POPULATION AND RESOURCE GROWTH RATES 1946 to 2010

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After World War II the world entered into an unprecedented period of growth in population, technology and standard of living. All required increased production of the primary earth resources upon which humanity depends. Over the 64-year period from 1946 to 2010 the world population grew by a factor of three from 2.3 billion to 6.9 billion with an overall annual average growth rate (Agr) of 1.73%. However, energy consumption and commodity growth rates were considerably higher.

Energy consumption:

Figures 1 and 2, from The Oil Drum; World Energy Consumption since 1820 in Charts, (www.theoildrum.com/node/9023) show the rapid rise in world energy consumption and the stepwise rise in per capita energy consumption following the introduction of new energy resources.

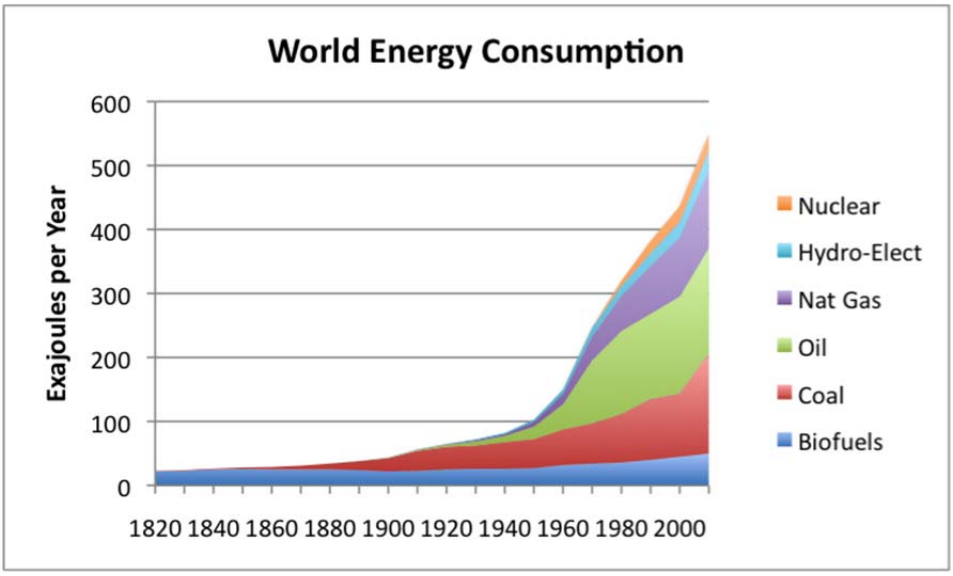

Figure 1: World Energy Consumption, 1820 to 2010

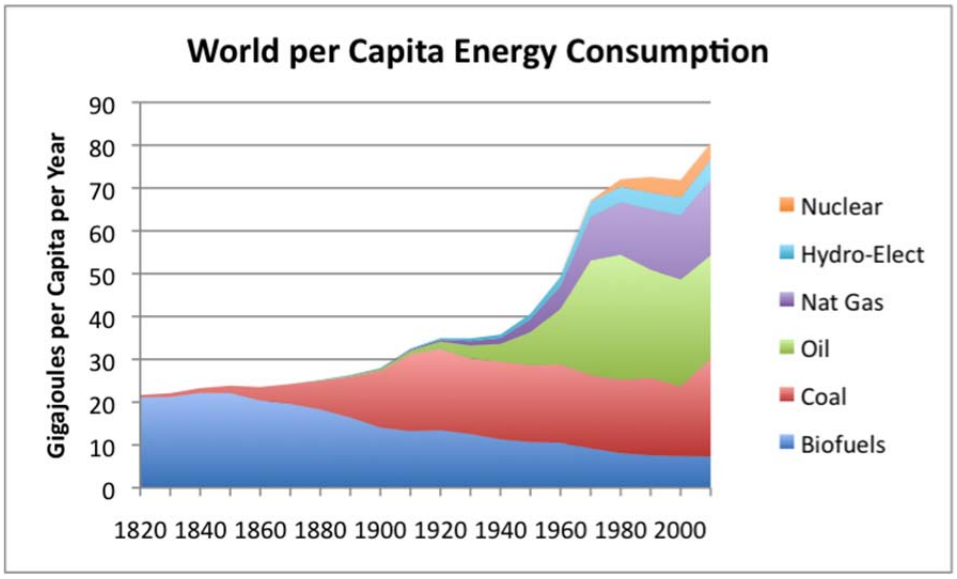

Figure 2: World per Capita Energy Consumption, 1820 to 2010

The timeframe for introducing a new energy source can be seen more clearly in Figure 2 than in figure 1.

As coal use grew over the one hundred year period from 1820 to 1920, the world per capita annual energy consumption (Gpcy) rose by 62% from 21 to 34 with an overall Agr of 0.48%. However, in the later years, the growth rate increased to a maximum close to 1% per year.

By contrast, in the 70 year oil transition period from 1910 to 1980, Gpcy increased 129% from 31 to 71, with an overall Agr of 1.2%. As with coal, the growth rate increased in the later years, averaging 1.9% over the period from 1950 to 1980.

Gpcy remained constant for the next 20 years until it jumped 12.7% from 71 to 80 in the ten year period from 2000 to 2010 with an Agr of 1.2%. This jump was driven by the large increase in coal consumption in China. The significance of China's rapid increase in coal consumption is highlighted in the April 2014 issue of National Geographic Magazine which reports a 54% increase in World coal consumption from 2000 to 2011. While US consumption decreased by 7.7% to just over 1 billion tons in 2011, Chinese consumption increased by 2.3 billion tons from 1.5 to 3.8, an Agr of 8.8%. On a per capita basis USA decreased from 3.9 to 3.1 tons, a decrease of 20%, while China's per capita consumption increased from 1.3 tons to 2.8 tons, an increase of 115%. To reach the lower US affluence level of 2011 China will have to grow another 11%, equivalent to another 418 million tons of coal, a 5.4% increase over 2011 world coal production. By contrast India's per capita coal consumption in 2011 was only 0.58 tons. To reach China's level of 2.8 tons per capita would require an additional consumption of 2.68 billion tons, an increase of 35% over 2011 World production and 2.68 times the US 2011 production.

