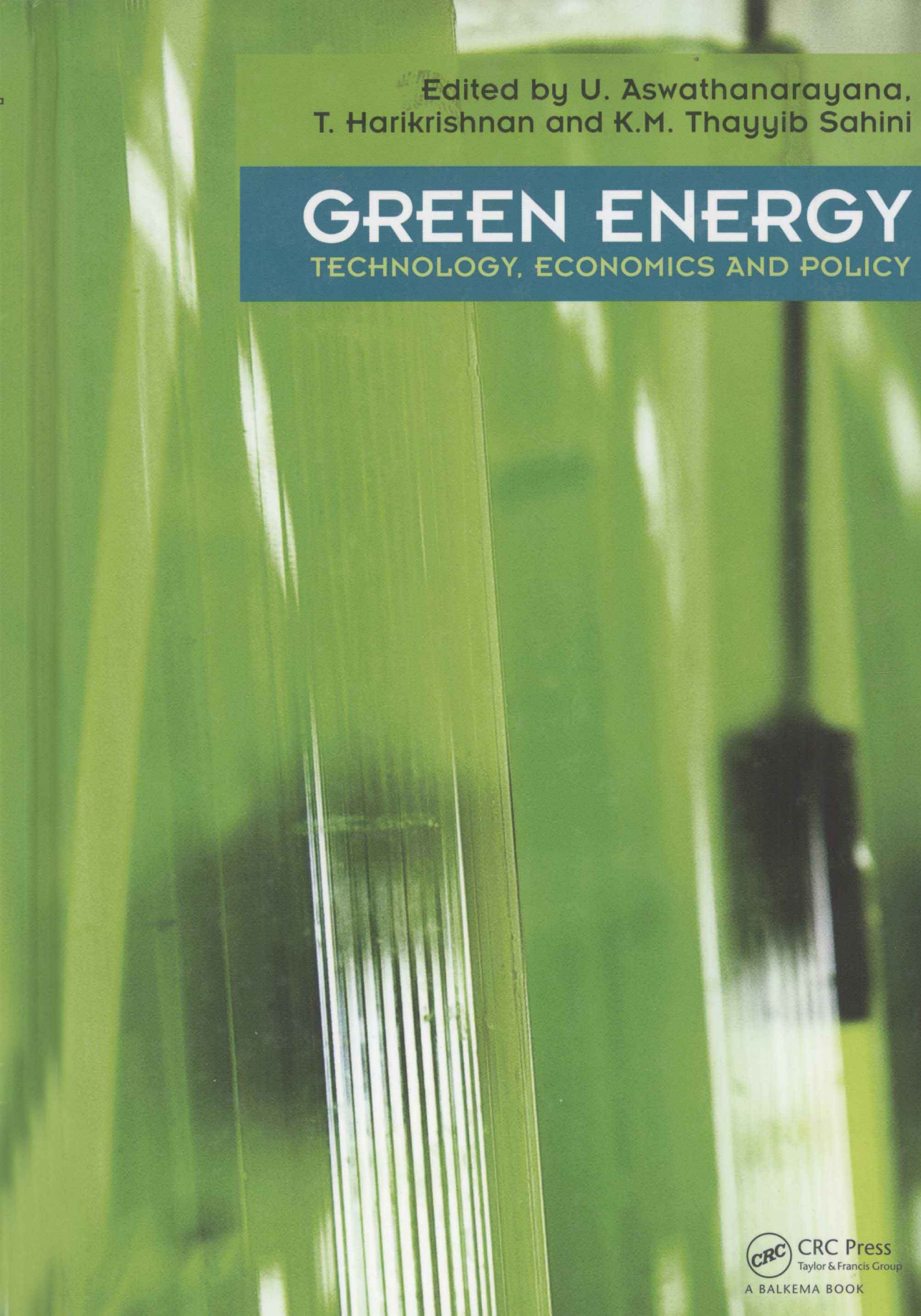
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T. Harikrishnan and K.M. Thayyib Sahini
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TECHNOLOGY, ECONOMICS AND POLICY
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A BALKEMA BOOK

Green Energy
Technology, Economics and Policy

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Dedicated to my Late Father, Sudarsanarao.

