ISEE BPE John Bryant Summary Paper 2

[Figure 1]

Economics, Thermodynamics and Entropy – the impact of resources and climate change on economic output.

[Figure 2]

Well, good morning everyone. If you've already had time to look at the paper I'm going to present, you'll know that it is rather large, with around 80 figures and tables, so I'll have to be selective this morning. The list you see covers the main topics, and I'll take a look mainly at those in red.

[Figure 3]

First, I'd like to re-emphasise the importance of energy to economic activity and well-being as we have come to know it. From the year 0 AD up to 1820 world population multiplied by a factor of 4.5, accompanied by a nominal factor change in GDP/head of only 1.5. But from then onwards to 2008, population multiplied by a factor of 6.4, and GDP/head by a factor of 11.4, giving a total factor rise in GDP of 73.4. This acceleration in growth was fuelled by a rapid rise in energy consumption, mostly of the non-renewable kind, allied to the technology of harnessing it, and gaining momentum around the turn of the 20th century.

[Figure 4]

Figures of the UN Food and Agricultural Organisation indicate that primary energy consumed to produce and transport food to the world's table is now around 5.7 times the energy value eaten. Clearly, without the availability of primary energy, many people in the world would have to find alternative, life-changing, self-sufficient means of feeding themselves. Returning to home-grown food in a city complex might be difficult.

To energy consumption linked to production and transport of food, should be added energy consumption for other economic activities, making a world total of 56.5 kWh per person per day, as at 2013, 17 times the energy value eaten. The figure for the USA is ***four times*** the world per capita average, while that for India is a just quarter of the world average, ***1 sixteenth*** of the USA figure.

[Figure 5]

One has only to think of the equipment, software and structures involved in an economy to see where this energy consumption arises, as in this table for the United States. Just about every capital asset and consumer durable involves energy consumption, both in its use and in its construction.

[Figure 6]

Turning now to resources, and first, the dynamics of those of a non-renewable kind, the chart you see illustrates the effect when additional reserves are discovered, extending the life of the reserve, such that maximum volume output can rise further, before an inevitable decline takes place.

[Figure 7]

This next slide shows the generation of economic entropy per unit of time as the resource reserve is used up. It rises to a maximum at the middle point, and thereafter declines as volume flow reduces. Of particular interest is the incremental entropy change [the green line], which starts at a maximum, creating a force to increase volume throughput. But as the reserve is used up, the incremental entropy generation line decreases to zero at the mid-point, and then become negative as the reserve further reduces in size.

[Relative entropy generation is calculated as $S = ln[b(1-b)]$].

[Figure 8]

By way of example, this ***next*** slide shows ***at the top***: charts of World oil production and consumption from 1965 onwards. And at the bottom of the slide, changes in an ***oil reserve ratio (b)*** for the World, defined as the ratio of net remaining reserves divided by total discovered proven reserves to date. Underneath the curve **(b**), is a ***complementary*** curve ***(1-b)***, reflecting changes in the ratio of cumulative production divided by total discovered proven reserves to date.

The lower left chart illustrates the picture if you believe data coming from the industry, and the lower right chart illustrates the position on the basis of adjustments highlighted in a paper by Owen et al, removing Canadian Tar Sands *[which has a low energy return on investment]* and some ***debatable*** reserve increases claimed by some OPEC countries in the 1980's. On the basis of the lower right chart, World oil has already reached a peak, though currently with some rebound arising from shale oil fracking.

[Figure 9]

Superimposed on changes in oil reserves and production, are the effects of changes in oil prices, arising from human, economic and political interactions. These effect periodic, short term changes in the elastic relationship between oil prices and world demand. Consequently, they impact also on incremental economic entropy generation. The dotted line in the chart excludes the price effect, and the solid line includes it, showing the marked effect of World economic events, particularly in 1973, the early 1980s and 2008 onwards.

I should say that the quality of this particular chart is poor, owing to the lack of short term monthly or quarterly volume data available. An elastic index based on annual volume and price data is not satisfactory.

[Figure 10]

The trend of reserve ratios for natural gas is much more restrained, suggesting a peak perhaps three or four decades away, but depending also upon any further switch into natural gas, and the discovery / exploitation of additional reserves, and new sources such as gas hydrates.

[Figure 11]

Turning now to World coal, consumption continues on an upward path, mostly on the back of Chinese demand supporting their power station programme, but coupled also with demand in India. The ratio of remaining reserves to production continues on a long term decline, though caution should be attached to reserve estimates, particularly those of China, which relate back to those estimated in 1992. Several papers have been published as to the timing of peak coal production, from the present ***– now –*** to up to two decades away.

[Figure 12]

Nuclear power, although having low operating costs compared to fossil-fired plant, entails high capital costs, and high waste and decommissioning costs, with waste potentially accumulating much beyond many generations of humankind. Nuclear capacity carries with it heightened risks of safety and security compared to conventional power plant. World electricity consumption from nuclear power flattened off by about 2004, but following the Fukushima Daichii tsunami disaster in 2011, consumption has fallen *[mostly in Japan]*. Notwithstanding the declining share of electricity consumption taken by nuclear power, the World Nuclear Association *[WNA]* reports that significant capacity is under construction, planned or proposed in the future, which could more than double capacity, with particular investment in China, Russia, India and USA.

