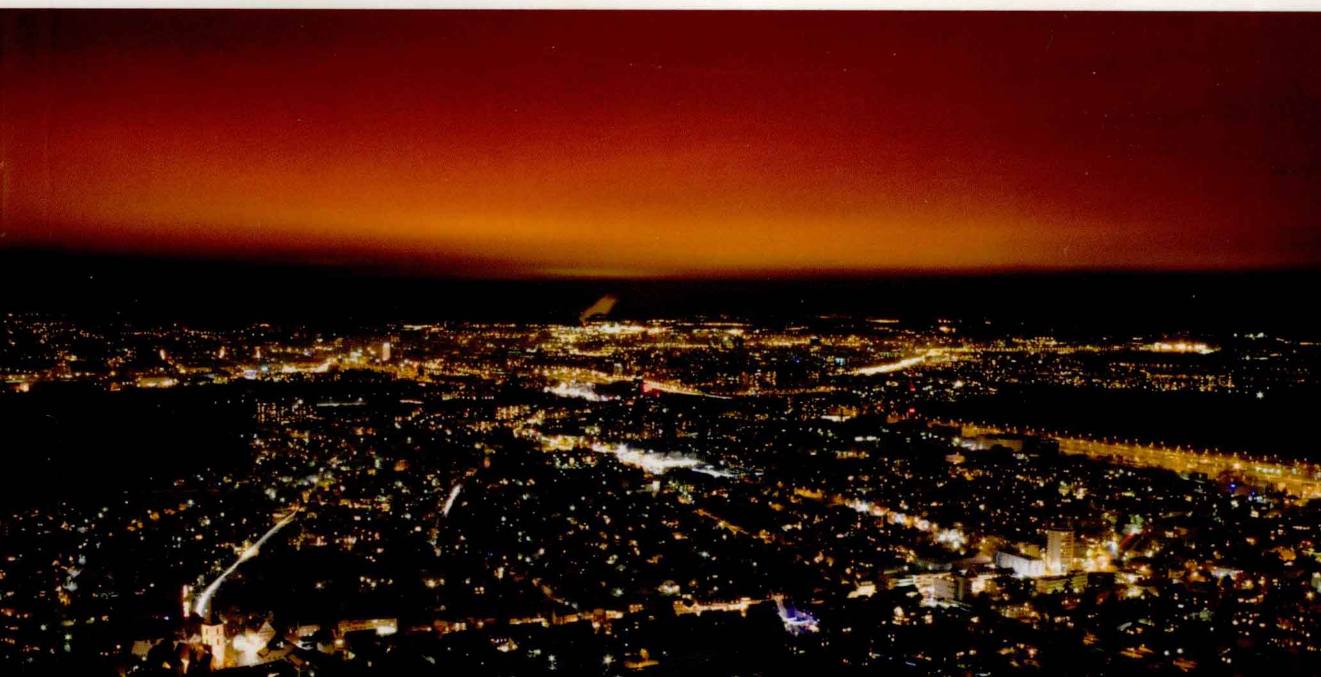
L. D. Danny Harvey

Energy and the New Reality 1

Energy Efficiency and the Demand for Energy Services



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earthscan
publishing for a sustainable future
London • Washington, DC

First published in 2010 by Earthscan
Reprinted 2011

Earthscan Ltd, Dunstan House, 14a St Cross Street, London EC1N 8XA, UK

Earthscan LLC, 1616 P Street, NW, Washington, DC 20036, USA

Earthscan publishes in association with the International Institute for Environment and Development

For more information on Earthscan publications, see www.earthscan.co.uk or write to earthinfo@earthscan.co.uk

ISBN: 978-1-84971-072-5

Typeset by Domex e-Data, India
Cover design by Susanne Harris

A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
Harvey, Leslie Daryl Danny, 1956-
Energy and the new reality / L. D. Danny Harvey.
v. cm.
Includes bibliographical references and index.
Contents: 1. Energy efficiency and the demand for energy services.
ISBN 978-1-84407-912-4 (hardback) -- ISBN 978-1-84971-072-5 (pbk.) 1. Energy conservation. 2. Energy consumption. 3. Climatic changes--Prevention. I. Title.