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Preface

Lehman Brothers, a US bank with assets of over USD 600 billion, was considered to be too large to fail. But fail it did, most spectacularly – it declared bankruptcy on Sept. 15, 2008. This shook the banking industry round the world to its roots. Many banks and companies collapsed. Unemployment rose to unprecedented levels. There was a steep drop in international trade and commodity prices. Only China and India got off lightly, because of their prudent lending practices. Governments round the world came up with stimulation packages to address this catastrophic situation. Most of such packages contained promotion of green energy technologies, as a way to create employment while at the same time mitigating the adverse consequences of climate change. It has been found that renewable energy technologies employ about five times more people than the conventional energy technologies. That said, the most important challenge facing the renewables is to bring down their costs.

The issue of renewable energy has become so important that an International Renewable Energy Agency (IRENA) came to be established in Germany. Countries and institutions need a roadmap to figure out ways and means of integrating technology, economics and policy to provide clean, reliable, secure and competitive energy supply. The book addresses the need. It explains how jobs could be generated and climate change mitigated through the harnessing of the transformative power of low-carbon technologies.

The volume has seven sections. Section 1 Introduction, deals with what the book is about and how it came to be written. Section 2 gives an account of the characteristics, costs and deployment of Renewable Energy Technologies (RETs). Sections 3 and 4 deal with ways of reducing the carbon dioxide emissions and environmental impact and improving the efficiency, of Supply-side energy technologies (based on fossil fuels and CCS, nuclear power and Next Generation Green Technologies), and Demand-side energy technologies (covering industry, buildings and appliances, transport and electricity systems), respectively. The technological and R&D, improvements and

economical and policy interventions needed to make the Renewable Energy Technologies (RETs) competitive in the market are covered in Section 5. Section 6 gives a vision of a Green New Deal integrating the technological, socioeconomic and policy strands. The final section 7 provides an overview and Integration.

I thank Dr. R.A. Mashelkar, President, Global Research Alliance, for his perceptive Foreword. Drs. Makarand Phadke of RIL and R. Dhanraj (formerly of AMD) kindly reviewed the manuscript, and made suggestions for improvement. The volume is meant for university students, professionals and administrators in the areas of resource engineering, energy industries, environmental science and engineering, climate change, economics, etc.

Hyderabad, India
June, 2010

U. Aswathanarayana

Foreword

Green Energy: Technology, Economics and Policy is a very timely book written by Prof. U. Aswathanarayana, a highly respected scientist with excellent record of scholarship connected with the issues of environment, ecology and socio-economics. His coauthors are Drs. Harikrishnan and Thayyib Sahini, highly accomplished professionals.

As regards green energy, there are books that deal with the individual aspects of technology or of economics or of policy, but the subtle interplay of these three is not something that has been addressed. The book fills this need admirably. The relationship between poverty reduction, protection of environment and energy security is also not at once obvious. This has been very elegantly covered in the book.

Getting into fundamentals, for our sustainable energy future, there is a common global objective that needs to be met and that is 'getting more from less for more'. And this has to be interpreted in different ways. Whereas enterprises aim at getting more (performance) at less (cost) for more (profit), they must also aim at getting more (performance) at less (cost) for more and more (people). Increasingly, affordability (more from less) and sustainability (for more and more people, both current generations and in the future) is becoming the key. In fact dealing with challenges as wide ranging as global economic meltdown to climate change, to national competitiveness, getting 'more from less for more' seems to be the only solution.

Take climate change, as an example. The answer is getting more (delivered performance) from less (carbon dioxide emissions and therefore less global warming) so that we can save the planet for more (generations to come).

This book deals both explicitly and implicitly on the technological and non-technological interventions in the form of policy, that can be made to increase the affordability and sustainability, which meet with the above objective of getting 'more from less for more'.

The book deals with the current status and the future prospects of renewable energy technology, traversing the whole range of design, development and delivery. Because

the world population is growing and poor countries are becoming richer, we require fundamental changes in the way we produce and use energy. We require changes in the way we manage forests, land use, and agriculture. Greater energy efficiency, management of energy demand, and diffusion of low-carbon electricity sources such as wind, hydro, and nuclear could produce half of the required emission cuts.

The solutions that can potentially lead to 'carbon neutrality' are currently expensive. To satisfy future global energy demand will require improving the performance of low-carbon technologies and developing breakthrough technologies through not 'incremental' but 'disruptive' innovations. Our current hope rests on potential success in carbon capture and storage, second-generation biofuels, and solar photovoltaics.

