The Oil Drum: Australia & New Zealand
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

The Trouble With Energy - Part 3.

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Topic: Demand/Consumption

This is part 3 of a series of posts co-authored by phoenix, who is an Engineer heavily involved in the energy sector. It will be based on a submission we made recently to the Australian Government.

Part 1 is here.

Part 2 is here.

Introduction

In part 2 we introduced a model for looking at energy use over the next few decades and applied it to the Australian situation. This model:

- Estimates how much time will be needed to achieve a transition to alternate and renewable energy sources.
- Estimates how much energy will be needed to achieve this.
- Estimates the cost of this transition.
- Calculates (based on industry figures) how much energy we have left in our remaining energy reserves and how long this will last.

The model shows that:

- If Business As Usual is the assumed paradigm, the energy required may exceed the energy available.
- If Business As Usual is the assumed paradigm, the cost of the transition is likely to place an untenable strain on GDP.

The market can be counted on to deal with this problem, but over the last few months we have seen that the market can be brutal. BAU is not an option. Our choice is to manage the problem, or let the market manage it for us.

There is a gap between our current expectations and the reality we will experience over the next few decades. In developing this model we are quantifying that gap. This allows decisions to be made based on hard numbers.

In this post we apply the model to the larger picture.

World Situation

Following on from the analysis of Australia's energy security the following broad analysis has been performed to ascertain the relationship between remaining fossil fuel energy and the capacity to put in place an equivalent economy based of renewable energy.

The basis for this analysis is the presumption of a Business As Usual (BAU) transition from an economy based on fossil fuels to an economy based on renewable energy. Although we assume BAU for the purposes of vthis post, the authors are not advocating BAU. This analysis clearly demonstrates that a BAU future is simple not possible. Although we demonstrate that BAU is not possible, this does not indicate that we believe that an alternate infrastructure cannot be achieved. It merely shows that the requirements associated with a building an alternate energy structure are not compatible with the profligate lifestyle associated with BAU.

How Much Time Do We Have?

As discussed in the previous post, most production vs. resource figures are established by assuming a continuation of the current demand or extraction rate. While this may be a reasonable methodology for determination of the life of a mine or the value of the resource it is patently false for determination of our overall resource security. Demand rates for all of our energy resources are climbing year by year.

The paradigm of continually increasing growth driven by an increasing population and an expectation of improving standards of living demands a continuing increase in production of our natural resources. The following table shows the World's major non renewable energy resources together with their expected life calculated on this basis.

	Coal	Oil(inc all liquids)	Gas	Uranium
Unit	Billion Tonnes	Billion Barrels	Trillion M3	ThousandTonnes
Base Year	2007	2007	2007	2007
Resource	847	1,238	177	5,469
Consumption	6.4	27	2.3	65
Growth Rate	2.95%	1.39%	2.1%	1.2%
Life Expected	63 years	32 years	41 years	59 years
Resource Exhausted	2070	2039	2048	2066

Sources: BP World Energy

Note 1: All of the above numbers including growth rates have been established from the industry-recognised source listed above. Long term growth rates have been used based on growth from 1998 to 2007.

Note 2: This is a simplistic analysis, assuming an exponential increase up to a precipitous fall. Of course this will not occur. Each of the fuels will undergo their own peaking curve. In order to generate the most conservative possible result, we have not taken this into account, nor have we considered the resulting cost increases that will occur when the supply and demand curves separate for these basics energy commodities.

Of course there will be continual additions to the current proven reserves that will have the potential to extend the above calculated life expectancies. On the other hand there are a number of factors that will tend to decrease available life expectancies:

- The exponential effects of EROEI will dramatically increase energy demand as we approach exhaustion of the energy resources.
- Higher energy demands will also result from higher extraction (or recycling) costs associated with the whole range of other economy related resources.
- The figures quoted above do not take into account any restriction in fuel availability as a result of greenhouse gas limitations.
- As depletion occurs in some of the above resources it is likely that alternative fossil fuels will

be transmuted to fill the required shortfall eg. coal to oil, gas to oil, etc. These transfers of energy almost always result in lower overall energy efficiencies.

On balance then the above figures represent a reasonable view of the expected life of our non-renewable energy resources in a business as usual scenario. The above life expectancies can then be averaged based on energy values.

We have until around 2052 to put in place renewable technologies to provide for our energy needs.

The size of the task

In order to establish the time required to put in place renewable sources for energy supply, it is necessary to make assumptions with regard to the infrastructure that needs to be constructed. This is a very difficult task given that much of the technology is in a developmental phase. Picking winners is not easy and frequently not wise. However by taking an average developmental cost for a range of possible technologies,we can be fairly confident about the expected implementation effort and time required.

