Chapter 1: Sustainability, Engineering and Design

1-1. Genetically modern humans appeared on Earth about 200,000 years ago and biologically and behaviorally modern humans appeared about 70,000 years ago. The number of people and their effects upon the planet were negligible, or as Douglas Adams says, "as near nothing as makes no odds," for most of the history of the planet. When did the planets population reach 1 billion people? Assuming that the population has grown exponentially since that time, what was the time interval required to increase by 1 billion people – for up to 7 billion people, the approximate global population in 2012?

Answer:

From page 1-3 the planet reached 1 Billion people in approximately 1800.

October 31, 2011 was declared by the United Nations, as the day the world population reached 7 billion.

1-2. List the three dimensions and four categories used to calculate the Human Development Index (HDI) for a country.

Answer:

The Life Expectancy index

The Educational Index

The Income Index

1-3. For the countries listed in the table below, calculate

a. The Life Expectancy Index
b. The Educational Index
c. The Income Index
d. The Human Development Index

Country and 2011 Data	Life Expectancy at Birth (years)	Expected years of schooling	Mean years of schooling	GNI per capita in PPP terms (constant 2005 international $)
Australia	81.9	18.0	12.0	34,431
China	73.5	11.6	7.5	7,476
Ireland	80.6	18.0	11.6	29,322
Kenya	57.1	11.0	7.0	1,492
South Africa	52.8	13.1	8.5	9,469

Answer:

Life Expectancy (LE) at birth using the 2011 Life Expectancy Index:

$$\text{Life Expectancy Index (LEI)} = (\text{LE}-20)/(83.2-20) \tag{1.1}$$

The Education Index (EI) based upon the Mean Years of Schooling Index (MYSI) and Expected Years of Schooling Index (EYSI), where:

$$\text{MYSI} = \text{Mean Years of Schooling}/13.2 \tag{1.2}$$

$$\text{EYSI} = \text{Expected Years of Schooling}/20.6 \tag{1.3}$$

$$\text{EI} = \{(\text{MYSI} \times \text{EYSI})^{0.5}\}/0.951 \tag{1.4}$$

And the Income Index (II) which is based upon the Gross National Income (GNI_{pc}) at purchasing power parity per capita, which is an estimate and standardization of each individuals' income in a country:

$$\text{II} = \{\ln(GNI_{pc})-\ln(100)\}/\{\ln(107{,}721)-\ln(100)\} \tag{1.5}$$

The Human Development Index is determined from the geometric mean of the Life Expectancy, Education and the Income Index:

$$\text{HDI} = (\text{LEI} \times \text{EI} \times \text{II})^{1/3} \tag{1.6}$$

Australia	0.979	0.874	0.909	0.937	0.837	**0.916**
China	0.847	0.563	0.568	0.595	0.618	**0.678**
Ireland	0.959	0.874	0.879	0.921	0.814	**0.896**
Kenya	0.587	0.534	0.530	0.560	0.387	**0.503**
South Africa	0.519	0.636	0.644	0.673	0.652	**0.611**

1-4. For the countries listed in the table below, calculate:
a. The Life Expectancy Index
b. The Educational Index
c. The Income Index
d. The Human Development Index
e. Determine the United Nations Development Category for the country

Country and 2011 Data	Life Expectancy at Birth (years)	Expected years of schooling	Mean years of schooling	GNI per capita in PPP terms (constant 2005 international $)
Canada	81.0	16.0	12.1	35,166
Japan	83.4	15.1	11.6	32,295
Mexico	77.0	13.9	8.5	13,245
Nigeria	51.9	8.9	5.0	2,069
United Kingdom	80.2	16.1	9.3	33,296

Answer:

See Problem 1.3 for methodology

Canada	0.965	0.777	0.917	0.887	0.840	**0.896**
Japan	1.003	0.733	0.879	0.844	0.827	**0.888**
Mexico	0.902	0.675	0.644	0.693	0.700	**0.759**
Nigeria	0.505	0.432	0.379	0.425	0.434	**0.453**
United Kingdom	0.953	0.782	0.705	0.780	0.832	**0.852**