The fact that a particular source of energy exists does not mean that it automatically becomes techno-economically or a socially acceptable option. Thus in the case of wind energy, despite the advances in technology, the costs need to be still brought down. Protests are heard from conscious society so social acceptability remains a challenge.

The book provides an interesting analysis of the factors that will make green energy competitive. For instance, it is brought out that the role of technology is as important as innovative energy taxation policies. The book examines both supply side and demand side energy technologies. There is a very thoughtful discussion on nuclear power economics.

This book is a 'must read' for students (both in education and research) and professionals (both producers and managers of sustainable energy solutions) and policy planners (dealing with energy, environment and economics).

Provision of energy supply with the characteristics of cleanliness, reliability, security and competitiveness is a challenge facing the 21st century world. This book is a valuable resource, which guides us towards an analysis of critical factors that will help us in achieving this path. I offer my congratulations to the authors for this timely and valuable contribution.

Pune, India
June, 2010

R.A. Mashelkar
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Units, Abbreviations and Acronyms, Definitions, Conversion Constants

Units

bbl	barrel
bcm	billion cubic metres
boe	barrels of oil equivalent (1 BOE = 159 L)
GJ	gigajoule = 10^9 joules
Gt	gigatonnes = 10^9 tonnes
Gtpa	gigatonnes per annum
GW	gigawatt = 10^9 watts
GWh	gigawatt hour
kW	kilowatt = 10^3 watts
kW_{el}	kilowatt electric capacity
kWh	kilowatt hour
kW_{th}	kilowatt thermal capacity
lge	litre gasoline equivalent
mb	million barrels
mbd	million barrels per day
Mbtu	million British thermal units
Mha	million hectares
MJ	megajoule = 10^6 joules
Mpg	miles per gallon
Mt	megatonne = 10^6 tonnes
Mtce	million tonne of coal equivalent
Mtoe	million tonnes of oil equivalent
Mtpa	million tonnes per annum
MW	megawatt = 10^9 watts

MW_e	megawatt electrical
MWh	megawatt hour
PJ	petajoule = 10^{15} joules
EJ	Exajoule = 10^{18} joules
ZJ	Zettajoule = 10^{21} joules
toe	tonne of oil equivalent
TW	terawatt = 10^{12} watts
TWh	terawatt hour
Wp	watt-peak

Abbreviations and Acronyms

(source: IEA's *Energy Technology Perspectives*, 2008. p. 602–613)

AFC	Alkaline Fuel Cell
API	American Petroleum Institute
APU	Auxiliary Power Unit
ASU	Air Separation Unit
ATR	Auto Thermal Reforming
B2B	Business-to-Business
B2C	Business-to-Consumer
B2G	Business-to-Government
BEMS	Building Energy Management System
BFB	Bubbling Fluidised Bed
BIGCC	Biomass Integrated Gasification with Combined Cycle
BtL	Biomass to Liquids
CAES	Compressed Air Energy Storage System
CAT	Carbon Abatement Technologies
CBM	Coal-Bed Methane
CCS	CO_2 Capture and Storage
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CFB	Circulating Fluidised Beds
CFL	Compact Fluorescent Light-bulb
CHP	Combined Heat and Power
CIS	Copper-Indium-Diselenide
CIGS	Gallium-doped Copper – Indium–Diselenide
CNG	Compressed Natural Gas
CSP	Concentrating Solar Power
CTL	Coal To Liquids
DME	Dimethyl Ether
EGR	Enhanced Gas Recovery
EIA	Environment Impact Assessment
FBC	Fluidised Bed Combustion
FDI	Foreign Direct Investment
FGD	Flue Gas Desulphurisation
HTGR	High Temperature Gas Cooled Reactor

IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IET	International Emissions Trading
IGCC	Integrated Gasification Combined Cycle
IGFC	Integrated Gasification Fuel cell combined Cycle
ITER	International Thermonuclear Experimental Reactor
LED	Light Emitting Diode
LNG	Liquified Natural Gas
LPG	Liquid Petroleum Gases
NEA	Nuclear Energy Agency
NGL	Natural Gas Liquids
NSG	Nuclear Suppliers Group
O&M	Operating and Maintenance
OECD	Organisation for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
PFBC	Pressurised Fluidised Bed Combustion
PM-10	Particulate matter of less than ten microns in diameter
PPP	Purchasing Power Parity
P&T	Partitioning and Transmutation
PV	Photovoltaics
PWR	Pressurised water Reactor
RDD&D	Research, development, demonstration and deployment
RETs	Renewable Energy Technologies
SACS	Saline Aquifer CO_2 Storage
SCSC	Supercritical Steam Cycle
SMR	Small and Medium-sized Reactor
T&D	Transmission and Distribution
USCSC	Ultra Super Critical Steam Cycle
VHTR	Very High Temperature Reactor