TJ163.3.H38 2010

333.79--dc22

2009032851

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This book was printed in the UK by the MPG Books Group

To all those dedicated to changing the world for the better

Preface

This book and the accompanying Volume 2 (*Carbon-Free Energy Supply*) are an attempt to objectively, comprehensively and quantitatively examine what it would take to limit the atmospheric carbon dioxide (CO_2) concentration to no more than 450 parts per million by volume (ppmv). By the time this book is published, the CO_2 concentration will have risen to 390ppmv from a pre-industrial concentration of about 280ppmv. With only 60ppmv to go, stabilization at no more than 450ppmv might seem like an impossible task, yet 450ppmv is already a dangerously high concentration. However, part of the CO_2 emitted by humans is quickly absorbed by the terrestrial biosphere and the oceans – the two 'sinks' of anthropogenic CO_2 – and the rest temporarily (for hundreds to thousands of years and longer) accumulates in the atmosphere. To stabilize the atmospheric CO_2 concentration requires reducing total sources only to the point where they equal the total rate of absorption by the sinks.

In 2005, industrial activities (primarily the combustion of fossil fuels) released about 8 billion tonnes (gigatonnes, Gt) of carbon (C) (in the form of CO_2) to the atmosphere, while land use changes (primarily deforestation) in recent years released another 1–2GtC. The total annual emission was therefore about 9–10GtC/yr, while the observed annual increase in the amount of CO_2 in the atmosphere amounted to 4–5GtC/yr. In the near term (two to three decades), stabilization requires reducing total emissions by 4–5GtC/yr, as this would bring emissions in line with sinks. If net deforestation and the associated 1–2GtC/yr emission can be eliminated, fossil fuel emissions would need to be reduced by 2–4GtC/yr, and by less if net deforestation can be turned into net reforestation. On a longer timescale, the sinks themselves would weaken, which would require further emission reductions. Indeed, given a modest positive feedback between climate and the carbon cycle, fossil fuel emissions would need to go to zero, but not until near the end of this century.

Stabilization at 450ppmv is still an enormous challenge. Until 2009, fossil fuel emissions had been growing rapidly, and if the global economy resumes growing, emissions can be expected to grow again as well. The stabilization task naturally divides itself into two parts. The first is to dramatically slow (and, in some regions, reverse) the growth in energy demand. The second is to dramatically increase the rate of deployment of C-free energy sources. The difference between total demand and C-free energy supply is what must be satisfied by fossil fuels, leading to emissions of CO_2 into the atmosphere.

Volume 1 examines the prospects for reducing the growth in, or reducing, energy demand. The generation of electricity from fossil fuels and all the major energy end use sectors (buildings, transportation, industry, agriculture, municipal services) are systematically examined. In each sector, an overview of recent trends and patterns of energy use is given, along with a description of the underlying physical processes involved in using energy, followed by a thorough discussion of the potential for reducing energy use through more efficient energy-using devices and systems. Practical issues, environmental impacts and benefits, and various other co-benefits are also discussed where these are potentially important considerations. However, the solutions to reducing future energy demand are not entirely technological. Behavioural and lifestyle factors are also important, as are the future human population and gross domestic product (GDP) per person. The penultimate chapter of Volume 1 synthesizes the findings of the preceding chapters through the construction of a number of different scenarios that incorporate close to the maximum potential efficiency improvements as determined here, combined with a variety of assumptions concerning population and economic growth. The final chapter of Volume 1 outlines the strategies and policies needed to slow population growth, to slow economic growth without destabilizing the world economy, and to achieve the dramatic improvements in the efficiency with which energy is used that are shown here to be possible.