1-5. For the country listed in the table below, calculate
a. The Life Expectancy Index
b. The Educational Index
c. The Income Index
d. The Human Development Index

Country and 2011 Data	Life Expectancy at Birth (years)	Expected years of schooling	Mean years of schooling	GNI per capita in PPP terms (constant 2005 international $)
Benin	56.1	3.3	9.2	1,364
Costa Rica	79.3	11.7	8.3	10,497
India	65.4	10.3	4.4	3,468
Malta	79.6	14.4	9.9	21,460
New Zealand	80.7	18.0	12.5	23,737
Rwanda	55.4	11.1	3.3	1,133

Answer:

See Problem 1.3 for methodology

Benin	0.571	0.223	0.045	0.106	0.348	0.276
Costa Rica	0.938	0.568	0.629	0.628	0.667	0.732
India	0.718	0.500	0.333	0.429	0.508	0.539
Malta	0.943	0.699	0.750	0.761	0.769	0.820
New Zealand	0.960	0.874	0.947	0.957	0.783	0.896
Rwanda	0.560	0.539	0.250	0.386	0.348	0.422

1-6. What are the HDI categories defined the United Nations? For each of the four categories, describe what you think people may drink, eat, and wear, the type of homes they may live in, the types of school they are likely to attend and the type of transportation they are most likely to use.

Answer:

Life Expectancy at Birth

Expected years of schooling

Mean years of schooling

GNI per capita in PPP terms (constant 2005 international $)

1-7. Describe, using your own words, the purpose of human development.

Answers will vary.

1-8. Define the following terms:
a. Urban
b. Suburban
c. Peri-urban:
d. Rural

Answers will vary.

1-9. What is the "Brundtland definition" of sustainable development?

Answer:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

1-10. How would you describe sustainability to a 12 year old student at your local school?

Answers will vary.

1-11. Look up and describe one of the formative written works related to sustainable development. Research this work more and summarize the main premise of the work in a short 500 word essay.

Answers will vary.

1-12. The next time you drink from a drinking water fountain or buy a bottle of water, what are your expectations about the safety of the water? Who, exactly, would be responsible for fulfilling these expectations?

Answer:

In the United States, the United States Environmental Protection Agency (USEPA) is responsible for setting standards for municipal tap water drinking water supplies. However the local water municipality is responsible for compliance wit those regulations. The United States Department of Agriculture's Food and Drug Administration (FDA) is responsible for water quality in bottled water.

1-13. What characteristics define unsustainable development? Make a table of characteristics that might negatively affect development. Mark which of these characteristics are important in:
a. Very high human development index countries
b. Low human development index countries
c. Both?

Answers will vary.

1-14. Create a schematic or cartoon that relates the following trends
a. Human population
b. Resource consumption
c. Educational resources
d. Economic resources

Answers will vary.

1-15. List and describe in your own word the 8 United Nations Millennium Development Goals. Specifically describe the economic, environmental, social and technical challenges associated with meeting each of the goals within the next 5 years.

Answer:

Millennium Development Goals (Ref UN MDG 2012 Report)

1. Eradicate extreme poverty and hunger:

- Target 1.A: Halve, between 1990 and 2015, the proportion of people whose income is less than $1 a day
- Target 1. B Achieve full and productive employment and decent work for all, including women na dyoung people
- Target 1.C Halve the proportion of people who suffer from hunger

2. Achieve universal primary education

- Target 2. A Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling

3. Promote gender equality and empowerment in women

- Target 3.A Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education no later than 2015.