Historically a proportion of uranium consumption fuelling power plant has come from the decommissioning of nuclear warheads. For the rest, currently *[WNA 2011]*, total reserves of uranium from traditional sources are estimated at about 5.3 million tonnes; which suggests a reserves/production ratio of about 90 years. As with the analysis for coal, with a likely pickup in demand in the next two decades, the ratio could then come down significantly, raising the prospect of *'peak uranium'* under current technology. Roper *[2013]* has calculated that a peak may be reached in about 2½ decades, with production rapidly scaling down thereafter. As yet new technology has not provided an avenue to advance the cause of nuclear power.

[Figure 13]

In passing, I should mention that I ***have*** looked at the potential impact of renewable energy resources, but, as you can see from this chart, apart from hydroelectric power, renewables have yet to make a large impact on world energy consumption, though I acknowledge the investments made in countries such as China, USA, Brazil, Canada, Germany and others.

I should mention also that the steel, cement and aluminium industries, although not posing a threat with regard to resource limits, are nevertheless voracious consumers of energy; in particular, coking coal, electricity, gas and oil, and their environmental impact is therefore significant. In all three industries, China now has a continuing large share of world production.

Turning now to renewable resources, their dynamics are more complex than those of non-renewable ones. In an ideal scenario it might be imagined that available renewable resources would remain in tune with the demands placed on them by humankind and other living organisms, and that as fast as they are consumed or utilised, they are recycled by Nature and regenerated by the Sun, and thereby the population carrying capacities of humankind and other living organisms, feeding on the resources, would be maintained at relatively steady states.

A scenario of this kind is unlikely however. Ebb and flow of renewable resources is a ***normal*** feature, historically being brought about by changes in ***known*** natural factors, such as seasons and climate. The impact of human endeavour has been a more recent factor.

[Figure 14]

The first and most obvious renewable resource is that of humankind. Figures to date of the UN indicate first, a continuing rise in life expectancy across the world; second, a rapid and continuing fall in the number of deaths of children aged under 5 as a proportion of total deaths; and third, a rapid decline in fertility per woman to not much more than the replacement rate.

The chart you see is based on the UN, 2010 updates, of world population projections, based on fertility rate per woman being in the range 1.5 - 2.5.. What trajectory will eventually come to pass however will depend upon the unfolding forces at work and world events. Mass effects, such as famine, disease and human conflict, or a restriction on resources, or the effects of climate change could curtail some of the benefits that humans have more recently enjoyed, resulting perhaps in a step backwards in economic development. On the basis of what I've seen, I would have thought that a peak in the range 8-9 billion people might seem realistic.

[Figure 15]

Water is an *essential* ingredient to the sustenance of *all* life forms. The Earth contains a vast amount of it – approaching 1.4 billion *cubic kilometres* – but of this, only 2.5% is fresh water, and of this small proportion, more than 2/3rd is locked into the Arctic, Antarctic and mountainous regions, and another 30% appears as fresh groundwater around the world. Only 1.3% of fresh water appears in lakes, wetlands, rivers and clouds.

While fresh water is a renewable resource, it has variable cycles of renewal. Compared to soil moisture, which has an annual cycle from precipitation, by contrast groundwater is recharged slowly, over some 1400 years, with lakes in between at 17 years. Consequently, the two key water sources essential to land-based life are precipitation to the soil and river runoff. The top fifty rivers of the world account for approaching half of total river water resources. Fresh water is a key resource for industrial activity and agricultural irrigation and, outside of river flow and local precipitation; it is expensive, either to transport from other areas or to produce from ocean-water.

The chart you see indicates that World water withdrawals have escalated since 1950, particularly in Asia, but the rate has slowed down more recently. It is estimated that about one-third of the world's human population lives in countries with moderate to high water stress, defined by the United Nations to be water consumption that exceeds 10% of renewable freshwater resources. High on the list include countries in the Middle East, Mongolia, Pakistan, Spain and India. River basins with high water stress include the Indus and Ganges in *India,* and the Yongding, Liao and Huang in *China*. Figures of the 4th edition of the UN World Water Development Report indicate that groundwater abstractions are growing rapidly worldwide. As I've already pointed out, groundwater takes a ***long time*** to replenish, measured in ***hundreds*** of years, and some reserves are therefore in danger of being turned effectively into a non-renewable resource.

Water stress and availability worldwide will likely pose a potential constraint in the future, breeding negative forces and conflicts, to limit or reduce output, with effects across national boundaries.

Besides water, the states of land and soil resources are also key factors on which the carrying capacities of human, animal and plant life depend. According to the UN Food & Agricultural Organisation, of the 13.3 billion hectares of the Earth's Land surface, only 11.7% is cultivated, and another 1.1% is devoted to human settlement and infrastructure. The amount of arable land ***increased*** from 1950 to 1990, but thereafter it has begun to level off, and in some parts, notably in Europe, North America and Asia, it has reduced, arising from land degradation, soil erosion and a switch into industry. Rises in arable land areas in Africa and South America have been at the expense of losses in forest cover, in turn impacting on the greenhouse effect.