Volume 2 examines the prospects for rapid deployment of C-free energy sources, with a systematic examination of physical principles, technical potential and cost of each of the major and some not-so-major C-free energy sources. The demand scenarios from Volume 1 are combined with scenarios of deployment of C-free energy (constrained by what are thought to be the limits of feasibility) to develop scenarios of fossil fuel CO_2 emissions. These in turn are used as an input to a coupled climate–carbon cycle model to determine the resulting CO_2 concentration and global mean temperature change.

Some of the ideas presented here and in Volume 2 will be considered to be radical by some readers, and others will be considered to be politically impossible. However, recent history has shown that what is politically 'impossible' one day can become accepted practice the next. I refrain here from making any judgements concerning what is politically feasible or not. I am interested only in showing what is technically feasible and at what estimated cost, and in comparing this with what is required to achieve the 450ppmv concentration target. The onus is on politicians and other leaders to respond with the urgency dictated by the situation that the world now faces. The well-being of future generations, and indeed of much of the life on this planet, depends on their ability to do so.

These two books are a comprehensive blueprint concerning what needs to be done to solve the global warming problem (that is, which will stabilize climate at a warming that will still preserve much that is valuable and beautiful in the world). Nothing less than a complete and rapid transformation of our energy system, and indeed, of our deep-seated ways of thinking is required. However, the political and (in some cases) business response so far has been to consider incremental changes – adjustments – to what is still fundamentally a business-as-usual (BAU) trajectory. There is still little evidence of a political acceptance of the nature and the magnitude of the changes needed. Global warming changes all the old rules about energy, economic growth and the jostling for perceived comparative advantage in international negotiations. There is a new 'reality', but it is a new reality that we by and large have not yet faced up to. It is high time that we did.

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March 2010

Online Supplemental Material

The following supplemental material can be accessed by visiting www.earthscan.co.uk/resources and selecting the link for this book:

- Powerpoint presentations for each chapter, containing figures, bullet points suitable for teaching purposes, selected tables and supplemental photographs;
- Excel-based problem sets for many chapters;
- Supplemental tables;
- Excel spreadsheets used to generate the demand scenarios presented here.

Acknowledgements

I would like to thank the people listed below for kindly reviewing parts of (or, in some cases, all) of the indicated chapters, in many cases also providing additional information that I would not otherwise have obtained. As well, numerous people responded to questions about their work and in so doing contributed greatly to the final product. I accept responsibility, however, for any errors, misconceptions or important omissions that may remain.

Chapter 2 Alfred Cavallo (Department of Homeland Security, New York)
Chapter 3 Jacob Klimstra (Wärtsilä Corporation, Finland)
Chapter 4 This chapter is a factor-of-eight condensation and update of parts of *A Handbook on Low-Energy Buildings and District Energy Systems*, which was extensively reviewed prior to its publication by Earthscan in 2006.
Chapter 5 Richard Gilbert (Transportation Consultant, Toronto)
Chapter 6
Sections 6.1–6.5, 6.7 (Metals, cement) Hendrik van Oss (US Geological Survey)
Section 6.3 (Iron and steel) Andreas Orth (Outokumpu Technology, Germany)
Section 6.4 (Aluminium) Ken Martchek (Alcoa Corporation)
Section 6.5 (Copper) Damien Giurco (University of Technology Sydney)
Section 6.6 (Stainless steel and titanium) Jeremiah Johnson (Yale University)
Section 6.7 (Cement) Ellis Gartner (Lafarge Cement, France)
Section 6.9 (Pulp and paper) Kenneth Möllersten (Swedish Energy Agency)
Chapter 7 Stefan Wirsenius (Chalmers University of Technology, Gothenburg, Sweden)
Chapter 10 Paul York (University of Toronto), Helmut Haberl (Institute of Social Ecology, Alpen Adria Universität, Vienna)
Chapter 11 Don Dewees (University of Toronto)