4. Reduce child mortality

- Target 4. A Reduce by two thirds the under five mortality rate

5. Improve maternal health

- Target 5 A. Reduce by three quarters the maternal mortality ratio

6. Combat HIV/Aids, malaria, and other diseases

- Target 6. A Have halted by 2015 and begun to reverse the spread of HIV/AIDS
- Target 6. B Achieve, by 2010, universal access to treatment for HIV/AIDS for all who need it
- Target 6. C Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases

7. Ensure environmental sustainability

- Target 7. A integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
- Target 7. B Reduce biodiversity loss, achieving by 2010, a significant reduction in the rate of loss
- Target 7. C Halve by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation
- Target 7. D By 202, to have achieved a significant improvement in the lives of at least 100 million slum dwellers

8. Develop a global partnership for development

- Target 8. A develop an open, rule-based, predictable, non-discriminatory trading and financial system
- Target 8. B and C Address the special needs of the least developed countries, landlocked developing countries and small island States
- Target 8. D Deal comprehensively with developing countries debt
- Target 8. F In cooperation with the private sector, make available the benefits of new technologies, especially information and communications

1-16. Do you believe that sustainable products are morally superior to non-sustainable products? If so, what does this belief imply about the developed world's largely consumer based economic system of retail merchandise? How are technology and moral convictions woven into the fabric of our definitions of sustainable design?

Answers will vary.

1-17. If you had to live on $2 per day, how would you meet your basic needs for food, shelter, water, sanitation and other needs?

a. Determine from recent utility bills of your own or a relative, how much you spend per day on
   i) Water
   ii) Sanitation (sewer or wastewater company bill)
   iii) Garbage collection services
   iv) Energy
   v) Heating/Cooling
   vi) Communications (phone, cell phone, internet, etc)
   vii) Food
   viii) Shelter (based upon rent or mortgage payment)
   ix) Entertainment
b.
c. Determine your total daily expenditure
d. If you were to pay 25% of your income on taxes, how much would your income need to be each year to pay for your daily expenses?
e. What level of the human development index would this income be associated with?

Answers will vary.

1-18. Imagine you were part of a company designing a school for a low-income country (based upon the countries HDI). Use online resources to help address the following questions for the design of the proposed school:

a. Are parts readily available, either locally or nationally, if a component were to fail?
b. Are there individuals who have the necessary skill or technical training to repair the component or system if it were to fail?
c. Would members of the household readily understand how to use this system?
d. What is the local availability of required infrastructures, such as electric power?

Answers will vary.

1-19. Compare and contrast the definition of sustainability as defined by The Merriam Webster dictionary, the United States Environmental Protection Agency, and the Bruntland commission report.

Answers will vary.

1-20. Describe how concepts of sustainability might be applied to the fundamental canons of the National Society of Professional Engineers.

Answers will vary.

1-21. It took about 12 years, between 2000 and 2012, for the world population to increase by 1 billion people. In contrast, the world's population was estimated to be 300 million people in the year 0 AD. By the year 1500 the world's population was estimated to be 500 million people.

a. Assuming exponential growth, what was the world' population growth rate, in percent, between 2000 and 2012?
b. Assuming exponential growth, what was the world' population growth rate, in percent, between 0 and 1500?
c. How many times greater was the population growth rate in recent times compared to that between AD 0 and 1500?

Answer:

(a) $A_t = A_o e^{(k(t-t_o))}$

Solve for k.

$$\frac{A_t}{A_o} = e^{(k(t-t_o))}$$

$$\ln\frac{A_t}{A_o} = k(t-t_o)$$

$$k = \frac{\ln\frac{A_t}{A_o}}{(t-t_o)}$$

$$k = \frac{\ln\frac{7{,}000{,}000{,}000}{6{,}000{,}000{,}000}}{(2012-2000)}$$

$$k_{2000-2012} = \frac{0.154}{12} = 0.0128 = 1.3\%$$

$$k_{2000-2012} = 1.3\%$$

(b)

$$k = \frac{\ln\frac{500{,}000{,}000}{300{,}000{,}000}}{(1500-0)}$$

$$k_{0-1500} = 0.00034$$

$$k_{0-1500} = 0.03\%$$

(c) How many times greater is $k_{2000-2012}$ compared to k_{0-1500}?

$$\frac{1.3\%}{0.03\%} = 43$$

The growth rate is 43 times higher between 2000-2012 A.D. than between 0-1500 A.D.

1-22. World Population in 1850 has been estimated at about 1 billion. World population reached 4 billion in 1975. What was the exponential growth rate during this time in percent?

