Global Energy Assessment

Toward a Sustainable Future

Council Co-Presidents: Ged Davis and José Goldemberg

Executive Committee Co-Chairs: Thomas B. Johansson and Anand Patwardhan

Director: Nebojsa Nakicenovic

Associate Director: Luis Gomez-Echeverri

Convening Lead Authors: Rangan Banerjee, Sally M. Benson, Daniel H. Bouille, Abeeku Brew-Hammond, Aleh Cherp, Suani T. Coelho, Lisa Emberson, Maria Josefina Figueroa, Arnulf Grubler, Mark Jaccard, Suzana Kahn Ribeiro, Stephen Karekezi, Kebin He, Eric D. Larson, Zheng Li, Susan McDade, Lynn K. Mytelka, Shonali Pachauri, Anand Patwardhan, Keywan Riahi, Johan Rockström, Hans-Holger Rogner, Joyashree Roy, Robert N. Schock, Ralph Sims, Kirk R. Smith, Wim C. Turkenburg, Diana Ürge-Vorsatz, Frank von Hippel, and Kurt Yeager

Review Editors: John F. Ahearne, Ogunlade Davidson, Jill Jäger, Eberhard Jochem, Ian Johnson, Rik Leemans, Sylvie Lemmet, Nora Lustig, Mohan Munasinghe, Peter McCabe, Granger Morgan, Jürgen Schmid, Jayant Sathaye, Leena Srivastava, Youba Sokona, John Weyant, and Ji Zou

Secretariat: Martin Offutt, Mathis L. Rogner, Hal Turton, and Pat Wagner

Global Energy Assessment (GEA)

Editors

Thomas B. Johansson
Co-Chair

Anand Patwardhan
Co-Chair

Nebojsa Nakicenovic
Director

Luis Gomez-Echeverri
Associate Director

International Institute for Applied Systems Analysis
Schlossplatz 1, A-2361 Laxenburg, Austria
www.iiasa.ac.at

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Mexico City

www.cambridge.org
www.globalenergyassessment.org

First published 2012

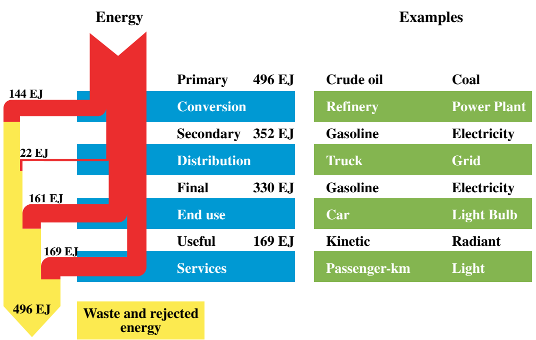
Printed in the United States of America

A catalog record for this book is available from the British Library.

ISBN 9781 10700 5198 hardback
ISBN 9780 52118 2935 paperback

GEA, 2012: *Global Energy Assessment – Toward a Sustainable Future*, Cambridge University Press, Cambridge UK and
New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria.

Cover photo:
Figure 1.2 | Global energy flows of primary to useful energy, including losses, in EJ for 2005. Source: adapted from Nakicenovic et al., 1998, based on IEA, 2007a; 2007b; 2010. Artwork by Anka James.



Global Energy Assessment (GEA) Council

Michael Ahearn, First Solar Inc., USA, 2009–2012

Dan Arvizu, National Renewable Energy Laboratory, USA, 2008–2012

Bert Bolin†, Stockholm University, Sweden, 2007

Tariq Banuri, formerly Division for Sustainable Development, United Nations Department of Economic and Social Affairs, 2011

Monique Barbut, Global Environment Facility, 2009–2012

Corrado Clini, Italian Ministry for the Environment and Territory, 2008–2012

Robert Corell, Global Environment and Technology Foundation, USA, 2007–2012

Ged Davis, GEA Council Co-President, 2007–2012

Bo Diczfalusy, formerly Swedish Ministry of Enterprise, Energy and Communications, 2008–2009

Gerald Doucet†, World Energy Council, 2007–2008

Fei Feng, Development Research Centre of the State Council of China, China, 2009–2012