Chapter Highlights

Chapter 1 Prospective climatic change, impacts and constraints

Four independent lines of evidence (simulations with three-dimensional coupled atmosphere–ocean models, observations of temperature changes during the past century, inferences concerning temperature changes and driving factors during the geological past, and inferences concerning natural variations in atmospheric CO_2 concentration during the geological past) indicate that the long-term, global average temperature response to a sustained doubling of the atmospheric CO_2 concentration is very likely to be a warming of 1.5 Celsius degrees (°C) to 4.5°C. Under typical BAU emission scenarios, the concentration of greenhouse gases (GHGs) will rise to the equivalent of three to four times the pre-industrial CO_2 concentration by the end of this century and the climate will have warmed by 3–9°C on average. Likely impacts include an eventual sea level rise of at least 10 metres, reductions in food production in key food-producing regions, reductions in the availability of water in regions already subject to water stress, eventual extinction of the majority (up to 90 per cent) of species of life on this planet, and acidification of the oceans (with potentially catastrophic consequences for marine life). To stabilize the atmospheric CO_2 concentration at 450ppmv (which is the rough equivalent of a CO_2 doubling when the heating effect of other GHGs is taken into account) requires the near elimination of human emissions before the end of this century. Even at 450ppmv, significant ecosystems losses and negative impacts on humans cannot be avoided.

Future CO_2 emissions depend on the future human population, average gross domestic product (GDP) per person, the average energy intensity of the global economy (primary energy required per dollar of GDP) and the average carbon intensity of the global economy (kg of C emitted per gigajoule of primary energy use). The carbon intensity in turn depends on how rapidly C-free energy sources grow compared to the growth in total energy consumption. For middle population and GDP/person scenarios, stabilization of atmospheric CO_2 at a concentration of 450ppmv requires either that the rate of decrease in the global mean energy intensity increase from 1.1 per cent/year (the average over the period 1965–2005) to 3 per cent/year until 2050 with no increase in C-free power, or that annual average C-free power supply increase from 3.3TW in 2005 to 21TW in 2050 (almost 1.5 times total world primary power supply in 2005) with no increase in the rate of reduction in energy intensity, or some less stringent combination of the two.

Chapter 2 Energy basics, usage patterns and trends, and related greenhouse gas and pollutant emissions

A peaking in the global supply of oil by 2020 or sooner is a near certainty. Rates of discovery of new oil have been steadily declining over the last few decades, while the rate of decline in the supply of oil from individual utilized oilfields has occurred at progressively faster rates for oilfields peaking progressively later in time. Data for gas supply are much more uncertain than for oil, but it is likely that gas supply will peak soon after oil supply peaks. Until recently, supplies of coal were thought to be sufficient to last several hundred years. However, recent re-evaluations indicate that the supply of mineable coal is much less than previously thought, and it is possible that the global availability of coal could peak as early as 2050.

Chapter 3 Generation of electricity from fossil fuels

Technologies exist to dramatically improve the efficiency with which electricity is generated from fossil fuels. The global average efficiency in generating electricity from coal powerplants is about 34 per cent, that of new state-of-the-art plants is about 45 per cent, and both advanced pulverized coal powerplants and integrated gasification combined cycle (IGCC) powerplants are expected to achieve efficiencies of 48–52 per cent. State-of-the-art natural gas combined cycle powerplants have an efficiency of 60 per cent. With cogeneration (the co-production of electricity and useful heat), the effective efficiency of electricity generation can exceed 100 per cent. The key to high effective electrical efficiency in cogeneration is to make use of almost all of the waste heat that is produced.

Chapter 4 Energy use in buildings

Technologies already exist to reduce the energy use in new buildings by a factor of two to four compared to conventional practice for new buildings. This is true for buildings of all types and in all climate zones of the world. The keys to achieving such large reductions in energy use are: (1) to focus on a high-performance thermal envelope, (2) to maximize the use of passive solar energy for heating, ventilation and daylighting, (3) to install energy-efficient equipment and especially energy-efficient systems, (4) to ensure that all equipment and systems are properly commissioned and that building operators and occupants understand how they are to be used, and (5) to engender enlightened occupant behaviour. In order to design buildings with factors of two to four lower energy use, an integrated design process is required, in which the architects and various engineering specialists and contractors work together simultaneously in an iterative fashion before key design decisions are finalized. Attention to building form, orientation, thermal mass and glazing fraction is also critical. With regard to renovations of existing buildings, factors of two to four reductions for overall energy use, and up to a factor of ten reduction in heating energy use, have frequently been achieved. In many parts of the world, the cost of reductions in energy use of this magnitude is already justified at today's energy prices.