Year (t)	Tuition (A)
1962	1,500
2010	25,000
2050	A_{2050}

Answer:

$A_t = A_o e^{(k(t-t_o))}$

Solve for k.

$$\frac{A_t}{A_o} = e^{(k(t-t_o))}$$

$$\ln\frac{A_t}{A_o} = k(t-t_o)$$

$$k = \frac{\ln\frac{A_t}{A_o}}{(t-t_o)}$$

$$k = \frac{\ln\frac{4}{1}}{(1975-1800)}$$

$$k = \frac{1.38}{175} = 0.00792$$

$$k = 0.8\%$$

1-23. Tuition at a University rose from \$1,500/year in 1962 to \$25,000/year in 2010.

a. What exponential growth rate characterized that period of time?

b. If that rate of growth were to continue until 2050 (when your children might be paying tuition), what would the tuition be?

Answer:

(a) Use Equation 1.8 and solve for k

$$A_{(t)} = A_o \exp\big(k(t - t_o)\big)$$

$$\ln \frac{A_{(t)}}{A_o} = k(t - t_o))$$

$$k = \frac{\ln\left({A_{(t)}}/{A_o}\right)}{t - t_o} = \frac{\ln\left({25{,}000}/{1{,}500}\right)}{2010 - 1962}$$

$$k = 0.059 \text{ years}^{-1}$$

(b)

$$A_{2050} = A_{2010} \exp^{k(t - t_o)}$$

$$A_{2050} = \$25{,}000 \exp^{0.059(2050 - 2010)}$$

$$A_{2050} = \$260{,}000$$

1-24. In 1999, RSU tuition was \$1,963 per semester. In 2009, RSU tuition was \$3,622 per semester. This increase is represented by an exponential growth rate of 6.1%, if tuition rates increase exponentially, assuming exponential tuition growth, what value is closest to in-state semester tuition cost predicted in 2035?

Answer:

$A_o = \$1{,}963$

$A_t = \$3{,}622$

$k = 6.1\%$

$\Delta t = 10$

Find $A_{t_{2035}}$

$$A_t = A_o \mathrm{e}^{(k(t - t_o))}$$

$$A_{t_{2035}} = (\$1{,}963)\mathrm{e}^{(0.061(2035 - 1999))}$$

$$A_{t_{2035}} = \$17{,}645$$

1-25. In 2007 the world's population was estimated to be 6.7 billion people. The UN forecasts the population will begin to level off at 9.2 billion people in 2050. What is the population growth rate in percent over this period of time?

Answer:

$$A_o = 6.7 \times 10^9 \qquad t_o = 2007$$

$$A_t = 9.2 \times 10^9 \qquad t = 2050$$

$$A_t = A_o \mathrm{e}^{(k(t-t_o))}$$

$$A_t/A_o = \mathrm{e}^{(k(t-t_o))}$$

$$\ln\left(A_t/A_o\right) = k(t - t_o)$$

$$k = \frac{\ln\left(A_t/A_o\right)}{(t - t_o)}$$

$$k = \frac{\ln\left(9.2 \times 10^9/6.7 \times 10^9\right)}{2050 - 2007}$$

$$k = 0.00737$$

$$k = 0.74\%$$

1-26. Latest estimates are that 11.6 x 10^6 m^2 of rainforest will be destroyed in two hours. Assuming that the initial area of tropical rainforests is 20 x 10^{12} m^2:

a. What is the exponential rate of rainforest destruction?
b. If this rate is representative of the past and future and there were 24.5 x 10^{12} m^2 of rainforest in 1975, how much rainforest was left (in m^2) in 2010?
c. It is estimated that tropical rainforests remove or take-up 0.83 kg(C)/m^2-year. How much less carbon [kg(C)] was removed in 2010 by rainforests compared to that removed in 1975?

