ENERGY IN SOCIETY

WORKBOOK

John R. Fanchi

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PREFACE

ENERGY IN SOCIETY WORKBOOK was originally developed for a class called Energy in Society. I taught the class to undergraduate liberal arts students at TCU and a version of the class to MBA students. The material is designed to complement an introductory energy course. Chapter topics are aligned with the textbook ENERGY IN THE 21ST CENTURY, 5th Edition [J.R. Fanchi, 2023, World Scientific: Singapore] for ease of reference. The problems can also be used to complement material from other energy books or online AI.

A List of Problems at the end of the book serves as an index to problems. The problems introduce useful information. Problems with multiple parts provide procedures that can be used with information from different time periods. Many problems can stimulate discussions about topics ranging from technical to economic and geopolitical.

Solutions are provided for all problems and are placed at the end of each chapter. Solving problems, either in class or as self-learning, can improve critical thinking skills and refresh practical math skills.

A variety of unit systems are used in the problems to help the reader become familiar with the range of unit systems being applied to energy topics. Unit conversion calculators are readily available online.

Prof. Dr. John R. Fanchi
Texas Christian University (retired)
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ABOUT THE AUTHOR

John R. Fanchi has a Ph.D. in physics from the University of Houston and is the author of a variety of books in the areas of physics, earth science, mathematics, and engineering. He has worked in the energy industry, and has taught courses in energy, engineering, and physics at Texas Christian University (TCU), Colorado School of Mines (CSM), and the University of Tulsa. He was co-founder and first President of the International Association for Relativistic Dynamics and is a Distinguished Member of the Society of Petroleum Engineers.

BOOKS BY THE AUTHOR

Confronting the Enigma of Time (2024, World Scientific)
Energy in the 21st Century (5th edition, 2023, World Scientific)
Reason, Faith, and Purpose: The Ultimate Gamble (2021, World Scientific)
The Goldilocks Policy: The Basis for a Grand Energy Bargain (2019, World Scientific)
Principles of Applied Reservoir Simulation (2018, 4th edition, Elsevier)
Math Refresher for Scientists and Engineers (2006, 3rd edition)
Energy: Technology and Directions for the Future (2004, Elsevier Academic)
Shared Earth Modeling (2002, Butterworth-Heinemann)
Parametrized Relativistic Quantum Theory (1993, Kluwer)

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CHAPTER 1

A BRIEF HISTORY OF ENERGY CONSUMPTION

Problems

Problem 1-1. Scientific Notation

Exponents obey the three laws tabulated as follows:

EXPONENTS*	
Products	$a^m \cdot a^n = a^{m+n}$
Quotient	$\frac{a^m}{a^n} = a^{m-n}$ if $m > n$ $\frac{a^m}{a^n} = 1$ if $m = n$ $\frac{a^m}{a^n} = \frac{1}{a^{n-m}}$ if $m < n$
Power	$(a^m)^n = a^{mn}$
*After **Math Refresher for Scientists and Engineers** (J.R. Fanchi, Wiley, 2006)	

The number a raised to a negative power is given by $a^{-m} = \frac{1}{a^m}$. Any nonzero real number raised to the power 0 equals 1, thus $a^0 = 1$ if $a \neq 0$. In the case of the number 0, we have the exponential relationships $0^0 = 0,\ 0^x = 0$ for all x.Scientific notation relies on properties of exponents to perform calculations. It is a means of compactly writing very large or very small numbers.

A. 1
B. 1,000
C. 1 million
D. 1 trillion
E. 1 billion
F. 1000 billion
G. 1 quadrillion
H. 1/100

I. 1/1000
J. 1/1,000,000 (micro)
K. 1/1,000,000,000 (nano)

Problem 1-2. Dimensional Analysis

A. Given:
Energy E has SI dimension Joule = J = $kg \cdot m^2/s^2$
Mass m has SI dimension kg
Time t has SI dimension s.
Velocity v has SI dimension m/s
Speed of light c is a velocity
Show that Einstein's relation $E = mc^2$ has the correct dimensions by showing that both sides of the equation have the same basic units of length, mass, and time (m, kg, s).

B. Given:
Energy density with respect to mass ρ_m has SI dimension J/kg
Mass m has SI dimension kg
What is the SI dimension of the product $m \cdot \rho_m$?

C. Given:
Energy density with respect to volume ρ_V has SI dimension J/m^3
Volume V has SI dimension m^3
What is the SI dimension of the product $V \cdot \rho_V$?

D. Given:
Power W has SI dimension Watt = W = J/s = energy / time
What is the SI dimension of the term $(m \cdot \rho_m)/t$?

Problem 1-3. National Energy Need and Cost

Consider a country with a population of 25 million people. Suppose we need 200,000 MJ/person each year to support a satisfactory UN Human Development Index.

A. How much energy (in MJ) is needed each year by the country?
B. How much power (in MW) is required?
C. How many 1000 MW power plants are needed?
D. How much energy (in MJ) is needed each day?
E. Suppose the energy is obtained by consuming crude oil with an energy density of 37,000 MJ/m^3. How many barrels of crude oil are required each day?
F. If the price of oil is US$60/bbl, what is the cost of oil per kWh of energy used each day? Hint: first calculate the energy used each day in kWh/day and the cost of oil per day in US$/day before calculating the cost of oil per kWh.