Chapter 5 Transportation energy use

Urban form (in particular, residential and employment density, and the intermixing of different land uses) and the kind of transportation infrastructure provided are the most important factors affecting future urban transportation energy use. Today there is almost a factor of 10 difference in per capita transportation energy use between major cities with the lowest and largest transportation energy use per capita.

Existing or foreseeable technologies could reduce the fuel requirements of gasoline automobiles and light trucks (sport utility vehicles (SUVs), vans, pickup trucks) by 50–60 per cent with no reduction in vehicle size or acceleration. With a modest reduction in vehicle size and acceleration (to that of the 1980s), a factor of three reduction in fuel consumption could be achieved. Due to the inherent high efficiency of electric drivetrains compared to gasoline or diesel drivetrains, plug-in hybrid electric vehicles (PHEVs) would reduce the onsite energy requirements per kilometre driven by about a factor of three to four when compared to otherwise comparable gasoline vehicles. The economic viability of PHEVs depends on significant reductions in the cost of batteries and verification that they will maintain adequate long-term performance, but the prospects look good. Use of hydrogen in fuel cells could reduce onsite energy requirements by up to a factor of two compared to advanced gasoline–electric hybrid vehicles (depending on the performance of the latter) and by a factor of four compared to current gasoline vehicles, but significant problems remain concerning the cost of fuel cells and onboard storage of hydrogen. The global supply of platinum (Pt) would probably be a significant constraint on the development of a global fleet of hydrogen fuel cell automobiles.

The foreseeable feasible reductions in the energy intensity (energy use per passenger kilometre or tonne kilometre) of other modes of transportation are as follows: transport of freight by trucks, 50 per cent; transport of freight by ship, 45 per cent; diesel freight trains with conversion to trains using hydrogen in fuel cells, 60 per cent; air travel, 25–30 per cent; urban buses, 25–50 per cent (through use of diesel–electric hybrids); interurban buses, 50 per cent.

Chapter 6 Industrial energy use

Compared to the current world average energy intensity, improved technology could reduce the primary energy requirements per unit of output by almost a factor of three for iron and steel, by almost a factor of two for aluminium and cement, by 25 per cent for zinc, and by 20 per cent for stainless steel. Technical improvements in the production of refined copper should roughly balance the tendency for increasing energy requirements as poorer grades of copper ore are exploited. However, much larger reductions in primary energy requirements for metals are possible through recycling combined with projected technical advances: a reduction in primary energy requirements by a factor of 7 for aluminium, a factor of 4.5 for regular steel, a factor of 2.5 for zinc, and a factor of 2 for copper and stainless steel (these savings pertain to uncontaminated materials and assume that the recycled fraction reaches 90 per cent for steel, aluminium and copper, and 80 per cent for zinc and stainless steel). Yet larger reductions in primary energy requirements would occur in combination with ongoing improvements in the efficiency with which electricity is generated. Increasing the recycled fraction of new glass from 25 per cent to 60 per cent reduces on-site energy requirements by about 10–15 per cent compared to production of glass from virgin materials. If the world population and material stock stabilizes by the end of this century, then the production of metals would be used almost exclusively for replacement of existing materials and so could be largely based on recycling, with attendant energy savings. The pulp and paper industry can become energy self-sufficient or a net energy exporter through the efficient utilization of all biomass residues. The potential energy savings in the plastics industry is unclear, but is probably at least 25 per cent through improved processes and at least 50 per cent through recycling of plastics. Potential energy reductions in the chemical industries appear to be very large but cannot be specifically identified at present. Better integration of process heat flows through pinch analysis and better organization of motor systems can save large amounts of energy in a wide variety of different industries.