Answer:

$$A_o = 2.00 \times 10^{13} \qquad t_o = 0$$

$$t = 1$$

(a)

$$\frac{11.6 \times 10^6}{2}\ \frac{\text{m}^2}{\text{h}} \times \frac{24\ \text{h}}{\text{d}} = 1.39 \times 10^8 \frac{\text{m}^2}{\text{d}}$$

$$A_t = 2.0 \times 10^{13}\ \text{m}^2 - 1.39 \times 10^8\ \text{m}^2$$

$$\Delta_t = A_o \text{e}^{(k(t-t_o))}$$

$$A_t/A_o = \text{e}^{(k(t-t_o))}$$

$$\ln\left(A_t/A_o\right) = k(t - t_o)$$

$$k = \frac{\ln\left(A_t/A_o\right)}{(t - t_o)}$$

$$k = \frac{\ln\left(2.0 \times 10^{13} - 1.39 \times 10^8 / 2.0 \times 10^{13}\right)}{(1 - 0)}$$

$$k = -6.96 \times 10^{-6}\ \text{d}^{-1}$$

(b)

$$A_{1975} = 2.45 \times 10^{13}\ \text{m}^2$$

$$2010 - 1975 = 35\ \text{yr} = 12{,}775\ \text{d}$$

$$A_t = A_o \text{e}^{(k(t-t_o))}$$

$$A_{2010} = 2.45 \times 10^{13} \text{e}^{\left(-6.96 \times 10^{-6}(12{,}775)\right)}$$

$$A_{2010} = 2.24 \times 10^{13}\ \text{m}^2$$

(c)

$$0.83 \frac{\text{kg (C)}}{\text{m}^2\text{yr}} \times 2.45 \times 10^{13}\ \text{m}^2 = 2.03 \times 10^{13} \frac{\text{kg (C)}}{\text{yr}} \text{ in 1975}$$

$$0.83 \frac{\text{kg (C)}}{\text{m}^2\text{yr}} \times 2.24 \times 10^{13}\ \text{m}^2 = 1.86 \times 10^{13} \frac{\text{kg (C)}}{\text{yr}} \text{ in 2010}$$

$$2.03 \times 10^{13} \frac{\text{kg (C)}}{\text{yr}} - 1.86 \times 10^{13} \frac{\text{kg (C)}}{\text{yr}} = 1.70 \times 10^{12} \frac{\text{kg (C)}}{\text{yr}} \text{ less in 2010}$$

1-27. The world's population 10,000 years ago has been estimated at about 5 million. What exponential growth rate would have resulted in the population in 1800, which is estimated at 1 billion? Had that continued what would have been the world's population in 2010?

Answer:

$A_t = 10{,}000 \text{ years} - (2010 - 1800) \text{ years} = 9{,}800 \text{ years}$

$A_o = 5 \times 10^6 \text{ people}$

$A_t = 1 \times 10^9 \text{ people}$

$A_t = A_o \mathrm{e}^{(k(t-t_o))}$

$$k = \frac{\ln(A_t/A_o)}{\Delta t} = \frac{\ln(1 \times 10^9 \text{ people}/5 \times 10^6 \text{ people})}{9{,}800 \text{ years}}$$

$k = 0.00054 \text{ yr}^{-1} = 0.054\%$

$A_{2010} = (1 \times 10^9 \text{ people})\mathrm{e}^{0.00054(2010-1800)}$

$A_{2010} = 1.12 \times 10^9 \text{ people}$

1-28. In 2007 the population of the world's 50 least developed countries was estimated to be 0.8 billion people. The UN expects the population in these countries to grow at 1.75% until 2050. What would be the predicted population in the world's 50 least developed countries in 2050?

Answer:

$t_o = 2007$

$A_o = 0.8 \times 10^9 \text{ people}$

$$k = 1.75\% = 0.0175 \frac{1}{\text{yr}}$$

$A_t = A_o \mathrm{e}^{(k(t-t_o))}$

$A_{2050} = (0.8 \times 10^9 \text{ people})\mathrm{e}^{0.0175(2050-2007)}$

$A_{2050} = 1.7 \times 10^9 \text{ people}$

1-29. What must engineers hold paramount in their designs according to most professional ethics codes?

Answer:

The engineer shall hold paramount the health, safety, and welfare of the public.