Christoph Frei, World Energy Council, 2009–2012

Irene Giner-Reichl, Foreign Ministry of Austria, 2007–2012

Jose Goldemberg, GEA Council Co-President, 2007–2012

Leen Hordijk, formerly International Institute for Applied Systems Analysis, 2007–2008

Pavel Kabat, International Institute for Applied Systems Analysis, 2012

Tomas Kåberger, formerly Swedish Energy Agency, 2011–2012

Olav Kjørven, United Nations Development Programme, 2007–2012

Manfred Konukiewitz, German Federal Ministry for Economic Cooperation and Development, 2009–2012

Celso Fernando Lucchesi, Petrobras, Brazil, 2008–2012

Sten Nilsson, formerly International Institute for Applied Systems Analysis, 2008–2009

Kirit Parikh, formerly Indian Planning Commission and Integrated Research and Action for Development, 2008–2012

Thomas Rosswall, formerly International Council for Science, 2007

Jamal Saghir, World Bank, 2007–2012

John Schellnhuber, Potsdam Institute for Climate Impact Research, Germany and International Council for Science, 2007–2012

Nikhil Seth, Division for Sustainable Development, United Nations Department of Economic and Social Affairs, 2011–2012

Achim Steiner, United Nations Environment Programme, 2007–2012

Björn Stigson, formerly World Business Council for Sustainable Development, 2007–2012

Uno Svedin, formerly Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, 2007–2009

Claude Turmes, European Parliament, 2010–2012

Detlof von Winterfeldt, formerly International Institute for Applied Systems Analysis, 2009–2012

Robert Watson, Department for Environment Food and Rural Affairs and Tyndall Centre at the University of East Anglia, 2007–2012

Anders Wijkman, formerly European Parliament, 2010–2012

Timothy E. Wirth, United Nations Foundation, 2007–2012

Kandeh Yumkella, United Nations Industrial Development Organization, 2007–2012

Dadi Zhou, Energy Research Institute, China, 2007–2012

Sponsoring Organizations

Austrian Development Agency
Climateworks Foundation
Deutsche Gesellschaft für Internationale Zusammenarbeit
First Solar Inc.
Global Environment Facility
Global Environment and Technology Foundation
Italian Ministry for the Environment and Territory
International Institute for Applied Systems Analysis
Petrobras
Research Council of Norway
Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning/
Swedish Energy Agency
United Nations Development Programme
United Nations Environment Programme
United Nations Foundation
United Nations Industrial Development Organisation
United States Department of Energy
United States Environmental Protection Agency
World Bank/ESMAP
World Energy Council

Cambridge University Press
978-1-107-00519-8 - Global Energy Assessment (GEA)
Edited by Thomas B. Johansson, Anand Patwardhan, Nebojsa Nakicenovic and Luis Gomez-Echeverri
Frontmatter
More information

Contents

Cambridge University Press
978-1-107-00519-8 - Global Energy Assessment (GEA)
Edited by Thomas B. Johansson, Anand Patwardhan, Nebojsa Nakicenovic and Luis Gomez-Echeverri
Frontmatter
More information

Cambridge University Press
978-1-107-00519-8 - Global Energy Assessment (GEA)
Edited by Thomas B. Johansson, Anand Patwardhan, Nebojsa Nakicenovic and Luis Gomez-Echeverri
Frontmatter
More information

I Foreword and Preface

Foreword

Energy is central to addressing major challenges of the 21st Century, challenges like climate change, economic and social development, human well-being, sustainable development, and global security. In 2005, Prof. Bert Bolin, the founding Chair of the Intergovernmental Panel on Climate Change (IPCC), with other eminent scientists and policy-makers, identified that a comprehensive, science-based assessment of the global energy system was needed if these challenges were to be realistically addressed. The Global Energy Assessment (GEA) is the result of this shared vision.

Since the establishment of the GEA in 2006 by governing Council of the International Institute for Applied Systems Analysis (IIASA), 500 independent experts (about 300 authors and 200 anonymous reviewers) from academia, business, government, intergovernmental and non-governmental organizations from all the regions of the world have contributed to GEA in a process similar to that adopted by the IPCC.

