr.org/publication/15923/royal_dutch_shell_ceo_on_the_end_of_easy_oil.html

[57] "Sustainable Energy Security – Strategic Risks and Opportunities for Business", 360 Risk Insight, Lloyds / Chatham House, London, July 2010

[58] "Shell Chief Warns of Era of Energy Volatility", Peter Voser, CEO, Royal Dutch Shell, Financial Times, 21st September 2011: http://www.shell.com/home/content/media/speeches_and_webcasts/2011/peter_voser_financial_times_21092011.html

[59] ibid "Greenhouse gas emission targets for limiting global warming to 2°C",

[60] ibid "The Oil Crunch", P16

[61] ibid "World Energy Outlook 2010", IEA

[62] "Deep Water – The Gulf Oil Disaster and the Future of Offshore Drilling", Report to The President, January 2011: http://www.oilspillcommission.gov/final-report

[63] "The Dirty Truth About Tar Sands", John Podesta, Centre for American Progress, 23rd June 2010. http://www.americanprogress.org/issues/2010/06/tar_sands.html

[64] "The White House and Tar Sands", James Hansen, 29th August 2011: http://www.columbia.edu/~jeh1/mailings/2011/20110902_WhiteHouseAndTarSands.pdf

[65] "The Case for Young People and Nature: A Path to a Healthy, Natural, Prosperous Future", James Hansen et al, May 2011: http://www.columbia.edu/~jeh1/mailings/2011/20110505_CaseForYoungPeople.pdf

[66] ibid "World Energy Outlook 2010", IEA

[67] ibid "Shell Chief Warns of Era of Energy Volatility", Peter Voser

[68] ibid "The Oil Crunch", P31

[69] ASPO Base Case 2009, Australian Association for the Study of Peak Oil. http://www.aspo-australia.org.au/

[70] "Tipping Point. Near-Term Systemic Implications of a Peak in Global Oil Production", David Korowicz, FEASTA & the Risk/Resilience Network, March 2010. http://www.feasta.org/documents/risk_resilience/Tipping_Point_summary.php

[71] "Technology Roadmap – Carbon Capture & Storage", International Energy Agency, Paris, 2009. http://www.iea.org/papers/2009/CCS_Roadmap.pdf

[72] "Assessment of the Greenhouse Gas Footprint of Natural Gas from Shale Formations", Robert Howarth, Cornell University, January 2011: http://www.eeb.cornell.edu/howarth/GHG%20update%20for%20web%20--%20Jan%202011%20%282%29.pdf

[73] "Natural Gas, The Green Choice? ", Chris Vernon, The Oil Drum Europe, July 2010: http://europe.theoildrum.com/node/6638

[74] "Are we entering a Golden Age of Gas?", IEA, Paris, June 2011: http://www.iea.org/weo/docs/weo2011/WEO2011_GoldenAgeofGasReport.pdf

[75] "Coal to Gas: the influence of methane leakage", Tom Wigley, NCAR, September 2011: http://www2.ucar.edu/news/5292/switching-coal-natural-gas-would-do-little-global-climate-study-indicates

[76] "Global Energy: The Latest Infatuations", Vaclav Smil, American Scientist, May 2011: http://www.vaclavsmil.com/wp-content/uploads/docs/smil-article-2011-AMSCI.11.pdf

[77] "Carbon Capture and Strorage: Trouble in Store", The Economist, 5th March 2009: http://www.economist.com/node/13226661

[78] "Unburnable Carbon", J. Leggett et al, Carbon Tracker Initiative, July 2011: http://www.carbontracker.org/wp-content/uploads/downloads/2011/07/Unburnable-Carbon-Full-rev2.pdf

---

[79] "World's top firms cause $2.2 trillion of environmental damage", Guardian, 18th February 2010: http://www.guardian.co.uk/environment/2010/feb/18/worlds-top-firms-environmental-damage

[80] "Ten Fundamental Principles of Net Energy", The Encyclopedia of Earth, 2008. http://www.eoearth.org/article/Ten_fundamental_principles_of_net_energy

[81] "Economic Scenarios for an Age of Declining EROEI's", H.Kunnes, ASPO-USA, October 2009. http://aspo-usa.com/2009presentations/Hannes_Kunz_Oct_11_2009.pdf

[82] "Peak Oil and Energy Return on Investment: The End of Economic Growth, D.Murphy, ASPO Brussels April 2011: http://www.aspo9.be/assets/ASPO9_Thu_28_April_Murphy.pdf

[83] "No quick switch to low-carbon energy", G.Kramer & M.Haigh, Shell International, Nature, December 2009: http://www.nature.com/nature/journal/v462/n7273/full/462568a.html

[84] "Clean Energy Progress Report", IEA Paris, April 2011: http://www.iea.org/papers/2011/CEM_Progress_Report.pdf