Chapter 7 Agricultural and food system energy use

Energy in the food system is used for the production of food, for transportation, processing, packaging, refrigerated storage and cooking. Energy use for the production of food consists of direct on-farm energy use and the energy used to produce fertilizers, pesticides and machinery used in farm operations. Fertilizers and pesticides are energy-intensive products. Fertilizer energy use can be reduced through substitution of organic fertilizers for chemical fertilizers, more efficient use of chemical fertilizers (30–50 per cent savings potential in the case of nitrogen (N) fertilizer), and more efficient production of chemical fertilizers (40 per cent savings potential in the case of N fertilizer). Pesticides are particularly energy intensive, but many jurisdictions have targets of reducing pesticide use in agriculture by 50 per cent or so through integrated pest management techniques. Organic farming systems reduce energy use per unit of farm output by 15 per cent to 70 per cent, but can also reduce yields by up to 20 per cent. However, rebreeding of crop varieties to maximize growth under organic farming systems could result in no yield reduction compared to current varieties with conventional methods. The biggest potential for energy savings in the food system is with a shift toward diets with lower meat content. Low-meat diets (and especially vegetarian and vegan diets) reduce direct and indirect fossil fuel energy inputs, and free up land that can be used to produce bioenergy crops.

Chapter 8 Municipal services

Energy is used in the supply of municipal water through pumping and water treatment. Per household, this energy use is comparable to that of major individual household appliances. It can be reduced through measures to use water more efficiently (up to 50 per cent savings potential), through the reduction of leakage in water distribution systems (up to 30 per cent of input water is lost), and through optimization of distribution system pressures and flow rates (10–20 per cent savings potential). The biggest opportunity to reduce net energy requirements at sewage treatment plants is through the recovery and use of methane from anaerobic digestion of sludge. Installation of systems (toilet, plumbing, storage tanks) to separately collect minimally diluted urine in new housing developments would facilitate energy-efficient recycling of nutrients from human wastes, something that will eventually be necessary. With regard to solid wastes, recycling of metals, plastics, paper and paper products is preferred to other management options. Dedicated anaerobic digestion with recovery and use of methane is the preferred option for organic wastes. Incineration with energy recovery is not particularly efficient but is preferred to landfilling for wastes that cannot be recycled further.

The energy requirements of new recreation facilities such as indoor skating arenas, swimming pools and gymnasia can generally be reduced by at least 50 per cent compared to current typical practice for new facilities.

Chapter 9 Community-integrated energy systems

Community-integrated energy systems involve district heating and/or district cooling systems consisting of underground networks of pipes to distribute hot or cold water, respectively, from centralized sources. Waste heat from electricity production can be provided to district heating networks as part of cogeneration, or heat can be captured from low-temperature heat sources (such as sewage water) and upgraded to a higher temperature with heat pumps. Cogeneration at the community scale can displace more centrally generated electricity and yield greater overall energy savings than cogeneration at the building scale (25–45 per cent instead of 10–25 savings, depending on the efficiency of central electricity generation). Centralized production of chilled water with electric chillers can save 30 per cent compared to cooling with separate chillers in each building. Due to economies of scale and reduced backup requirements, the investment cost of district cooling systems can be no greater than having separate chillers in each building. Use of cogeneration greatly reduces the impact of higher natural gas prices on the cost of electricity. Trigeneration (the production of cold water using steam from power generation to drive an absorption chiller) does not save energy compared to operating a powerplant to maximize electricity production and using the extra electricity so produced in highly efficient electric chillers.