1-30. Describe quantitatively (using numbers to show the differences) the differences between access to improved drinking water supplies in the United States to countries in Africa and the Caribbean.

Answers will vary.

1-31. List the UN Millennium Development Goals and describe briefly how they might relate to access to drinking water.

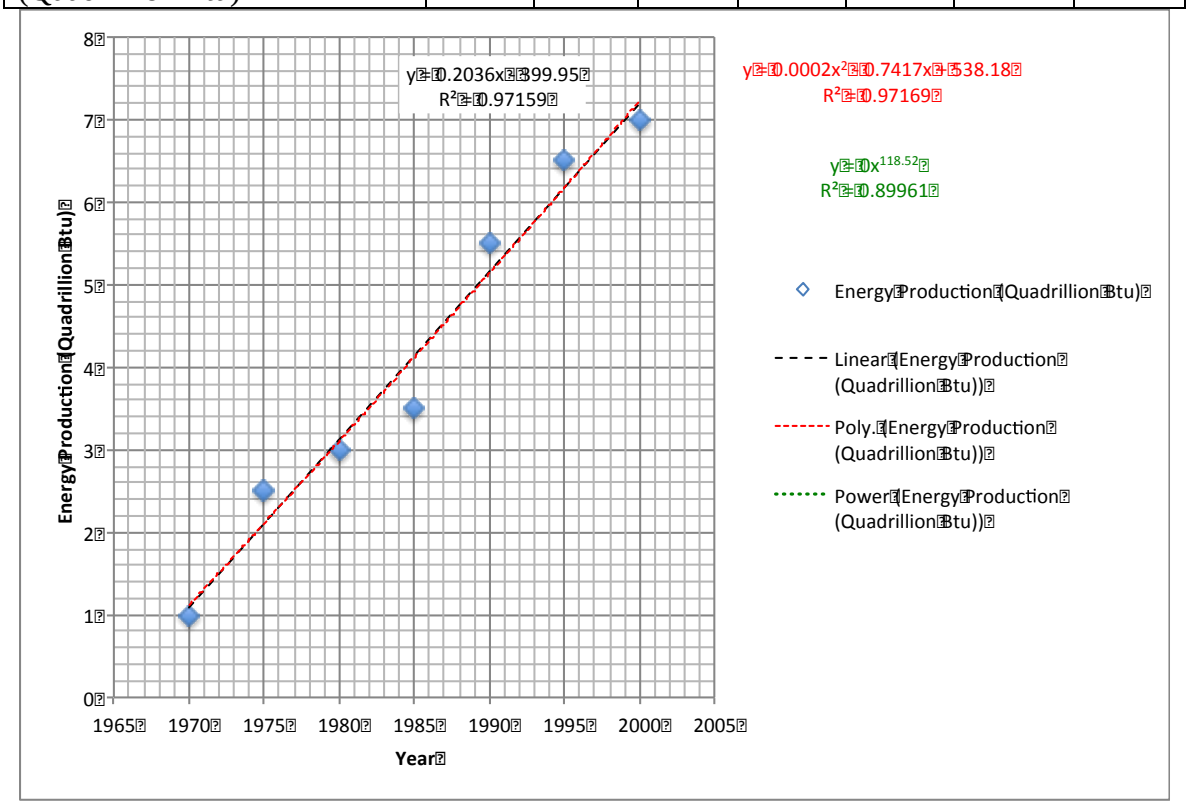
Answers will vary.

1-32. Energy derived from Nuclear Power has grown since 1970 according to the data below.

a. Plot the energy production from nuclear power between 1970 and 2000.
b. Find the best curve fit for the plot above (use either a linear fit, polynomial fit, or power function.) What is the equation for this best fit curve?
c. Take the mathematical or graphical derivative of the function from the plot above and graph the rate of change (first derivative) of energy derived from nuclear power between 1970 and 2000 in Excel or a similar spreadsheet program.