In the hundred year time period from 1910 to 2010, world population increased fourfold from 1.7 billion to 6.9 billion with an overall Agr of 1.4%. However total energy consumption increased by a factor 10.8, from 50 to 540 Exajoules/yr with an overall Agr of 2.4%. The rate increase over and above population growth is due to increased energy demands for technical innovations and the rise in the standard of living as more people move from farms to cities.

It is interesting to note that after the 100 year rise in coal Gpcy the coal consumption per capita stabilized at about 19 Gpcy. The transition to oil followed a similar but quicker pattern, rising for about 70 years then stabilizing around 29 Gpcy. Gas and Hydropower followed oil's pattern but at lower energy levels. Nuclear power was the latecomer starting around 1960 and currently contributing about 4 Gpcy.

Approximate energy consumption percentages in 2010 were as follows:

Biofuels	Coal	Oil	Gas	Hydro	Nuclear	Renewables
7.5	27.5	30.6	22.1	6.2	4.2	1.8

The world currently relies on fossil fuels for 80% of its energy. The time factors for the coal and oil transitions shown above give some insights into the timeframe facing any transition away from fossil fuels and into renewable energy sources.

Earth Resources:

The per capita energy graph above shows two distinct periods, substantial growth from 1946 to 1980 and virtually no per capita growth from 1980 to 2000.

The following section illustrates the growth of 24 mineral commodities over the period 1946 to 2010 and covers 20 metals (including Rare Earths) plus Sulfur, Phosphate Rock, Potash and Cement. Results shown in Table 1 were derived from statistics in the USGS file "Historical Statistics for Mineral and Material Commodities in the United States". The file also includes World production data for the commodities studied here and is available at:
http://minerals.usgs.gov/minerals/pubs/historical-statistics/

The multiplier column is the 2010 value divided by the 1946 value (also referred to as the growth factor) and shows how much the commodity grew in the 64year period. The commodities are listed in increasing order of growth, as shown in the multiplier column, from 2.76 times for Tin (8% below population growth) to 171 times for Rare Earths (57 times population growth). Columns A through D show average annual growth rates (Agrs) for the Boomer generation, 1946 to 1964 (A), Generation X from 1964 to 1980 (B), Millennials from 1980 to 2000 (C) and Post Millennials from 2000 to 2010 (D). Column E is the average Agr over the total 64year period and is plotted in Figure 3.

Table 1: Average Annual % Growth Rates from 1946 to 2010

			Average Annual % Growth Rate				
		Multiplier	A	B	C	D	E
1	Population	3	1.96	1.95	1.61	1.22	1.74
2	Tin	2.76	4.49	1.37	0.6	-1.2	1.60
3	Gold	2.99	2.70	-0.81	3.84	-0.08	1.73
4	Lead	4	5.12	2.09	-0.48	2.66	2.21
5	Selenium	4.65	4.11	1.68	0.66	4.23	2.43
6	Cadmium	5.63	6.56	2.27	0.55	1.17	2.74
7	Silver	5.99	3.77	2.05	2.66	2.78	2.84
8	Tungsten	7.49	6.50	3.92	-0.83	4.40	3.20
9	Zinc	8.47	5.88	2.47	1.96	3.36	3.40
10	Copper	9	5.22	3.05	3.08	2.01	3.50
11	Manganese	9.15	8.56	1.83	-1.63	8.05	3.52
13	Sulfur	9.48	6.69	5.46	0.38	1.59	3.58
12	Steel	11.7	7.30	3.13	0.86	5.41	3.92
14	Phos Rock	11.8	8.25	5.37	-0.5	3.21	3.94
15	Nickel	13.7	6.33	4.75	2.554	2.68	4.17
16	Potash	14.8	9.74	5.25	-0.16	2.36	4.30
17	Chromium	20.7	7.48	5.03	2.62	4.38	4.85
18	Molybdenum	22.6	6.80	7.42	0.98	6.10	4.99
19	Cobalt	30.3	9.46	3.59	1.14	10.43	5.47
20	Magnesium	31.5	13.65	1.73	1.46	5.99	5.54
21	Vanadium	44	9.54	10.59	0.67	4.09	6.09
22	Cement	45	10.19	4.82	3.21	6.98	6.13
23	Aluminum	52.2	11.86	6.13	2.31	5.42	6.37
24	Lithium	103	15.84	2.35	4.02	8.63	7.51
25	Rare Earths	171	9.48	13.34	6.20	3.07	8.36
	Average	26.77	7.73	4.10	1.55	4.07	5.23

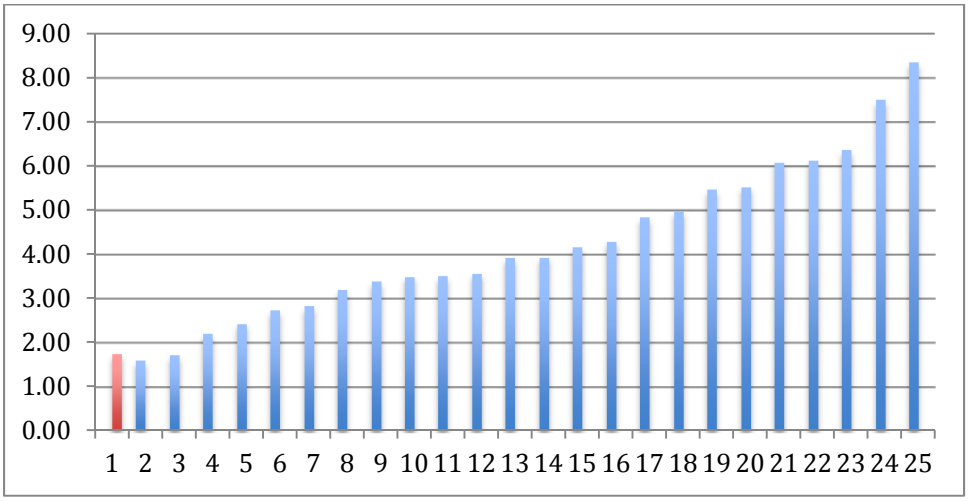

Figure 3: Average Annual Commodity % Growth Rates 1946 to 2010. Population in Red.

