SPM

Summary for Policymakers

Convening Lead Authors (CLA):

Thomas B. Johansson (Lund University, Sweden)
Nebojsa Nakicenovic (International Institute for Applied Systems Analysis and Vienna University of Technology, Austria)
Anand Patwardhan (Indian Institute of Technology-Bombay)
Luis Gomez-Echeverri (International Institute for Applied Systems Analysis, Austria)

Lead Authors (LA)

Rangan Banerjee (Indian Institute of Technology-Bombay)
Sally M. Benson (Stanford University, USA)
Daniel H. Bouille (Bariloche Foundation, Argentina)
Abeeku Brew-Hammond (Kwame Nkrumah University of Science and Technology, Ghana)
Aleh Cherp (Central European University, Hungary)
Suani T. Coelho (National Reference Center on Biomass, University of São Paulo, Brazil)
Lisa Emberson (Stockholm Environment Institute, University of York, UK)
Maria Josefina Figueroa (Technical University of Denmark)
Arnulf Grubler (International Institute for Applied Systems Analysis, Austria and Yale University, USA)
Kebin He (Tsinghua University, China)
Mark Jaccard (Simon Fraser University, Canada)
Suzana Kahn Ribeiro (Federal University of Rio de Janeiro, Brazil)
Stephen Karekezi (AFREPREN/FWD, Kenya)
Eric D. Larson (Princeton University and Climate Central, USA)
Zheng Li (Tsinghua University, China)
Susan McDade (United Nations Development Programme)
Lynn K. Mytelka (United Nations University-MERIT, the Netherlands)
Shonali Pachauri (International Institute for Applied Systems Analysis, Austria)
Keywan Riahi (International Institute for Applied Systems Analysis, Austria)
Johan Rockström (Stockholm Environment Institute, Stockholm University, Sweden)
Hans-Holger Rogner (International Atomic Energy Agency, Austria)
Joyashree Roy (Jadavpur University, India)
Robert N. Schock (World Energy Council, UK and Center for Global Security Research, USA)
Ralph Sims (Massey University, New Zealand)
Kirk R. Smith (University of California, Berkeley, USA)
Wim C. Turkenburg (Utrecht University, the Netherlands)
Diana Ürge-Vorsatz (Central European University, Hungary)
Frank von Hippel (Princeton University, USA)
Kurt Yeager (Electric Power Research Institute and Galvin Electricity Initiative, USA)

Introduction

Energy is essential for human development and energy systems are a crucial entry point for addressing the most pressing global challenges of the 21st century, including sustainable economic and social development, poverty eradication, adequate food production and food security, health for all, climate protection, conservation of ecosystems, peace and security. Yet, more than a decade into the 21st century, current energy systems do not meet these challenges.

A major transformation is therefore required to address these challenges and to avoid potentially catastrophic future consequences for human and planetary systems. The Global Energy Assessment (GEA) demonstrates that energy system change is the key for addressing and resolving these challenges. The GEA identifies strategies that could help resolve the multiple challenges simultaneously and bring multiple benefits. Their successful implementation requires determined, sustained and immediate action.

Transformative change in the energy system may not be internally generated; due to institutional inertia, incumbency and lack of capacity and agility of existing organizations to respond effectively to changing conditions. In such situations clear and consistent external policy signals may be required to initiate and sustain the transformative change needed to meet the sustainability challenges of the 21st century.

The industrial revolution catapulted humanity onto an explosive development path, whereby, reliance on muscle power and traditional biomass was replaced mostly by fossil fuels. In 2005, some 78% of global energy was based on fossil energy sources that provided abundant and ever cheaper energy services to more than half the people in the world. Figure SPM-1 shows this explosive growth of global primary energy with two clear development phases, the first