Chapter 10 Energy demand scenarios

Scenarios of energy use as fuels and as electricity to the year 2100 are constructed for ten different world regions, taking into account differences in per capita income, floor area and travel today, and are then summed to give a scenario of global demand for fuels and electricity. A low population scenario (global population peaking at 7.6 billion around 2035) combined with modest growth in GDP per capita is considered along with a high population scenario (global population reaching 10.3 billion by 2100) and high growth in GDP per capita. Slow (by 2050) and fast (by 2020) implementation of stricter standards for new and renovated buildings are considered along with the assumption that all existing buildings are either replaced or undergo a major renovation between 2005 and 2050 and that all buildings existing in 2050 undergo a major renovation between 2050 and 2095. Relatively slow and fast rates of improvement in automobile and industrial efficiencies to the potentials identified here are considered, but replacement of existing fossil fuel powerplants with the current state-of-the-art is not assumed to be completed before 2050.

For the low population and GDP scenario, global fuel demand peaks at 20 per cent and 35 per cent above the 2005 demand for fast and slow implementation of energy efficiency measures, respectively, before dropping to about half the 2005 demand by 2100, while global electricity demand rises to and stabilizes at about 70 per cent above the 2005 demand. For the high population and GDP scenario, global fuel demand peaks at 30 per cent and 60 per cent above the 2005 demand for fast and slow rates of efficiency improvement, respectively, then returns to about the 2005 level, while global electricity demand rises to 2.6 times the 2005 demand. When additional structural shifts in the economy (50 per cent of baseline value-added for industry and freight transport shifted to commercial services by 2100), the resulting annual average compounded rate of decrease in the primary energy intensity of the global economy is 2.7 per cent a year between 2005 and 2050 and 1.8 per cent a year between 2005 and 2100.

Chapter 11 Policies to reduce the demand for energy

This chapter outlines strategies for non-coercively promoting lower fertility rates, and gives examples of recent rapid reductions in fertility rates in several countries. Strategies for promoting slower economic growth while simultaneously improving human well-being are discussed. Foremost among these are the channelling of increasing labour productivity into shorter working weeks and greater investment in public transportation systems, affordable housing and other public services. Policies for promoting much greater energy efficiency in all sectors of the economy and for promoting diets low in meat and with less embodied energy are outlined. Important areas where additional research and development are needed are identified. Strategies for reducing or reversing the rebound effect (the tendency for the energy cost savings due to more efficient use of energy in specific applications to result in greater energy use in other areas) are also outlined. Some final reflections on the present overarching policy goal of promoting economic growth and of the urgent need to figure out how to build stable economies that don't depend on continuous growth are offered.

List of Abbreviations

°C	degrees Celsius
μm	micron
AC	alternating current
ACH	air changes per hour
Adt	air-dried tonne
AFC	alkaline fuel cell
AIC	advanced insulation component
AIP	advanced insulation panel
AOGCM	atmosphere–ocean general circulation model
APU	auxiliary power unit
ASHP	air-source heat pump
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASK	available seat-kilometre
BaP	benzo-a-pyrene
BAU	business-as-usual
BEV	battery-electric vehicle
BFG	blast furnace gas
BIGCC	biomass integrated gasification combined cycle
BLGCC	black liquor gasification combined cycle
BOF	basic oxygen furnace
BWS	balanced wind stack
C	carbon
$CaCO_3$	calcium carbonate
CAFE	corporate automobile fuel economy
CAV	constant air volume
CBIP	Commercial Building Incentive Program
CC	chilled ceiling
CCFL	cold cathode fluorescent lamp
CCS	carbon capture and storage
CEE	Consortium for Energy Efficiency
CFC	chlorofluorocarbon
CFL	compact fluorescent lamp
cgs	centimetres, grams, seconds
CH_4	methane
CHP	combined heat and power
CI	compression ignition
CMH	ceramic metal halide
CO	carbon monoxide
CO_2	carbon dioxide
COG	coke oven gas
COP	coefficient of performance
CRF	cost recovery factor
CRT	cathode ray tube
CSA	calcium sulphoaluminate