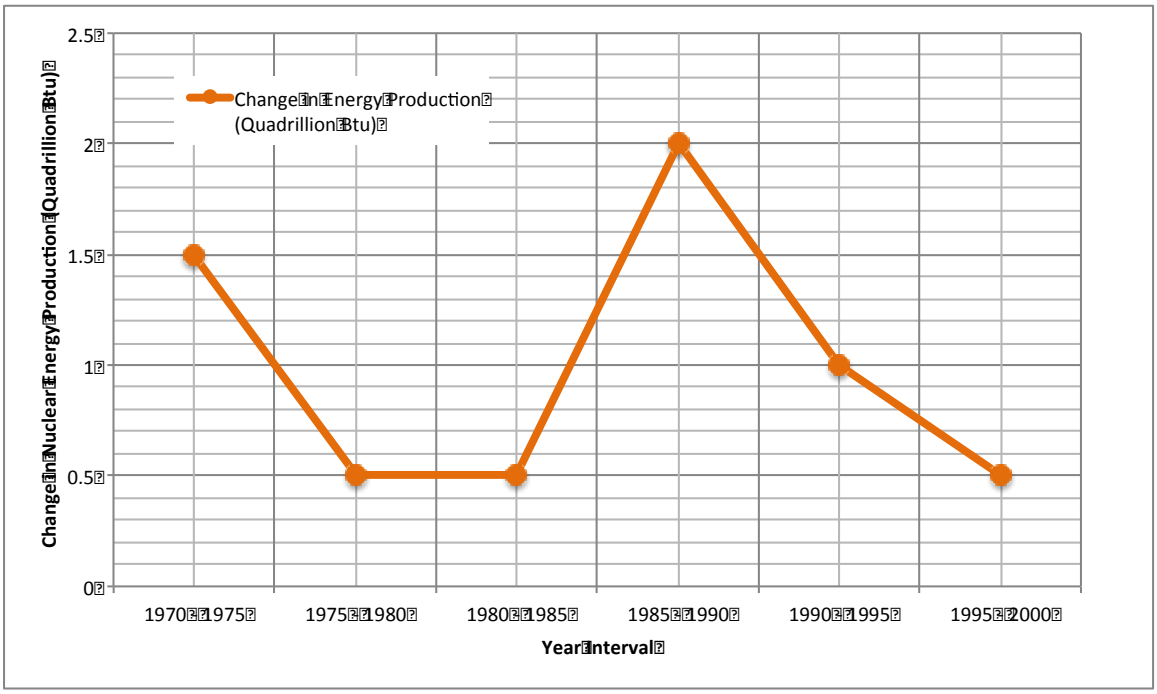
Answer:

Year	1970	1975	1980	1985	1990	1995	2000
Energy Production (Quadrillion Btu)	1	2.5	3	3.5	5.5	6.5	7



1-32 (continued)

Delta Year	1970 - 1975	1975 - 1980	1980 - 1985	1985 - 1990	1990 - 1995	1995 - 2000
Change in Energy Production (Quadrillion Btu)	1.5	0.5	0.5	2	1	0.5



1-33. Thomas Malthus described a situation where population could overcome the available supply of natural resources near the year 1800. Over 200 years later scientist, policy makers and demographers fear the same situation may be occurring, that we may exceed the bio capacity of the planet. Malthus's original arguments have been reworked in modern writings such as the Tragedy of the Commons and the Population Bomb. What role do scientist and engineers play in the debate about the likelihood of humans, based upon our current lifestyle, exceeding the planets biocapacity of the planet? Base you essay upon economic, environmental, social and technical parameters.

Answers will vary.

1-34. Describe which of the grand challenges of engineering you are most interested in. Frame the problems that must be overcome associated with the challenge you've selected in terms of the variables in the IPAT equation.

Answers will vary.

1-35. Sustainable development is extremely difficult, since the environmental footprint of a nation generally increases with increasing development. Use the IPAT equation and determine whether each variable is likely to increase, decrease, or remain unchanged if the HDI of a country increases. What must the response of each variable in the IPAT equation be (increase, decrease, or no change) if development is to be truly sustainable?

Answers will vary.

1-36. Describe how social and environmental accounting might be a useful tool in developing policies to promote sustainable development.

Answers will vary.