Per capita data was obtained by dividing the commodity production by the world population for 1946, 1964, 1980, 2000 and 2010 respectively. The average annual per capita rates for each period were then calculated.

The per capita growth rates remove the population growth contribution to basic commodity growth rates and are shown in Table 2 that also includes the increase in per capita consumption from 1946 to 2010 in the first column. Values for the overall per capita average annual growth rates are plotted in Figure 4 by commodity number.

Table 2: Per Capita Average Annual % Growth Rates

	Commodity	Multiplier	46/64	64/80	80/00	00/10	46/10
1	Population		0.00	0.00	0.00	0.00	0.00
2	Tin	0.9	2.47	-0.57	-1.0	-2.36	-0.13
3	Gold	1.0	0.73	-2.71	2.19	-1.28	-0.01
4	Lead	1.3	3.09	0.13	-2.06	1.42	0.46
5	Selenium	1.5	2.11	-0.27	-0.94	2.98	0.68
6	Cadmium	1.9	4.50	0.31	-1.05	-0.05	0.98
7	Silver	2.0	1.77	0.10	1.03	1.54	1.08
8	Tungsten	2.5	4.45	1.93	-2.41	3.15	1.44
9	Zinc	2.8	3.84	0.50	0.34	2.11	1.63
10	Copper	3.0	3.20	1.08	1.44	0.78	1.74
11	Manganese	3.0	6.47	-0.13	-3.19	6.75	1.75
12	Sulfur	3.2	4.64	3.44	-1.22	0.36	1.81
13	Phos Rock	3.9	6.16	3.35	-2.1	1.97	2.16
14	Steel	3.9	5.23	1.16	-0.74	4.15	2.15
15	Nickel	4.5	4.28	2.74	0.93	1.44	2.39
16	Potash	4.9	7.62	3.23	-1.75	1.13	2.52
17	Chromium	6.9	5.41	3.02	0.99	3.12	3.06
18	Molybdenum	7.5	4.74	5.36	-0.62	4.82	3.20
19	Cobalt	10.1	7.35	1.60	-0.46	9.10	3.67
20	Magnesium	10.5	11.46	-0.22	-0.15	4.72	3.74
21	Vanadium	14.6	7.43	8.47	-0.93	2.84	4.28
22	Cement	15.0	8.06	2.81	1.57	5.70	4.32
23	Aluminum	17.3	9.71	4.10	0.68	4.15	4.56
24	Lithium	34.2	13.60	0.39	2.36	7.33	5.67
25	Rare Earths	56.7	7.37	11.17	4.51	1.83	6.51
26	Average		5.65	2.12	-0.8	2.8	2.49

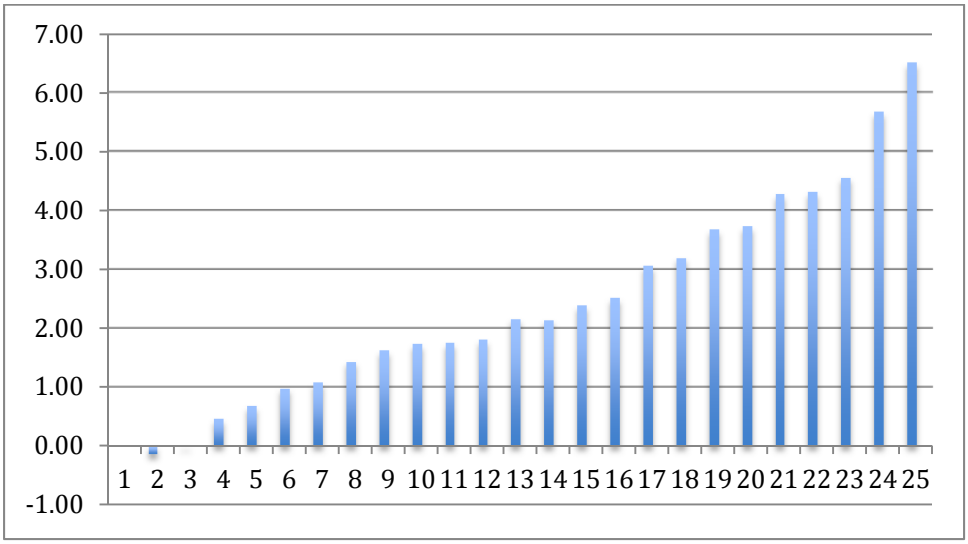

Figure 4: Per Capita Average Annual % Growth Rate 1946 to 2010

The ratio of the commodity growth rates in Table 1 to the population growth rate over the same time interval gives a measure of how much faster the commodity consumption grew compared to population growth. This ratio is shown in Table 3 and the overall 46/10 ratio is plotted in Figure 5.