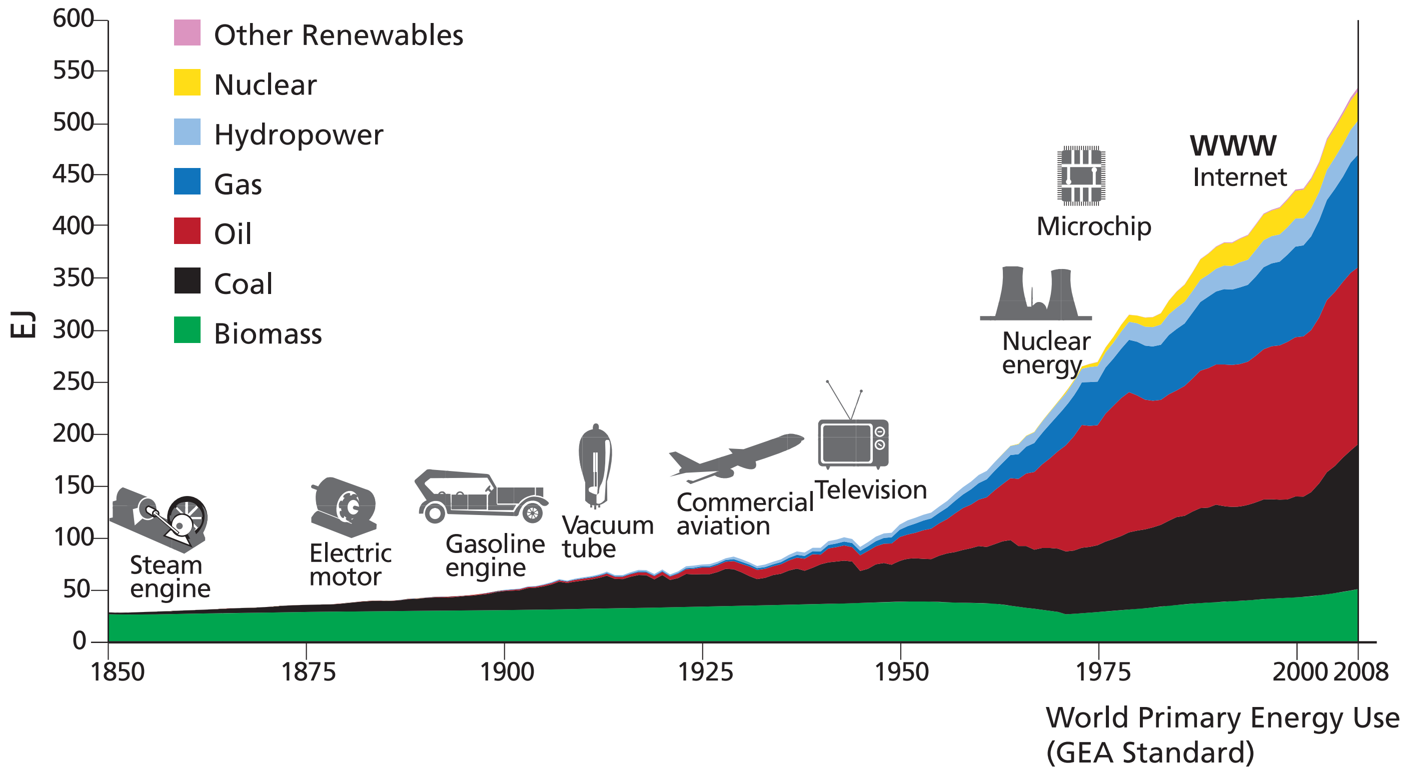

Figure SPM-1. | Evolution of primary energy shown as absolute contributions by different energy sources (EJ). Biomass refers to traditional biomass until the most recent decades, when modern biomass became more prevalent and now accounts for one-quarter of biomass energy. New renewables are discernible in the last few decades. Source: updated from Nakicenovic et al., 1998 and Grubler, 2008, see Chapter 1.[1]

1 **Nakicenovic, N., A. Grubler and A. McDonald (eds.), 1998:** *Global Energy Perspectives*. International Institute for Applied Systems Analysis (IIASA) and World Energy Council (WEC), Cambridge University Press, Cambridge, UK.

Grubler, A., 2008: Energy transitions. In *Encyclopedia of Earth. C. J. Cleveland (ed.), Environmental Information Coalition, National Council* for Science and the Environment, Washington, DC.

characterized by a shift from reliance on traditional energy sources to coal and subsequently to oil and gas. Hydropower, biomass and nuclear energy during the past decades have a combined share of almost 22%. New renewables such as solar and wind are hardly discernible in the figure.

Despite this rapid increase in overall energy use, over three billion people still rely on solid fuels such as traditional biomass, waste, charcoal and coal for household cooking and heating. The resulting air pollution leads to over two million premature deaths per year, mostly of women and children. Furthermore, approximately 20% of the global population has no access to electricity. Addressing these challenges is essential for averting a future with high economic and social costs and adverse environmental impacts on all scales.

An energy system transformation is required to meet these challenges and bring prosperity and well-being to the 9 billion people expected by 2050. The encouraging news is that a beginning of such a transformation can be seen today in the rapidly growing investments in renewable energy sources, high-efficiency technologies, new infrastructures, near zero-energy buildings, electric mobility, 'smart' energy systems, advanced biomass stoves, and many other innovations. The policy challenge is to accelerate, amplify and help make the implementation of these changes possible, widespread and affordable. Initial experience suggests that many of these changes are affordable, although they may be capital intensive and require high upfront investments. However, in general they have lower long-term costs that offset many of the up-front added investment requirements. Many of these innovations also lead to benefits in other areas such as equity and poverty, economic development, energy security, improved health, climate change mitigation, and ecosystem protection.

This Summary for Policymakers expands on the GEA approach and the Key Findings. The Technical Summary provides further support for the key findings.