Definitions

Source A: *Energy Technology Perspectives*, 2008, p. 601–605
Source B: *International Energy Markets*. 2004. Carol A. Dahl, Pennwell Corporation, p. 475–533.

Ad valorem tax: A tax that is a percentage of the price of a good or a service (B)
Amortization: Allocating the cost of intangible assets over their legal life as specified in the tax code (B).
API Gravity: Specific gravity measured in degrees on the American Petroleum Institute scale. The higher the number, the lower the density. Twentyfive degrees API equals 0.904 kg/m^3. Forty-two degrees API equals 0.815 kg/m^3. (A)
Avoided cost: The amount avoided for the incremental purchase or the production of a good (B).
Benefits of Pollution: Any costs that you forego by being able to pollute rather than to abate. Benefits of pollution are then equal to the costs of abatement. (B)

Biodiesel: Biodiesel is a diesel-equivalent, processed fuel made from the transesterification (a chemical process which removes the glycerine from the oil) of vegetable oils or animal fats. (A)

Biogas: A mixture of methane and carbon dioxide produced by bacterial degradation of organic matter and used as fuel. (A)

Blackouts: A non-isolated power loss over an extended period of time due to capacity shortage. It may result from peak loads higher than available capacity or from equipment failure (B).

Black liquor: A by-product from chemical pulping processes which consists of lignin residue combined with water and the chemicals used for the extraction of lignin. (A)

Breakeven Pricing: Charging a price for which revenues exactly equal all costs including opportunity costs. (B)

Brent Forward Market: The over-the-counter market for buying Brent Crude oil at some future date. (B)

Clean Coal Technologies (CCT): Technologies designed to enhance the efficiency and the environmental acceptability of coal extraction, separation and use. (A)

Clearinghouse: An institution that is a part of an organized exchange that guarantees each transaction and matches buyers to sellers when contracts come due. (B)

Coal: Lignite (with gross calorific value of less than 4165 kcal/kg), sub-bituminous coal (4165–5700 kcal/kg) and hard coal (greater than 5700 kcal/kg, on an ash-free but moist basis). Clean Coal Technologies (CCTs) are designed to enhance the efficiency and the environmental acceptability of coal extraction, preparation and use. Coal-bed methane is methane found in coal seams, and is a source of unconventional natural gas (A).

Coases Theorem on Externalities: In the absence of transaction costs and market power, that private markets will arrive at an optimal allocation in the presence of market externalities no matter how property rights are originally distributed. (B)

Condensates: Condensates are liquid hydrocarbon mixtures recovered from non-associated gas reservoirs. They are composed of C4 and higher carbon number hydrocarbons and normally have an API between 50° and 85°. (A)

Cross Price Elasticity: The percentage change in quantity of one good that results from the percentage change in price of another good. (B)

Data Mining: Techniques for extracting information from large databases. (B)

Deregulation: Removing government regulations. (B)

Discounted Cash Flow (DCF): The present value of future flows of income. (B)

Discount Rate: The interest rate for converting or discounting future cash values to present values. (B)

Electricity Generation: Total amount of electricity generated by power plants. It includes its own use, and transmission and distribution losses. (A)

Energy Futures: A standardized contract offered and guaranteed on an organized exchange to buy or sell an energy product in the future. (B)

Enhanced Coal-bed Methane Recovery (ECBM): A technology for the recovery of methane through CO_2 injection into uneconomic coal seams. (A)

Enhanced Gas Recovery (EGR): A speculative technology in which CO_2 is injected into a gas reservoir in order to increase the pressure in the reservoir, so that more gas can be extracted. (A)

Ethanol: Ethanol is an alcohol made by fermenting any biomass high in carbohydrates (such as, starches and sugars). Emerging technologies will allow ethanol to be produced from cellulose and hemicellulose fibres that make up the bulk of the most plants. (A)