The final GEA report examines: (a) the major global challenges and their linkages to energy; (b) the technologies and resources available for providing adequate, modern and affordable forms of energy; (c) the plausible structure of future energy systems most suited to addressing the century's challenges; and (d) the policies and measures, institutions and capacities needed to realize sustainable energy futures.

Undertaking such a massive assessment has required extraordinary leadership, intellectual input, support and coordination. Governance of the Assessment has been overseen by the GEA Council, led by two Co-Presidents, Ged Davis and José Goldemberg and comprising members of supporters and sponsors of the GEA, including international organizations, government agencies, corporations, and foundations and non-governmental organizations. Convening Lead Authors (CLAs) coordinated the 25 Chapters and the contributions of Lead and Contributing Authors. The GEA Executive Committee, led by two Co-Chairs, Thomas B. Johansson and Anand Patwardhan includes all CLAs. Review Editors were appointed by the GEA Council for each Chapter. They in turn appointed anonymous reviewers and guided the rigorous peer-review process.

Completion of GEA has involved dedication and sustained contributions from many colleagues around the world. Our thanks and gratitude go to: Leen Hordijk, the IIASA Director who initiated GEA at IIASA; Sten Nilsson, IIASA Acting Director and Deputy Director; and Detlof von Winterfeldt, the IIASA Director who provided personal and institutional support throughout. The resources and the encouragement they provided helped make GEA a reality. The GEA Organizing Committee and the GEA Council provided wise counsel and guidance throughout. Additionally the GEA Council solicited financial and in-kind resources without which GEA would not have been possible.

We are especially grateful for the contribution and support of the GEA Council, the Executive Committee, the Organizing Committee, the Secretariat, as well as the IIASA Council and management. As host organization for the GEA Secretariat, IIASA has provided substantial in-kind support to GEA over the past seven years.

The Co-Chairs Thomas B. Johansson and Anand Patwardhan of the GEA Executive Committee and the Associate Director, Luis Gomez-Echeverri, coordinated the work of multiple authors and provided intellectual leadership, the vision needed to conduct an assessment of this magnitude, and guidance consistent with the GEA Council resolutions.

It is a pleasure to acknowledge the contribution of the team of editors, Geoff Clarke, Esther Eidinow, Valerie Jones, Susan Guthridge-Gould, Karen Holmes, Gail Karlsson, Wendy Knerr, John Ormiston, Emily Schabacker, Misti Snow, Mark F. Speer, Jon Stacy, Linda Starke, Julia Stewart, Lloyd Timberlake, Michael Treadway, Thomas Woodhatch who patiently edited GEA manuscripts. Thanks to IIASA colleagues who worked with the GEA Secretariat – including Colin Adair, Brigitte Adamik, Marilyn Bernardo, Anita Brachtl, Claire Capate, Elisabeth Clemens, Katalin David, Susanne Deimbacher, Sanja Drinkovic, Linda Foith, Walter Foith, Amy Fox, Bill Godwin-Toby, Amnah Kasman, Martin Gugumuck, Margit Hegenbart, Anka James, Shari Jandl, Elizabeth Lewis, Monica Manchanda, Eri Nagai, Olivia Nilsson, Patrick Nussbaumer, Sheila Poor, Leane Regan, Susan Riley, Michaela Rossini, Iain Stewart, Ingrid Teply-Baubinder, Mirjana Tomic, and Alicia Versteegh.

Finally we express our sincere gratitude to the GEA authors, whose knowledge and experience has made possible this unique and valuable volume. Behind these people are families who have generously foregone time such that GEA could be completed, we thank them also.

The publication of GEA in June 2012 and the importance of energy at Rio+20 is no coincidence. The UN General Assembly declared 2012 the year of "Sustainable Energy for All" and the UN Secretary General's office initiated a campaign for an Action Agenda to meet the world's energy challenges. The GEA shows that an energy transformation toward a sustainable future is possible with strong political commitment. It is our belief that this assessment will provide policy- and decision-makers around the world, with invaluable new knowledge to inform action and commitment towards achieving these goals and thereby resolving the 21st Century's greatest challenges.