Table 3: Ratio of Commodity to Population Growth Rates

		46/64	64/80	80/00	00/10	46/10
1	Tin	2.29	0.7	0.39	-0.96	0.92
2	Gold	1.38	-0.42	2.38	-0.06	0.99
3	Lead	2.61	1.07	-0.3	2.18	1.27
4	Selenium	2.1	0.86	0.41	3.47	1.4
5	Cadmium	3.34	1.17	0.34	0.96	1.57
6	Silver	1.92	1.05	1.65	2.28	1.63
7	Tungsten	3.32	2.01	-0.52	3.61	1.84
8	Zinc	3	1.26	1.22	2.75	1.95
9	Copper	2.66	1.57	1.91	1.64	2.01
10	Manganese	4.37	0.94	-1.01	6.6	2.02
11	Sulfur	3.42	2.8	0.23	1.3	2.06
12	Steel	3.72	1.61	0.54	4.44	2.25
13	Phos Rock	4.21	2.75	-0.33	2.63	2.26
14	Nickel	3.23	2.43	1.59	2.19	2.4
15	Potash	4.97	2.69	-0.1	1.94	2.47
16	Chromium	3.82	2.58	1.63	3.59	2.79
17	Molybdenum	3.47	3.81	0.61	5	2.87
18	Cobalt	4.82	1.84	0.71	8.55	3.15
19	Magnesium	6.96	0.89	0.9	4.91	3.18
20	Vanadium	4.87	5.43	0.41	3.35	3.5
21	Cement	5.2	2.47	1.99	5.72	3.52

22	Aluminum	6.05	3.15	1.43	4.44	3.66
23	Lithium	8.08	1.2	2.49	7.08	4.32
24	Rare Earths	4.84	6.84	3.85	2.52	4.81
	Average	3.94	2.11	0.94	3.34	2.45

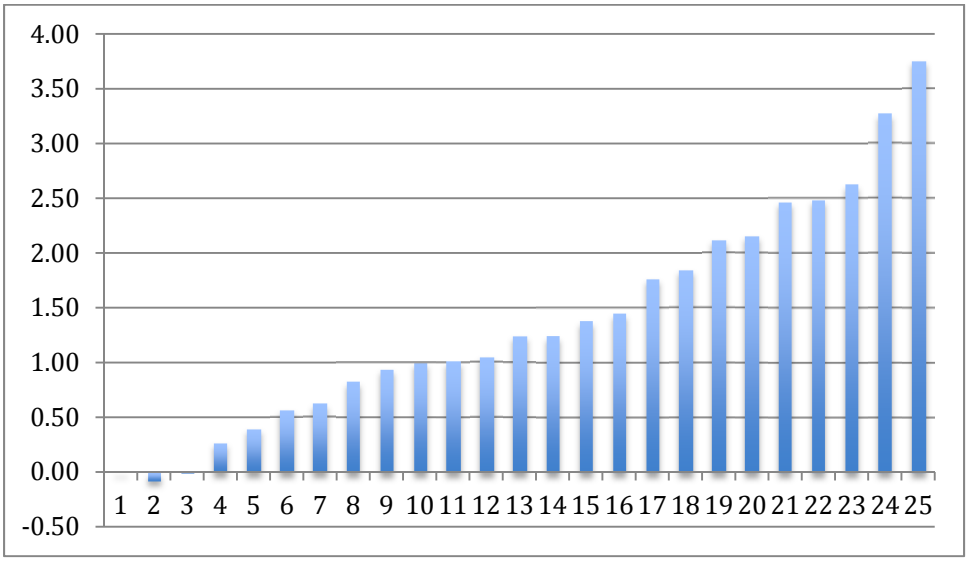

Figure 5: Commodity Growth rate/ Population Growth Rate.

The order established by the multiplier column in Table 1 is naturally preserved in the final column of each table showing the respective overall values for each commodity. However, looking at the rates in the four time periods, some very large differences can be seen. Results for the per capita rates (Table 2) for each time period are shown in the four charts in Figure 6, while individual plots of the per capita growth rates for each commodity over the four time periods are shown in Figures 7, 8 and 9. Figure 7 shows the six basic patterns observed with plus or minus changes from the previous period shown below the graph. Sixteen commodities exhibit pattern P1, which follows the general economy, and are shown in Figures 8a and 8b and the eight commodities that have patterns differing from the overall economy are shown in Figure 9. The multiplier value in Table 1 is included after the commodity name in Figures 8 and 9 and Figure 9 also includes the plus or minus pattern changes.

Note that the %/yr scales (y axis) are not constant.