The following table represents one possible scenario in respect of the conversion of demand from fossil based energy to renewables. The table indicates both a growth in demand up to the year 2050 and the effects in energy efficiency terms of conversion from one form of energy base to an alternate renewable source.

Energy Source Conversion

Energy uses	**Current**				**Renewable Conversion**		
	Source	**Usage EJ/y**	**Growth Rate**	**Usage 2050**	**Source**	**Efficiency Gain**	**Usage 2050**
(Non- electricity based)							
Agriculture	Oil	7	1.2%	11	Biofuels	-33%	15
Industry/Commerce	Oil	18	2.5%	50	Electricity	10%	45
	Gas	34	2.5%	94	Electricity	10%	85
Road Transport							
Personal	Oil	58	0.0%	58	Electricity	70%	17
Freight (Road/Rail/Sea)	Oil	39	2.5%	107	Biofuels	-33%	71
					Electricity	60%	21
Public Transport	Oil	7	7.0%	110	Electricity	70%	33
Air Transport	Oil	15	0.0%	15	Biofuels	-33%	20
Products	Oil	24	2.5%	65	Biofuels	-33%	86
Heating	Oil	14	1.2%	22	Electricity	60%	9
	Gas	26	1.2%	43	Electricity	60%	17
Metal smelting	Coal	19	2.5%	53	Electricity	20%	43
Electrical demand		72	2.5%	198	Electricity	0%	198
Sub-total Electricity							270
Sub-total Biofuels							192
Total		333		827			661

Notes

1/ The basis of GDP growth has been assumed be a 2.5% p.a.. This value is in line with the relatively modest world GDP growth posted in 2008 - lower than 2007, but higher than the projected figure for 2009. The authors believe that even this low level of growth will be difficult to achieve, given the energy constraints that will be place on the world economies.

2/ In line with other analysis described in this paper the energy demand forecast has been kept in direct proportion to the projected GDP figures for all industry and commercial based energy uses.

3/ Population related energy uses have been kept in line with the world's current 1.2% p.a. population increase rate.

4/ The classification of energy use into sectors has been a very difficult exercise and represents an amalgam of numerous published data sets. If readers have any better definitive data that provides energy use by source and sector the authors would appreciate any input.

4/ In anticipation of a dramatic
increases in energy pricing, the growth figures for personal transport have been forecast at 0%. As a complimentary allowance the growth in public transport has been increased to 7%. The balance between these growth numbers represents a reasonable transference of energy use between these two categories.

5/ Again in anticipation of the effects of high energy costs the level of air transport growth has been limited to 0%.

6/ The efficiency gain nominated for all conversions from oil based fuel to biofuels is a loss of 33%. This represents a nominal loss due to EROEI effects. It assumes an EROEI for future biofuels of around 3. Given the current analysis from the USA on ethanol based biofuels this is very optimistic assumption.

7/ The conversion efficiency for most oil to electricity conversions has been assumed to be 70%. This figure represents a combination of a number of factors including:

- Change in mechanical efficiency between electric and internal combustion engine drives
- Losses due to transmission and storage of electricity
- Reduction in vehicle weights due to energy cost drivers

8/ No currently viable technology exists for large scale smelting of iron ore using renewable energy sources. The figures for energy efficiency therefore represent a nominal allowance that this technology when developed will be based on electrically derived heat.

Therefore under this scenario to completely replace the world's energy sources with renewables will require the construction of the appropriate infrastructure to produce:

- **270 EJ or 75,092 TWHr of electricity and**
- **192 EJ or approximately 5,800 gigalitres of biodiesel**

The cost of the task

With respect to the electrical demand, our future energy requirements will undoubtedly come from a range of renewable sources. These will include hydro, wind, biomass, solar thermal and solar PV and geothermal. The table below indicates a possible mix of sources and their respective capital construction costs.

Renewable Electricity Generation

Source	Proportion	Generation TWhr/y	Utilisation	Capacity GW	Capital Cost USD$/kW	US$Billion
Hydro	15%	10,716	70%	1,748	2500	4,369
Wind	30%	21,433	25%	9,787	1600	15,658
Biomass	15%	10,716	70%	1,748	2000	3,495
Solar Thermal	20%	14,288	20%	8,155	2400	19,573
Solar PV	10%	7,144	20%	4,078	5000	20,389
Geothermal	10%	7,144	70%	1,165	2500	2,913
Plus already built		3,650				
Total	100%	75,092		26,680		66,397

Notes

1/ Utilisation factors indicated above reflect the relationship between the average working generation capacity and that needed to provide a consistent reliable grid supply.