Pavel Kabat
IIASA Director/CEO

Nebojsa Nakicenovic
GEA Director

Preface

Today the world of energy has many of the features established in the 20th century:

- Energy consumption grows on average at 2% per year, most of it (80%) originates in fossil fuels
- Energy growth is driven by population growth and economic growth, now predominantly in developing countries and high levels of consumption in the developed countries
- 3 billion people don't have access to basic energy services and have to cook with solid fuels

However, the present path of uninterrupted reliance on fossil fuels poses four challenges to sustainability:

- Soaring greenhouse gas emissions
- Decreasing energy security
- Air pollution at the local and regional levels with resulting health problems
- Lack of universal access to energy services

Most reviews of the energy system needed for the 21st century start with "business as usual" futures and then analyze the effectiveness of specific corrections of course. For many the preferred options are technological fixes such as such as carbon capture and storage (CCS), nuclear energy and even geo-engineering schemes. However, to achieve sustainable development all the needed attributes of energy services, that is availability, affordability, access, security, health, climate and environmental protection, must be met concurrently. The Global Energy Assessment (GEA) accepts this and is unashamedly normative, examining future energy pathways that point to new solutions. The aspirational goals in GEA are defined as:

- Stabilizing global climate change to 2°C above pre-industrial levels to be achieved in the 21st century
- Enhanced energy security by diversification and resilience of energy supply (particularly the dependence on imported oil),
- Eliminating household and ambient air pollution, and
- Universal access to modern energy services by 2030.

GEA's approach is the one adopted by policy planners and governments, that is to take a holistic view of the problems they faced, of which energy supply is only one of them. In such an approach externalities play a big role in determining choice among options. This is what governments do all the time, and is exemplified by the current debates on the future of nuclear energy, shale gas, the building of big dams or a large expansion of biofuels production. None of the preferred options can be established without an understanding of the wider policy agenda. For example, integrated urban planning leads to lower costs than a combination of non-integrated policies in building efficiency, compact layout and decentralized energy production.

The main purpose of GEA has been to establish a state-of-the-art assessment of the science of energy. This work examines not only the major challenges that all face in the 21st Century, and the importance of energy to each, but also the resources that we have available and the various technological options, the integrated nature of the energy system and the various enablers needed, such as policies and capacity development. Central to the integrated analysis of the energy system has been a novel scenario exercise exploring some 40 pathways that satisfy simultaneously the normative social and environmental goals outlined above.

Without question a radical transformation of the present energy system will be required over the coming decades. Common to all pathways will be very strong efforts in energy efficiency improvement for buildings, industry and transportation, offering much-needed flexibility to the energy supply system. But in implementing efficiency options there will be a need to avoid continued lock-in to inefficient energy demand patterns and obsolescent technologies. we will see an increased share of renewables (biomass, hydro, wind, solar and geothermal), which could represent by 2050 over a half of the global energy supply. The foundation is being put in place. For example, half the world's new electric generating capacity added during 2008–10 was renewable, the majority in developing countries. Global 2010 renewable capacity, with additions of ~66 GW, is larger than nuclear power's global installed capacity. In the European Union electric capacity additions have been over 40% renewables in each year between 2006 and 2010, and in Denmark 30% of the electricity produced in 2010 was renewable. Even though China is still building coal plants, its 2010 net capacity additions were 38% renewables.

This will come at a cost, increasing the 2% of global GDP investment currently spent in the energy sector, especially in the next 20 years. However, this should not constrain the drive for universal access, which could be achieved by 2030 for as little as $40 billion per year, less than 3% of overall yearly investment. This would build on successful programs for energy access in a number of developing countries, such as Brazil, Mexico and South Africa. And results have been dramatic. In Brazil, during the ten years prior to September 2011 14 million people were connected to the electricity grid, at a cost of some 10 billion dollars.

Although the required transformation of the energy system is substantial, it is not without precedent. Last century between the 1920's and the 1970's oil replaced coal as the dominant energy source despite the immense available coal reserves. This occurred due to oil, as a liquid, being superior to coal in many respects, particularly for transportation. Similarly energy efficiency and renewables can be an easier way to solve energy security than producing fossil energy at higher costs that usually exacerbate environmental problems.

There are many combinations of energy resources, end-use, and supply technologies that can simultaneously address the multiple sustainability challenges. There will be an increased role of electricity and gases as energy carriers, co-utilization of biomass with fossil fuels in integrated systems, co-production of energy carriers, electricity, and chemicals, and, CCS.