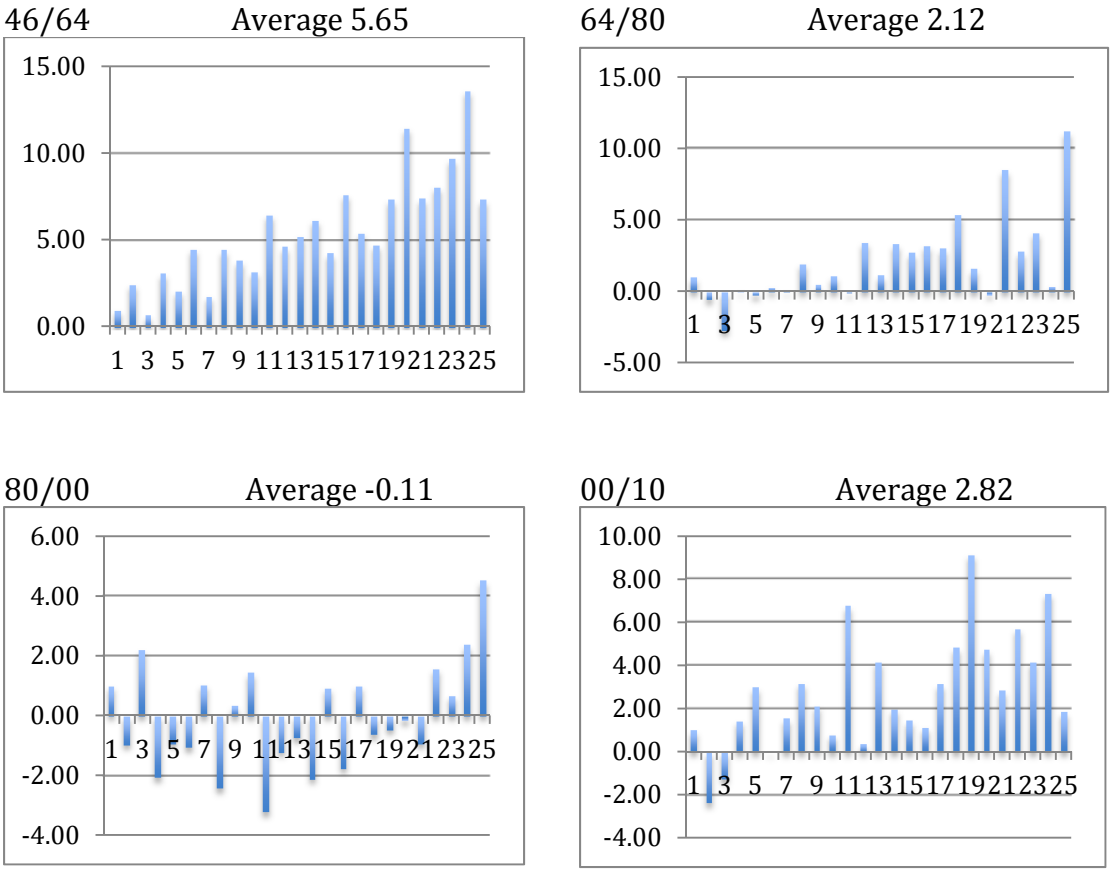

Figure 6: Commodity Per Capita Growth Rates in Four Time Periods

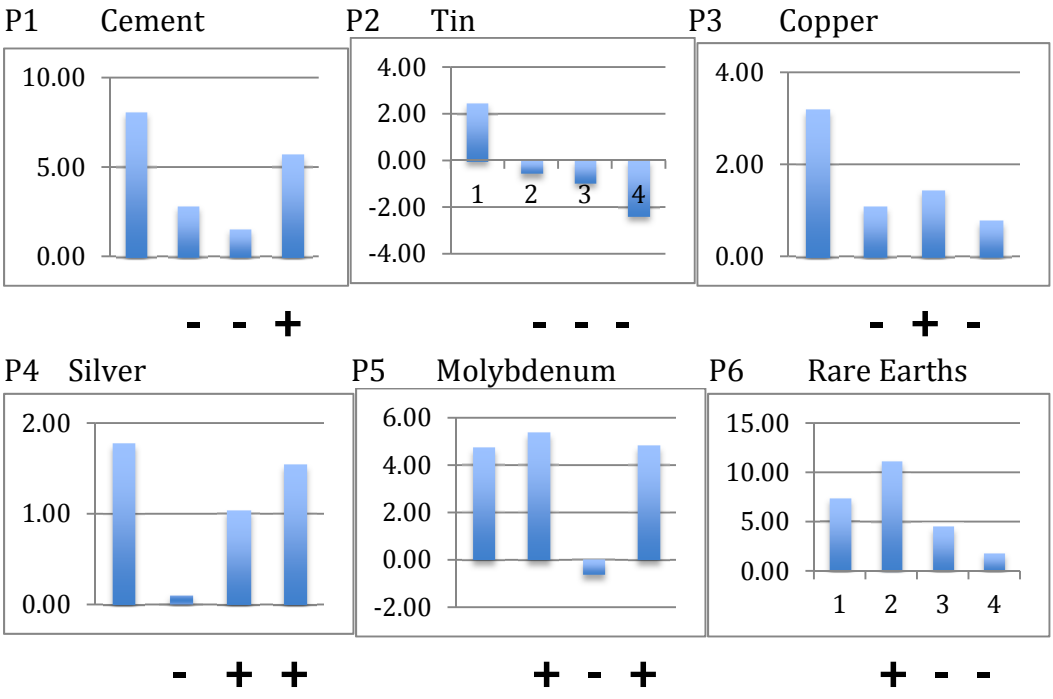

Figure 7: Six Commodities Illustrating the Basic Per Capita Growth Rate Patterns.