Given the rise in world human population over the last five decades, the amount of arable land *per capita*, on which crops can be grown to feed each human being, has fallen dramatically to about 0.2Hectares *[equivalent to an area 40 x 50 metres per person]*. This area appears set to decline further.

A key driver to land degradation is the activity of humans to change the world to their *[short-term]* benefit, though changes in climatic variations also have an input. Human activities impacting on trends, cited by the UN Convention to Combat Desertification, include deforestation, overgrazing, improper irrigation practices, poverty and political instability. Severe land degradation affects 168 countries across the world, and about 15% of the Earth's land surface is now degraded in some way, and of this, about 15% is at a strong/extreme level. Areas with high degradation included parts of Asia, Africa and Central America. Land resources are being degraded year by year, impacting on their ability to regenerate themselves, and thereby provide the basis on which to grow food to feed humans and other animate life. Thus, what ***was*** a renewable resource is gradually being turned into a ***non-renewable*** one.

[Figure 16]

At this point I should just say a few words about food production. The green revolution continues apace, with yields per hectare for wheat, maize and rice all increasing, though not exponentially, and with some hint of possible yield plateaus arising from various causes. These two charts show the inexorable rise in wheat and maize production, for the benefit of humans.

[Figure 17]

There is a rising trend towards meat consumption, as exemplified by this slide of chickens and pigs slaughtered. Animal stocks in the world, at the beck of humankind, have risen significantly over the years, and now include ***1.7 billion*** cattle and buffalo, ***23 billion*** poultry, ***2.2 billion*** sheep & goats and ***1 billion*** pigs. Meat is ***highly energy intensive*** to produce, compared to say corn, and the Worldwatch Institute concludes that meat-eating is becoming a problem for everyone on the planet.

Overall, World food supply per human has gradually risen over the last 50 years, and is now approaching 2,900 kcals/day *[2,858 kcals/day2011]*.

The World Health Organisation records that obesity has nearly doubled since 1980, and of the ***7 billion*** people on the planet, ***1.4 billion*** are overweight and ***0.5 billion*** are obese. Figures of the OECD indicate particularly high obesity levels in North America, Australasia and Europe.

I'll now briefly look at climate change as it affects world economic activity. It's a lot simpler in pictures so here goes.

[Figure 18]

First off, the temperature anomaly continues to rise, reaching a record in 2015. Early indications for 2016 indicate a further rise.

The latest figure from NASAGISS for CO_2 concentration in the atmosphere, is 403.9 parts per million by volume *[March 2016]*, which translates as about 3,158 $GtCO_2$ now in the atmosphere.

[Figure 19]

This slide summarises, on the left, Global CO_2 concentrations in the atmosphere, as a function of cumulative anthropogenic additions. The relationship is ***almost*** linear, and has ***<u>not</u>*** changed significantly. ***Many years*** pass before CO_2 removals begin to occur. The chart on the right illustrates this effect.

[CO_2 removed has been calculated as gross anthropogenic additions less the net rise in atmospheric CO_2.]

[Figure 20]

This slide shows the relationship between the temperature anomaly and cumulative anthropogenic emissions to 2014. Given that the temperature anomaly has risen significantly in 2015 and into 2016, it is likely that the relationship will continue to march towards the top right-hand corner of the chart.

[Figure 21]

This chart shows the ratio of CO_2 emissions to GDP, both annually and cumulatively. The annual ratio is beginning to come down, though there is a thermodynamic limit to this, as to the efficiency of use, if using fossil and gas-fired energy, ***even if improved*** by the storage of electrical power through batteries.

As noted earlier in this talk, the World has yet to switch significantly towards renewable energy. ***Consequently,*** CO_2 emissions in the atmosphere can be expected to accumulate further, and the temperature anomaly to continue to rise.

[Figure 22]

Following on from this, this chart shows the cumulative GDP and CO_2 emissions. They continue to march upwards.

[Figure 23]

This table shows the ***main*** physical, biological, and human effects arising from Climate Change that are ***anticipated*** by IPCC. Elsewhere, published research by Burke and Dell, support the predictions of IPCC, and indicate that, as the temperature rises, non-linear effects may occur in parts of the World, such as to bring down economic output ***substantially*** in those areas, accompanied by a rise in social conflict.

[Figure 24]

This last chart shows the growth rates of the world human population and of GDP per capita. It is my conclusion that in the decades to come we might expect some reduction in the sustainability of natural capital, affecting human population carrying capacity, with an associated effect on human activity, habitable areas, large scale migration and economic output.

I don't think that projections of economic activity can now be made on an exponential basis. And that, long term, GDP per head will begin to level off in many areas of the World, and decline in some vulnerable countries, which might cause some problems on capital financing for the longer term. The trends call for renewed modelling of the World economy, based on different principles to those used by traditional economists.

It is my belief, based on my research, that the link between the level of output demand in an economy and the impact of supply constraints, is the change in economic entropy generated, which change moves to zero as demand and supply alter to equate to each other.

Thank you for listening.