All GEA energy pathways to a more sustainable future represent transformative change from today's energy systems. Large, early, and sustained investments are needed to finance this change, and can be in part achieved through new and innovative polices and institutional mechanisms that should reduce risks and increase the attractiveness of early, upfront investments, that have associated low long-term costs.

The GEA pathways that meet the sustainability goals generate substantial benefits across multiple economic and social objectives. This synergy is advantageous and important, given that measures which lead to local and national benefits, e.g. improved local and immediate health and environment conditions, support the local economy, may be more easily adopted than those measures that are put forward primarily on the grounds of goals that are global and long-term in nature, such as climate mitigation. An approach that emphasizes the local benefits of improved end-use efficiency and increased use of renewable energy would also help address global concerns.

Policies and incentive structures that promote R&D should be key areas for intervention. Rationalizing and reallocating subsidies, including subsidies to fossil fuels and nuclear energy can create new opportunities for investment. A major acceleration of publicly financed R&D and its reorientation towards energy efficiency and renewable energy technologies is required. And to bring new technologies to market an integrated approach towards energy for sustainable development is needed; with policies in sectors such as industry, buildings, urbanization, transport, health, environment, climate, security, and others made mutually supportive.

The transition from coal to oil occurred without significant government regulations although subsidies played a role. However the transformation GEA envisages this century is more fundamental in character, and government policies are a key ingredient needed particularly in changing buildings codes, fuel efficiency standards for transportation and mandates for the introduction of renewables. A new found appreciation by policy-makers of the multiple benefits of sustainability options and their appropriate valuation will be critical for the transformation to occur.

The Global Energy Assessment's report establishes a benchmark for current understanding of the options for building a sustainable future for the energy system. But the Assessment consists more than just a report. Analytical tools have been developed to help translate the Assessment into actionable findings. Tools for decision making, that include global and regional scenarios, can be used to develop policy choices to address country-specific problems.

An important contribution to knowledge is the massive data base that is at the disposal of research and scientific community for their own use, and eventually analysis will be made available to the public at large.

Outreach has already started with the presentation of the early findings of GEA at the Vienna Energy Forum in June 2011. Importantly at that forum a Ministerial declaration, supported by the UNIDO leadership, endorsed the solutions offered by GEA, particularly:

- Ensure universal access to moderns forms of energy for all by 2030

- Reduce global energy intensity by 40% by 2030

- Increase the share of renewables 30% by 2030

These three objectives are reflected in the Action Agenda of the UN Secretary General's High-Level Group on "Sustainable Energy for All".

The aim going forward is to ensure the widest dissemination of GEA's work that is possible, including both national and regional policy dialogues.

This opportunity to layout a new approach to the design and implementation of sustainable energy pathways would not be possible without the extraordinary effort of the 500 or so contributors, be they authors from various disciplines and walks of life, reviewers, editors or members of the secretariat, executive team and council. We thank you all.

Ged Davis and José Goldemberg
GEA Co-Presidents

Key Findings

The Global Energy Challenge

Since before the Industrial Revolution, societies have relied on increasing supplies of energy to meet their need for goods and services. Major changes in current trends are required if future energy systems are to be affordable, safe, secure, and environmentally sound. There is an urgent need for a sustained and comprehensive strategy to help resolve the following challenges:

- *providing affordable energy services for the well-being of the 7 billion people today and the 9 billion people projected by 2050;*
- *improving living conditions and enhancing economic opportunities, particularly for the 3 billion people who cook with solid fuels today and the 1.4 billion people without access to electricity;*
- *increasing energy security for all nations, regions, and communities;*
- *reducing global energy systems greenhouse gas emissions to limit global warming to less than 2°C above pre-industrial levels;*
- *reducing indoor and outdoor air pollution from fuel combustion and its impacts on human health; and*
- *reducing the adverse effects and ancillary risks associated with some energy systems and to increase prosperity.*

Major transformations in energy systems are required to meet these challenges and to increase prosperity.