2/ Utilisation factors for Solar Thermal and Solar PV are indicative of current technologies in these respective fields with an overlay of system reliability. A number of proposals exist for extending the daily range of solar thermal. While these heat storage technologies may enhance the application of solar thermal they will not significantly alter the capital cost per MW delivered.

3/ The utilisation factor attributed to Wind is probably low by current wind farm development standards, which aim for an availability of between 30% and 35%. This number has been reduced to reflect actual return figures for installed wind generation and to reflect the fact that, in order to achieve the overall output required, wind-farms will need to be developed at locations not currently considered viable.

4/ Utilisation of Hydro, Biomass and Geothermal have been kept low to recognise that these technologies will probably fulfil the role of peaking power plant.

The infrastructure required for provision of biofuels will be a significant challenge, hence the limitation of this fuel source for all uses except where it is irreplaceable because of energy density. The production of biofuels on the scale required is unprecedented. Production of sugar or grain based ethanol for this volume could not be contemplated. It appears that the only viable biofuel at this level of production will be production of algal based biodiesel. Research has indicated that this form of biodiesel production will involve plant capital costs in the region of US$6.5 Million per megalitre of production capacity. The capital cost of the infrastructure to produce 5,800 GL per year will therefore be approximately US$37,900 Billion.

The total direct cost of revamping the world's energy production infrastructure will be in the order of US$104 Trillion.

Some points to note in respect to this number.

- Although the cost has been based on a range of assumptions concerning energy technologies, it is unlikely that a different mix of conversions or replacement technologies would greatly

affect the bottom line price.
- The figure quoted only represents the major energy production plant required. In parallel with this will be a similar cost associated with the changes made by energy users (i.e. electric vehicles, mining and manufacturing equipment, rail lines, power transmission, metal smelters etc. etc....)
- The cost assumes a single transition from the current energy production infrastructure to the final renewable infrastructure. This won't happen. As successive governments are driven by the need to maintain the power on and the fuel tanks full there will be a staged series of interim technologies implemented. Depending on the quality of vision of political and industry leaders these interim technologies could consume as much or more than the cost indicated for the final conversion.

Given the above considerations it is likely that the total costs associated with transitioning the world to the fully renewable economy will be in the order of US$ 150 Trillion.

What can we afford to spend?

Total world GDP is currently around US$ 70 Trillion per year. This GDP is growing in real terms at a long term average rate of around 3.5%. A growth rate of 1.2% is required to maintain a stable GDP per capita.

Looking at the US$150 Trillion required expenditure this represents an expenditure of US$3.5 Trillion per year over the period up to 2052. This figure is in turn represents 5% of world GDP for the period. Now, there are a few savings along the way:

- The expenditure that would normally be required for the replacement and building of new conventional power plant under a BAU future. Based on current capacity per capita this works out to be about US$250 Billion per year.
- There would be a progressive saving on fossil fuel extraction and supply costs. This would average out at approximately $US700 Billion per year.

The economic drag imposed by the required investment would therefore amount to about US$ 2.5 Trillion per year on the world economy. This continuous drag will occur over a period where we also experience the peaking of not only the fossil fuels being replaced but also the common construction materials such as copper, nickel etc. It is difficult to see how the world economy could cope with such a demand.

Is the world capacity associated with this investment possible ? The only way we can get a perspective on this is by looking at the construction requirements. The different power plant types listed in the table above will have a differing construction components ranging from hydro plant involving perhaps 90% construction to solar PV where the construction component may drop as low as 20%.. On average we will assume a construction component of 40% of the investment cost. This then amounts to US$1.4 Trillion per year. Over recent years the world has undertaken approximately US$5.5 Trillion in construction work per year. Of this less than 25% or US$ 1.4 Trillion is attributed to industrial construction of the type used on power plant or petrochemical plant. So in order to make the transition the entire world capacity for industrial construction would need to be dedicated to the task. This means no construction of new mines or manufacturing plants or materials processing lants. This does not seem at all feasible.

Conclusion

It appears that a conventional BAU transition to a completely renewable energy economy is just not possible or at the very least there are serious concerns over the capacity of the world economy to facilitate this transition over the remaining life of our fossil fuel reserves.

In order to make the transition possible we face a range of possible compromises to BAU:

- Reduction in energy demand through conservation
- reduction in energy demand growth through population limitation/reduction
- continuing the limited access to energy to large portions of the world population
- breakthroughs in energy conversion efficiency
- large new resource identification
- the roll out of renewable energy generation raised to a war footing for all industrialised countries

In part 4 we look at some possible solutions.