Financial Derivatives: Financial assets that derive their value from an underlying asset upon which they are based. (B)

Gas: Gas includes natural gas (both associated and non-associated with petroleum deposits but excluding natural gas liquids) and gas-works gas. (A)

Gas-to-Liquids: Fischer-Tropsch technology is used to convert natural gas into synthetic gas (syngas) and then, through catalytic reforming or synthesis, into very clean conventional oil products, such as diesel. (A)

Hydrocracking: Refinery process that heats heavy oil products under pressure in the presence of hydrogen to remove sulphur and increase lighter product yields. (B)

Hydropower: Hydropower refers to the energy content of the electricity produced in hydropower plants, assuming 100% efficiency. It excludes output from pumped storage plants. (A)

Marginal Production Cost: The cost of the last unit of production. (B)

Marketable Permits: Permits to pollute that can be bought and sold in the market place (B).

Metcalfe's Law: A network's value increases as the square of the number of connections (B).

Multivariate Time Series: A statistical forecasting technique in which a variable is forecast by using historical values of itself and other related variables (B).

Natural Gas Liquids (NGLs): They are the liquid or liquefied hydrocarbons produced in the manufacture, purification and stabilization of natural gas. These are those portions of natural gas which are recovered as liquids in separators, field facilities, or gas-forming plants. NGLs include but not limited to ethane, propane, butane, pentane, natural gasoline and condensates. (A)

Negative Externalities: An externality is an effect from an economic activity that involves some one not directly involved in the economic activity. (B)

Nuclear: Nuclear refers to the primary heat-equivalent of the electricity produced by a nuclear plant with an average thermal efficiency of 33%. (A)

Oil: Oil includes crude oil, condensates, natural gas liquids, refinery feedstocks, and additives and other hydrocarbons (including emulsified oils, synthetic crude oil, mineral oils extracted from bituminous minerals such as oil shale, bituminous sand, and oils from coal liquefaction) and petroleum products (refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes and petroleum coke). (A)

Opportunity Cost: What you forego by undertaking an economic activity. (B)

Outage: A temporary loss of power from isolated electricity transmission, generation or distribution failure. (B)

Peak load pricing: Charging higher prices during peak hours than off-peak hours. (B)

Pollution tax: A payment of tax to the government for the right to pollute. (B)

Power Generation: refers to fuel use in electricity plants, heat plants, and combined heat and power (CHP) plants. Both main activity producer plants and small plants that produce fuel for their own use (autoproducers) are included. (A)

Price Elasticity of Demand: Percentage change in the quantity demanded of a good divided by the percentage change in its own price (B).

Public good: A good that no one is excluded from using. (B)

Purchasing Power Parity (PPP): The rate of currency conversion that equalizes the purchasing power of different currencies, by making allowances for the differences in price levels and spending patterns between different countries. (A)

Research, development and Demonstration (RD&D)

Renewables: includes biomass and waste, geothermal, solar PV, solar thermal, wind, tide, and wave energy for electricity and heat generation. (A).

Straight-line Depreciation: Using an annual depreciation charge for tax purposes equal to the value of the asset divided by its allowed depreciable life. (B)

Strike Price: The price at which a put or a call entitles you to sell or buy the underlying asset (B).

Total Final Consumption (TFC): It is the sum of the consumption by the different end-use sectors: industry (including manufacturing and mining), transport, other (including residential, commercial and public services, agriculture/forestry and fishing), non-energy use (including petrochemical feedstocks), and non-specified. (A)

Total Primary Energy Demand: Total Primary Energy Demand represents domestic demand only, including power generation, other energy sector, and total final consumption. It excludes international marine bunkers, except for world energy demand where it is included. (A)

Conversion Constants

Source: "*World Energy Outlook 2007*", International Energy Agency, Paris, 2007, p. 633–641.

General Conversion factors for Energy

To	TJ	Gcal	Mtoe	MBtu	GWh
From	Multiply by				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11 630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3.412	1

TJ = Tera Joules; Gcal = Gigacalories ; Mtoe = Million tonnes of oil equivalent
MBtu = Million British Thermal Units; GWh = Gigawatt hours
1 million tonnes of oil equivalent = 1.9814 million tonnes of coal
= 0.0209 million barrels of oil/day
= 1.2117 billion cubic metres of gas

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