The Global Energy Assessment (GEA) assessed a broad range of resources, technologies and policy options and identified a number of 'pathways' through which energy systems could be transformed to simultaneously address all of the above challenges

These are the Key Findings:

1. Energy Systems can be Transformed to Support a Sustainable Future: the GEA analysis demonstrates that a sustainable future requires a transformation from today's energy systems to those with: *(i)* radical improvements in energy efficiency, especially in end use, and *(ii)* greater shares of renewable energies and advanced energy systems with carbon capture and storage (CCS) for both fossil fuels and biomass. The analysis ascertained that there are many ways to transform energy systems and many energy portfolio options. Large, early, and sustained investments, combined with supporting policies, are needed to implement and finance change. Many of the investment resources can be found through forward-thinking domestic and local policies and institutional mechanisms that can also support their effective delivery. Some investments are already being made in these options, and should be strengthened and widely applied through new and innovative mechanisms to create a major energy system transformation by 2050.

2. An Effective Transformation Requires Immediate Action: Long infrastructure lifetimes mean that it takes decades to change energy systems; so immediate action is needed to avoid lock-in of invested capital into existing energy systems and associated infrastructure that is not compatible with sustainability goals. For example, by 2050 almost three-quarters of the world population is projected to live in cities. The provision of services and livelihood opportunities to growing urban populations in the years to come presents a major opportunity for transforming energy systems and avoiding lock-in to energy supply and demand patterns that are counterproductive to sustainability goals.

3. Energy Efficiency is an Immediate and Effective Option: Efficiency improvement is proving to be the most cost-effective, near-term option with multiple benefits, such as reducing adverse environmental and health impacts, alleviating poverty, enhancing energy security and flexibility in selecting energy supply options, and creating employment and economic opportunities. Research shows that required improvements in energy efficiency particularly in end-use can be achieved quickly. For example:

- retrofitting buildings can reduce heating and cooling energy requirements by 50–90%;
- new buildings can be designed and built to very high energy performance levels, often using close to zero energy for heating and cooling;
- electrically-powered transportation reduces final energy use by more than a factor of three, as compared to gasoline-powered vehicles;
- a greater integration between spatial planning and travel that emphasizes shorter destinations and enhances opportunities for flexible and diverse choices of travel consolidating a system of collective, motorized, and non-motorized travel options offer major opportunities;
- through a combination of increased energy efficiency and increased use of renewable energy in the industry supply mix, it is possible to produce the increased industrial output needed in 2030 (95% increase over 2005) while maintaining the 2005 level of GHG emissions.

A portfolio of strong, carefully targeted policies is needed to promote energy efficient technologies and address, *inter alia*, direct and indirect costs, benefits, and any rebound effects.

4. Renewable Energies are Abundant, Widely Available, and Increasingly Cost-effective: The share of renewable energy in global primary energy could increase from the current 17% to between 30% to 75%, and in some regions exceed 90%, by 2050. If carefully developed, renewable energies can provide many benefits, including job creation, increased energy security, improved human health, environmental protection, and mitigation of climate change. The major challenges, both technological and economic, are:

- reducing costs through learning and scale-up;
- creating a flexible investment environment that provides the basis for scale-up and diffusion;
- integrating renewable energies into the energy system;
- enhancing research and development to ensure technological advances; and
- assuring the sustainability of the proposed renewable technologies.

While there remain sound economic and technical reasons for more centralized energy supplies, renewable energy technologies are also well-suited for off-grid, distributed energy supplies.

5. Major Changes in Fossil Energy Systems are Essential and Feasible: Transformation toward decarbonized and clean energy systems requires fundamental changes in fossil fuel use, which dominates the current energy landscape. This is feasible with known technologies.

- CO_2 capture and storage (CCS), which is beginning to be used, is key. Expanding CCS will require reducing its costs, supporting scale-up, assuring carbon storage integrity and environmental compatibility, and securing approval of storage sites.

- Growing roles for natural gas, the least carbon-intensive and cleanest fossil fuel, are feasible, including for shale gas, if related environmental issues are properly addressed.

- Co-processing of biomass and coal or natural gas with CCS, using known technologies, is important for co-producing electricity and low-carbon liquid fuels for transportation and for clean cooking. Adding CCS to such coproduction plants is less costly than for plants that make only electricity.