CV	conventional vehicle
CVT	continuously variable transmission
dB	decibel
DC	direct current
DCV	demand-controlled ventilation
DECC	diesel engine combined cycle
DHW	domestic hot water
DME	dimethyl ether
DMFC	direct methanol fuel cell
DOAS	dedicated outdoor air supply
DSF	double-skin façade
DSM	demand-side management
DV	displacement ventilation
DVR	digital video recorder
EAF	electric arc furnace
EAHP	exhaust-air heat pump
ECF	elemental chlorine free
ED	electrodialysis
EER	energy efficiency ratio
EF	energy factor
EI	energy intensity
EIFS	external insulation and finishing system
EJ	exajoules
EMC	energetically modified cement
EOR	enhanced oil recovery
EPBD	Energy Performance of Buildings Directive
EPRI	Electric Power Research Institute
EROEI	energy return over energy invested
ESCO	energy service company
EU	European Union
EURIMA	European Mineral Wool Manufacturers Association
FACE	Free Air Concentration Enhancement
FBC	fluidized bed combustor
FCV	fuel cell vehicle
FGR	flue-gas recirculation
FO	forward osmosis
FOM	Farmers Own Market
FSU	former Soviet Union
GBS	granulated blast furnace slag
GDP	gross domestic product
Gg	gigagram
GHG	greenhouse gas
GIS	Greenland ice sheet
GJ	gigajoule
gm	gram
GRP	gross regional product
GSHP	ground-source heat pump
Gt	gigatonne
GTCC	gas turbine combined cycle

GW	gigawatt
GWP	global warming potential
H_2	hydrogen
HAT	humid air turbine
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HDD	heating degree day
HERS	Home Energy Rating System
HEV	hybrid electric vehicle
HFC	hydrofluorocarbon
Hg	mercury
HHV	higher heating value
HIR	halogen infrared-reflecting
HRSG	heat recovery steam generator
HRV	heat recovery ventilator
HSPF	heating season performance factor
HTS	high-temperature superconducting
Hz	Hertz
ICE	internal combustion engine
IDP	integrated design process
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
IRR	internal rate of return
IT	information technology
J	joule
K	kelvin
kHz	kilohertz
kg	kilogram
kph	kilometres per hour
kt	kilotonne
kW	kilowatt
kWh	kilowatt hour
LCD	liquid crystal display
LDV	light-duty vehicle
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LFG	landfill gas
LHV	lower heating value
LiBr	lithium bromide
lm	lumen
LNG	liquefied natural gas
m	metre
mb/d	million barrels per day
MBT	mechanical biological treatment
MCFC	molten carbonate fuel cell
MEB	multi-effect boiling
MEF	Modified Energy Factor

mg	milligram
MIT	Massachusetts Institute of Technology
MJ	megajoule
mks	metres, kilograms, seconds
mpg	miles per gallon
MSF	multi-stage flash
MSW	municipal solid waste
MTOW	maximum take-off weight
MV	mixing ventilation
N	nitrogen
NA-SI	naturally aspirated spark ignition
NGCC	natural gas combined cycle
NGSC	natural gas simple cycle
NH	northern hemisphere
NiMH	nickel-metal hydride
NIR	near-infrared
NO_x	nitrogen oxide
N_2O	nitrous oxide
NPV	net present value
NREL	National Renewable Energy Laboratory
NSPS	New Source Performance Standards
O_3	ozone
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OEW	operating empty weight
OLED	organic light emitting diode
OPEC	Organization of Petroleum Exporting Countries
P	phosphorus
PAFC	phosphoric acid fuel cell
PC	personal computer
PCB	polychlorinated biphenyl
PCM	phase-change material
PEM	proton exchange membrane
PEMFC	proton exchange membrane fuel cell
PET	polyethylene terephthalate
PFC	perfluorinated hydrocarbons
PHEV	plug-in hybrid electric vehicle
pkm	passenger-kilometre
PM	particulate matter
POU	point-of-use
ppbv	parts per billion by volume
PPE	polyphenylene ether
ppmv	parts per million by volume
Pt	platinum
PUF	polyurethane foam
PV	photovoltaic
PVC	polyvinyl chloride
RDF	refuse-derived fuel
RH	relative humidity