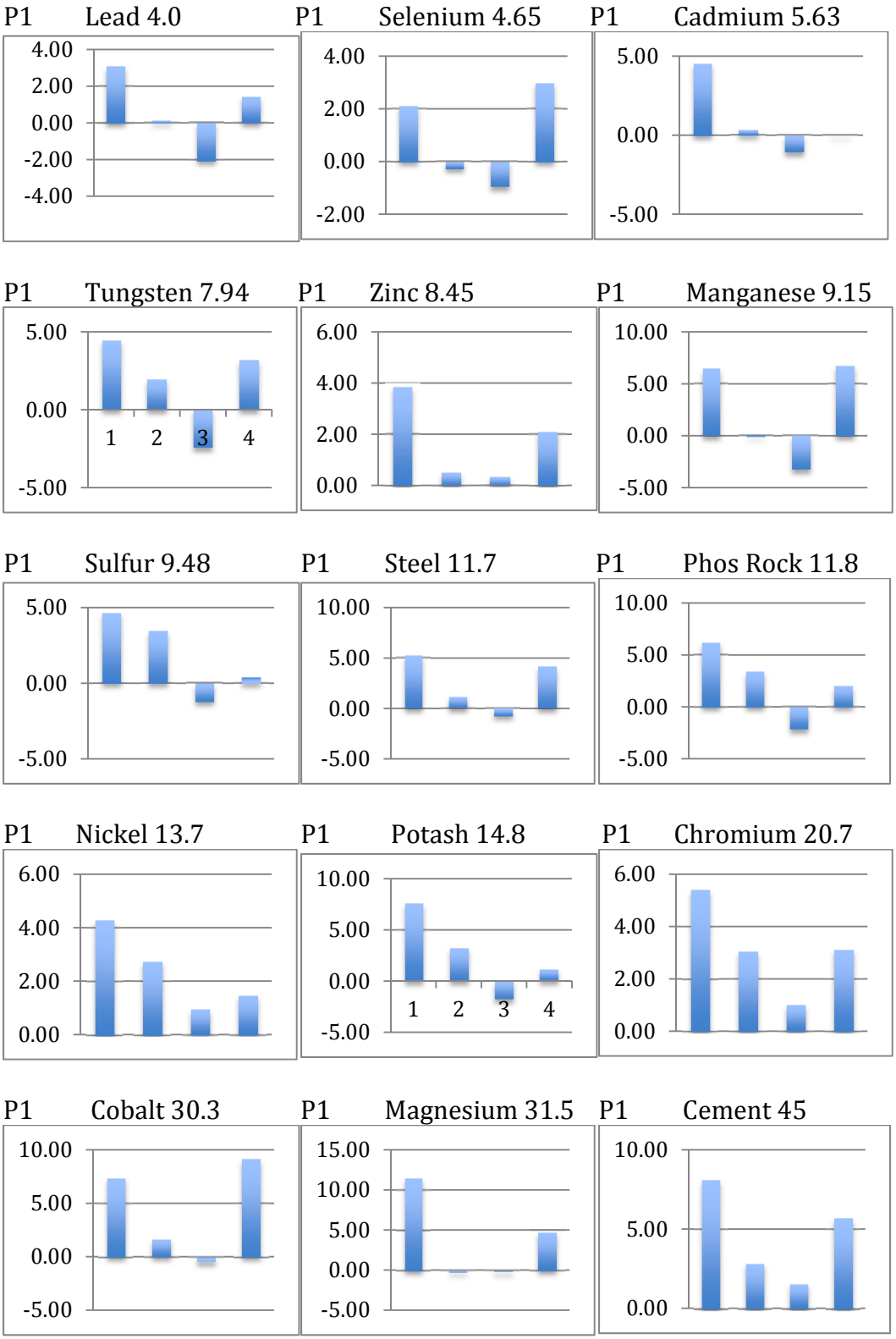

Figure 8a: First fifteen P1 Per Capita plots following the Overall Economy Pattern.

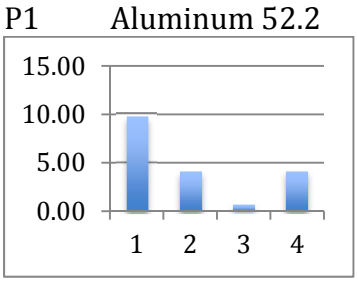

Figure 8b: Sixteenth P1 Per Capita plot.

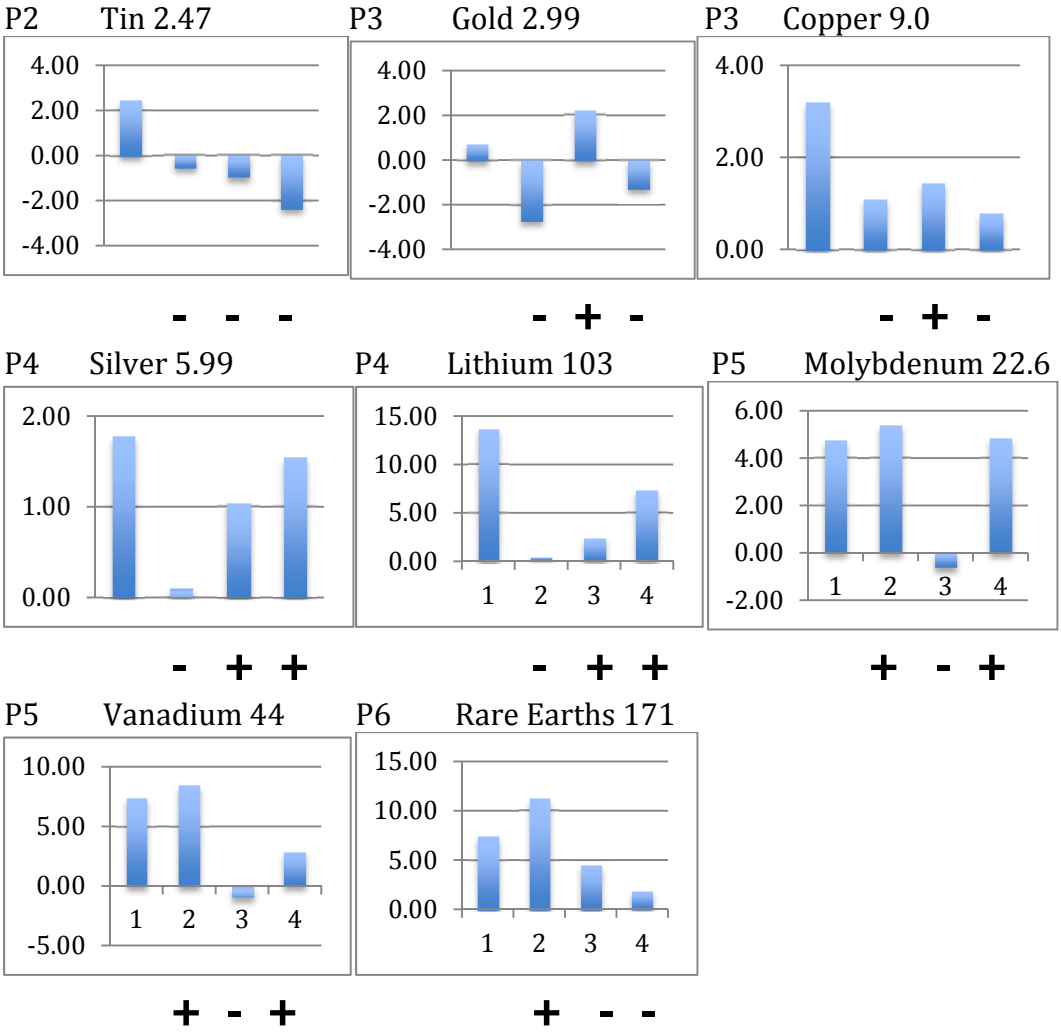

Figure 9: Eight Contrary Per Capita Growth Rate Patterns.