Strong policies, including effective pricing of greenhouse gas emissions, will be needed to fundamentally change the fossil energy system.

6. Universal Access to Modern Energy Carriers and Cleaner Cooking by 2030 is Possible: Universal access to electricity and cleaner cooking fuels and stoves can be achieved by 2030; however, this will require innovative institutions, national and local enabling mechanisms, and targeted policies, including appropriate subsidies and financing. The necessary technologies are available, but resources need to be directed to meet these goals. Universal access is necessary to alleviate poverty, enhance economic prosperity, promote social development, and improve human health and well-being. Enhancing access among poor people, especially poor women, is thus important for increasing their standard of living. Universal access to clean cooking technologies will substantially improve health, prevent millions of premature deaths, and lower household and ambient air pollution levels, as well as the emissions of climate-altering substances.

7. An Integrated Energy System Strategy is Essential: An integrated approach to energy system design for sustainable development is needed – one in which energy policies are coordinated with policies in sectors such as industry, buildings, urbanization, transport, food, health, environment, climate, security, and others, to make them mutually supportive. The use of appropriate policy instruments and institutions can help foster a rapid diffusion and scale-up of advanced technologies in all sectors to simultaneously meet the multiple societal challenges related to energy. The single most important area of action is efficiency improvement in all sectors. This enhances supply side flexibility, allowing the GEA challenges to be met without the need for technologies such as CCS and nuclear.

8. Energy Options for a Sustainable Future bring Substantial Multiple Benefits for Society: Combinations of resources, technologies, and polices that can simultaneously meet global sustainability goals also generate substantial and tangible near-term local and national economic, environmental, and social development benefits. These include, but are not limited to, improved local health and environment conditions, increased employment options, strengthened local economies through new business opportunities, productivity gains, improved social welfare and decreased poverty, more resilient infrastructure, and improved energy security. Synergistic strategies that focus on local and national benefits are more likely to be implemented than measures that are global and long-term in nature. Such an approach emphasizes the local benefits of improved end-use efficiency and increased use of renewable energy, and also helps manage energy-related global challenges. These benefits make the required energy transformations attractive from multiple policy perspectives and at multiple levels of governance.

9. Socio-Cultural Changes as well as Stable Rules and Regulations will be Required: Crucial issues in achieving transformational change toward sustainable future include non-technology drivers such as individual and public awareness, community and societal capacities to adapt to changes, institutions, policies, incentives, strategic spatial planning, social norms, rules and regulations of the marketplace, behavior of market actors, and societies' ability to introduce through the political and institutional systems measures to reflect externalities. Changes in cultures, lifestyles, and values are also required. Effective strategies will need to be adopted and integrated into the fabric of national socio-cultural, political, developmental, and other contextual factors, including recognizing and providing support for the opportunities and needs of all nations and societies.

10. Policy, Regulations, and Stable Investment Regimes will be Essential: A portfolio of policies to enable rapid transformation of energy systems must provide the effective incentive structures and strong signals for the deployment at scale of energy-efficient technologies and energy supply options that contribute to the overall sustainable development. The GEA pathways indicate that global investments in combined energy efficiency and supply will need to increase to between US$1.7–2.2 trillion per year compared to present levels of about US$1.3 trillion per year (about 2% of current world gross domestic product) including end-use components. Policies should encourage integrated approaches across various sectors and promote the development of skills and institutional capacities to improve the investment climate. Examples include applying market-oriented regulations such as vehicle emissions standards and low carbon fuel standards and as well as renewable portfolio standards to accelerate the market penetration of clean energy technologies and fules. Reallocating energy subsidies, especially the large subsidies provided in industrialized countries to fossil fuels without CCS, and nuclear energy, and pricing or regulating GHG emissions and/or GHG-emitting technologies and fules can help support the initial deployment of new energy systems, both end-use and supply, and help make infrastructures energy efficient. Publicly financed research and development needs to accelerate and be reoriented toward energy efficiency, renewable energy and CCS. Current research and development efforts in these areas are grossly inadequate compared with the future potentials and needs.

* * * * *

The full GEA report is available for download in electronic form at www.globalenergyassessment.org. The website includes an interactive scenario database that documents the GEA pathways.