Problem 1-4. Power Plant Demand for 400 Quads Annually
Use the following table to answer the questions below.

Typical Power Production Capacity	
Fossil Fuel	1000 MW per plant
Nuclear	1000 MW per reactor
Solar	10 MW per tower
Wind Turbine	4 MW (Denmark, Texas)
Wave	7.5 MW per km coastline*
*Includes power production efficiency estimate (25-50%)	

A. Express 400 Quads of energy per year as a power (in MW).
B. How many fossil fuel plants are needed to provide 400 Quads per year?
C. How many nuclear power plants are needed to provide 400 Quads per year?
D. How many solar towers are needed to provide 400 Quads per year?
E. How many wind turbines are needed to provide 400 Quads per year?
F. How many km of coastline are needed to provide 400 Quads per year using wave energy?

Problem 1-5. Energy Density by Combustion
The combustion of one barrel of oil with a mass of 125 kg provides 5625 MJ energy. What is the energy density of the barrel of oil in MJ/kg?

Problem 1-6. Power Plant Demand for 10 Billion People
Assume an average power plant provides 1000 MW. How many power plants will be needed to provide the energy needed each year for 10 billion people assuming the energy needed per person per year is 200,000 MJ?

Solutions to Problems

Solution 1-1. Scientific Notation

A. $1=10^0$
B. $1{,}000=10^3$
C. 1 million$=10^6$
D. 1 trillion$=10^{12}$
E. 1 billion$=10^9$
F. 1000 billion$=10^{12}$
G. 1 quadrillion$=10^{15}$
H. $1/100=10^{-2}$
I. $1/1000=10^{-3}$
J. 1/1,000,000 (micro) $=10^{-6}$
K. 1/1,000,000,000 (nano) $=10^{-9}$

Solution 1-2. Dimensional Analysis

A.
$E = J = kg \cdot m^2/s^2$
$mc^2 = kg \cdot (m/s) \cdot (m/s) = kg \cdot m^2/s^2$

B.
$m \cdot \rho_m = kg \cdot (J/kg) = J$

C.
$V \cdot \rho_V = m^3 \cdot (J/ m^3) = J$

D.
$(m \cdot \rho_m)/t = [kg \cdot (J/kg)] / s = J/s = W$

Solution 1-3. National Energy Need and Cost

A. Energy needed = 25×10^6 people (200,000 MJ/person/year) = 5×10^{12} MJ per year.

B. Power = (5×10^{12} MJ/year) $\times (1\ yr/3.1536 \times 10^7 s)$ = 1.59×10^5MW.

C. Number of power plants = (1.59×10^5 MW) / (1000 MW / plant) ≈159 plants.

D. Energy per day = (5×10^{12} MJ/year) × $(1\ yr/365\ days)$ = 1.37×10^{10} MJ/day.

E. Barrels of oil per day = $(1.37 \times 10^{10}$ MJ/day) × $(1m^3/37{,}000\ MJ)$ × $(1bbl/0.1589m^3)$ = 2.33×10^6 bbl/day.

F. Energy used each day = $(1.37 \times 10^{10}$ MJ/day) × $(1\ kW/3.6\ MJ)$ = 3.81×10^9 kWh/day.
Cost of oil per day = $(2.33 \times 10^6$ bbl/day) × (US\$60/bbl) = US\$$1.40 \times 10^8$/day.
Cost of oil per kWh = (US\$$1.40 \times 10^8$/day) / $(3.81 \times 10^9$ kWh/day) = US\$0.037/kWh.

Solution 1-4. Power Plant Demand for 400 Quads Annually
A. 400 Quads = 4.22×10^{14} MJ
Power = $(4.22 \times 10^{14}$ MJ per year)×(1 year / 3.1536×10^7 s) = 1.34×10^7 MW

B. Number of fossil fuel plants = 1.34×10^7 MW/1000 MW = 13,400

C. Number of nuclear power plants = 1.34×10^7 MW/1000 MW = 13,400

D. Number of solar towers = 1.34×10^7 MW/10 MW = 1.34 million

E. Number of wind turbines = 1.34×10^7 MW/4 MW = 3.4 million

F. Number of km of coastline = 1.34×10^7 MW/7.5 MW = 1.78 million

Solution 1-5. Energy Density by Combustion
Energy density = 5625 MJ/125 kg ≈ 45 MJ/kg

Solution 1-6. Power Plant Demand for 10 Billion People
200000 MJ/person/yr × $(10 \times 10^9$ people) = 2×10^{15} MJ/yr
Power in MW: $(2 \times 10^{15}$ MJ/yr) × (1 yr/ 3.1536×10^7 s) ≈ 6.34×10^7 MW
# of Power Plants needed: $(6.34 \times 10^7$ MW)/(1000 MW/plant) ≈ 63400 plants

LIST OF PROBLEMS