Discussion:

Looking first at the overall multiplier in Table 1 Tin did not keep up with population growth of 3 while Gold essentially matched population growth. The remaining 22 commodities exceeded population growth ranging from a low of 4 for Lead to highs of 103 for Lithium and 171 for Rare Earths.

Concrete and Steel are the basic components for buildings and infrastructure and cement with a multiplier of 45 grew substantially more than Steel with a multiplier of 12. However the increasing development of alloy steels is reflected in the higher multipliers of Nickel (14), Chromium (20.7), Molybdenum (22.6) and Vanadium (44). Over 90% of Vanadium consumption is for alloy steels.

Phosphate Rock (11.8) and Potash with a multiplier of 15 (five times the population growth) reflect the increase in food demand as standard of living and affluence increase.

The increases in Lithium (103) and Rare Earths (171) were driven by technology advances The two main uses for Lithium are ceramics and glass (35%) and batteries (29%), while Rare Earths have a wide range of applications including high strength magnets used in computer hard drives, wind turbines, hybrid cars, camera and telescope lenses, flat panel screens and X-ray and MRI medical equipment. The multiplier average is heavily influenced by the large increases of Lithium and Rare Earths. The average drops from 26.77 to 16.75 if Li and RE are removed, but is still more than five times larger than the growth in population.

In column E, showing Agrs over the total 1946 to 2010 period, values follow the order of the multiplier column and range from a low of 1.6%/yr to a high of 8.36%/yr, with an average of 5.23. The average growth rate for 24 commodities is three times larger than the population growth rate.

By contrast, rates in columns A, B, C, and D, vary significantly in the different time periods. The top five commodities in Table 1 are listed in Table 4 together with the corresponding Agr values. The superscript number indicates the top down rank in the multiplier column of Table 1.

Table 4: Top five commodity Agrs by time period.

46/64		64/80		80/00		00/10		46/10	
Li[2]	15.84	RE[1]	13.34	RE[1]	6.20	Co[7]	10.40	RE[1]	8.36
Mg[6]	13.65	V[5]	10.59	Li[2]	4.02	Li[2]	8.63	Li[2]	7.51
Al[3]	11.86	Mo[8]	7.42	Au[23]	3.84	Mn[15]	8.05	Al[3]	6.37
Cem[4*]	10.19	Al[3]	6.13	Cem[4*]	3.21	Cem[4*]	6.98	Cem[4*]	6.13
Pot[10^]	9.74	S[14]	5.46	Cu[16]	3.08	Mg[6]	5.99	V[5]	6.09
Ave.	12.26		8.59		4.07		8.01		6.95

Cem* Cement Pot^ Potash

Thirteen commodities make it into the top five list, Rare Earths retaining first place position in the second and third period, but are absent from the 46/64 or 00/10 periods. Cement is the most consistent performer, retaining its fourth place in three time periods. Lithium is the only other commodity listed in three places, retaining its first place in the first time period and placing second in the last two periods. Aluminum appears twice, retaining its third place in the 46/64 time period but dropping to fourth in the second period. Magnesium is sixth in the multiplier rank but makes it twice into the top five table, once in 46/64 and once in 00/10. Vanadium, fifth in the multiplier rank appears only once, in second place, in 64/80. The remaining seven commodities did not appear in the multiplier top five, appear only once and range in multiplier rank from Cobalt (7th) to Gold (23rd).

All 20 Agrs shown in Table 4 are listed in decreasing order in Table 5

Table 5: Agrs of Table 4 in decreasing order

Element	Agr	Period	# Years	Growth
Li[2]	15.84	1	18	14.1
Mg[6]	13.65	1	18	10.0
RE[1]	13.34	2	16	7.4
Al[3]	11.86	1	18	7.5
V[5]	10.59	2	16	5.0
Co[7]	10.40	4	10	2.7
Cem[4]*	10.19	1	18	5.7
Pot[10]^	9.74	1	18	5.3
Li[2]	8.63	4	10	2.3
Mn[15]	8.05	4	10	2.2
Mo[8]	7.42	2	16	3.1
Cem[4]*	6.98	4	10	2.0
RE[1]	6.20	3	20	3.3
Al[3]	6.13	2	16	2.6
Mg[6]	5.99	4	10	1.8
S[14]	5.46	2	16	2.3
Li[2]	4.02	3	20	2.2
Au[23]	3.84	3	20	2.1
Cem[4]*	3.21	3	20	1.9
Cu[16]	3.08	3	20	1.8

The changes in per capita rates over the four time periods vary widely as can be seen in the 24 individual commodity plots. Out of 24 commodities only four had per capita growth rates higher in the 00/10 period than in the initial baby boomer period. These commodities (with percent increase) are Molybdenum (+1.7%), Manganese (+4.3%), Cobalt (+24%) and Selenium (+41%).

Working with the multiplier column of table 2 the average per capita demand for the first twelve commodities increased 2.25 times over the 64 years period. For the next six commodities the average was 6.3 while the two highest three commodity groups increased 13.4 and 36.1 times respectively. The overall average was 8.9, meaning that for the 24 commodities studied the per capita demand was about 9 times

greater in 2010 than in 1946. This increase can be attributed to improvements in standard of living, mainly in the developed nations, and increased demand by new technologies that did not exist in 1946.

Future Needs:

The World population growth rate is declining and current estimates project a 2050 population of over 9 billion, 1.27 times the 2012 population of 7.08 billion with a corresponding average annual rate of 0.63%. By contrast, the average annual population growth rate over the 2000 to 2012 period was 1.21%. However, although population growth rates are declining, aspirations for improved standards of living and the rate of technological innovation are increasing.

In view of these factors what increases in mineral resource demand can be expected over the 2010 to 2050 period?

As in classical economic forecasting past performance is not necessarily a good indicator of future performance. However, with this cautionary note, estimates can be made using calculated average annual growth rates over different historic periods.

Table 6 shows the average annual growth rate over periods of 64, 46 and 30 years prior to 2010. The 64 year period had the highest overall rates for 23 of the 24 commodities, due to the strong influence of the high post war boom, while six of the lowest rates, highlighted in red, occur in the 46 year period and 18 in the 30 year period. These high and low rates were used to estimate growth in consumption from 2010 to 2050 and are listed in the High and Low columns. The final column shows the ratio of the high to low multiplier estimates and gives an indication of the difference in the spread of high to low estimates between different commodities. The Hi/Lo ratio is shown in ascending order in Table 7 and ranges from a 15% spread for silver to a 423% spread for Vanadium.

Table 6: Estimated Increases, 2010 to 2050

	Average Annual Rate			2010 to 2050 Multiplier			
	64yr	46yr	30yr	High	Low	Average	Hi/Lo
Tin	1.60	0.49	*0.03*	1.89	1.01	1.45	1.87
Gold	1.73	*1.35*	2.51	1.99	1.71	1.85	1.16
Lead	2.21	1.09	*0.56*	2.40	1.25	1.82	1.92
Selenium	2.43	*1.78*	1.84	2.61	2.03	2.32	1.29
Cadmium	2.74	1.28	*0.75*	2.94	1.35	2.15	2.18
Silver	2.84	*2.47*	2.70	3.06	2.66	2.86	1.15
Tungsten	3.20	1.93	*0.88*	3.52	1.42	2.47	2.48
Zinc	3.40	2.44	*2.42*	3.81	2.60	3.21	1.46
Copper	3.50	2.83	*2.72*	3.96	2.92	3.44	1.35

Manganese	3.52	1.61	*1.50*	3.99	1.81	2.90	2.20
Sulfur	3.58	2.38	*0.78*	4.08	1.36	2.72	2.99
Steel	3.92	2.63	*2.36*	4.66	2.54	3.60	1.83
Phos Rock	3.94	2.30	*0.70*	4.69	1.32	3.01	3.55
Nickel	4.17	3.34	*2.59*	5.13	2.79	3.96	1.84
Potash	4.30	2.24	*0.67*	5.39	1.31	3.35	4.12
Chromium	4.85	3.84	*3.20*	6.65	3.53	5.09	1.88
Molybdenum	4.99	4.29	*2.66*	7.01	2.86	4.94	2.45
Cobalt	5.47	*3.95*	4.15	8.42	4.71	6.56	1.79
Magnesium	5.54	*2.52*	2.95	8.64	2.71	5.67	3.19
Vanadium	6.09	4.77	*1.79*	10.64	2.04	6.34	5.23
Cement	6.13	4.58	*4.45*	10.79	5.71	8.25	1.89
Aluminum	6.37	4.30	*3.33*	11.82	3.71	7.77	3.18
Lithium	7.51	*4.42*	5.53	18.11	5.64	11.88	3.21
RE	8.36	7.93	*5.15*	24.82	7.44	16.13	3.34
	Average			6.71	2.77	4.74	
	Average ex Li & RE			5.37	2.42	3.90	

Table 7: Hi/Lo Values in Ascending Order

Silver	1.15
Gold	1.16
Selenium	1.29
Copper	1.35
Zinc	1.46
Cobalt	1.79
Steel	1.83
Nickel	1.84
Tin	1.87
Chromium	1.88
Cement	1.89
Lead	1.92
Cadmium	2.18
Manganese	2.20
Molybdenum	2.45
Tungsten	2.48
Sulfur	2.99
Aluminum	3.18
Magnesium	3.19
Lithium	3.21
RE	3.34
Phos Rock	3.55
Potash	4.12
Vanadium	5.23

Conclusions:

An examination of the demand for 24 commodities over the time period 1946 to 2010 shows wide variation over different time intervals with the largest growth during the postwar baby boom period from 1946 to 1964 during which commodity growth rates ranged from 2.7% for gold to 15.8% for lithium. Over the same 18 year period the average per capita growth rate for the 24 commodities studied was 5.65%/yr compared to the population growth rate of 1.96%/yr. In the following periods there was virtually no growth from 1980 to 2000 and average per capita growth rates of 2.12 and 2.82%/yr for the 1964/80 and 2000/10 periods respectively.

Major differences in overall commodity growth are also observed ranging from a low of 176% for Tin to the technology driven increases starting from low post war values and leaping to the exceptionable values of 10,200% for Lithium and 17,000% for Rare Earths.

By observing the growth rates in the different time periods estimates for high, low and medium commodity demands in 2050 were calculated. The High estimate showed individual increases from 2010 to 2050 ranging from 89% for Tin to 2,382% for Rare Earth, while the low estimate gave values of 1% for Tin and 644% for Rare Earths.

Examining per capita data, major increases in per capita consumption were observed over the 64year interval studied. Although Tin declined by 10% and gold held steady the per capita consumption for the remaining 22 commodities increased, ranging from 30% for lead to 5570% for Rare Earths. The average increase over the 24 commodities was 8.9 times.

Although it is not possible to predict actual commodity demand in 2050 it is clear that there will be considerable pressure on the mineral industry to satisfy the increased mineral demand of the 2050 global population.

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