Goals Used in the Assessment and in the GEA Pathways Analysis

For many of the energy related challenges, different goals have been articulated by the global community, including, in many instances specific quantitative targets. Meeting these goals simultaneously has served as the generic framework for all assessments in the GEA. The GEA pathways illustrate how societies can reach global normative goals of welfare, security, health, and environmental protection outlined below simultaneously with feasible changes in energy systems.

The selection of indicators and the quantitative target levels summarized here is a normative exercise, and the level of ambition has, to the extent possible, been guided by agreements and aspirations expressed through, for example, the United Nations system's actions, resolutions, and from the scientific literature. This, of course, only refers to the necessary changes of the local and global energy systems; much more is required in other sectors of societies for overall sustainability to be realized.

In the GEA pathways analysis, global per capita gross domestic product (GDP) increases by 2% a year on average through 2050, mostly driven by growth in developing countries. This growth rate falls in the middle of existing projections. Global population size is projected to plateau at about 9 billion people by 2050. Energy systems must be able to ***deliver the required energy services*** to support these economic and demographic developments.

To avoid additional complexity, the GEA pathways assume one intermediate population growth pathway that is associated with uncertainty. Given that population growth has significant implications for future energy demand, however, it should be remembered that policies to provide more of the world's men and women the means to make responsible parental decisions (including safe contraception technologies) can significantly reduce the growth in population over the century as well as energy demand and CO_2 emissions. By increasing birth spacing, they would also bring benefits for maternal and child health.

Access to affordable modern energy carriers and end-use conversion devices to improve living conditions and enhancing opportunities for economic development for the 1.4 billion people without access to electricity and the 3 billion who still rely on solid and fossil fuels for cooking is a prerequisite for poverty alleviation and socioeconomic development.

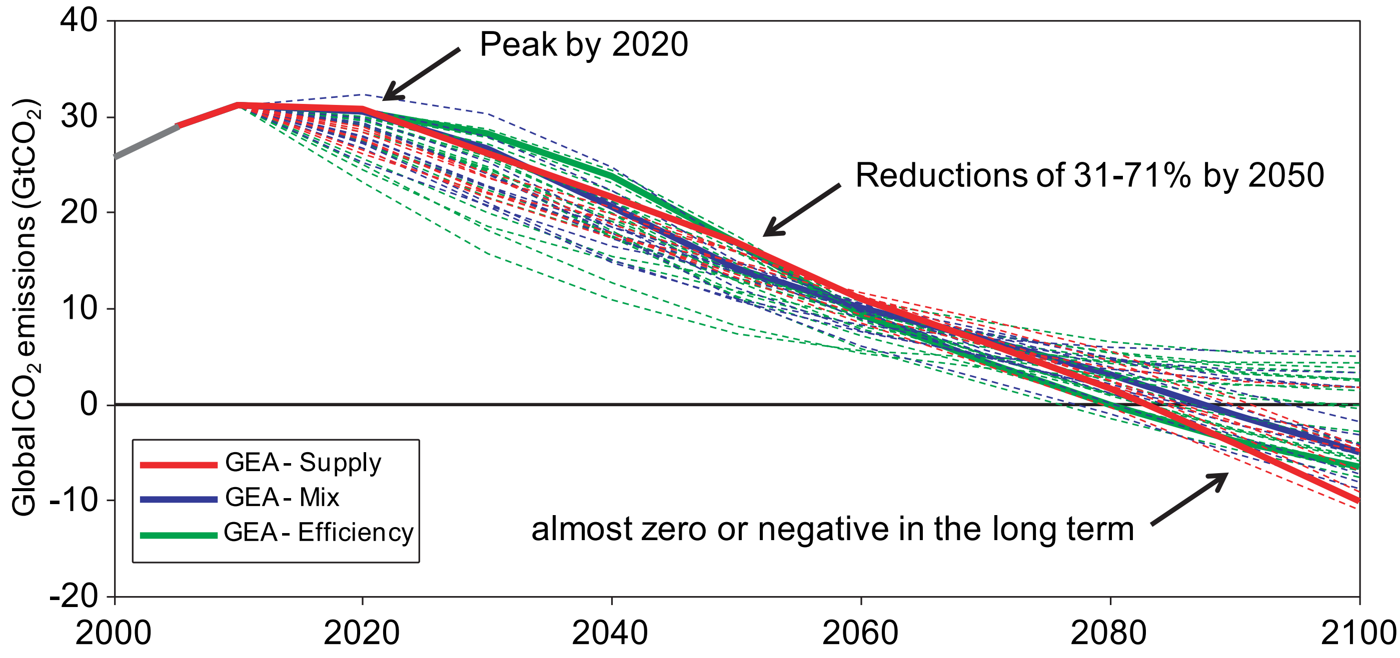

Figure SPM-2. | Development of global CO_2 emissions from energy and industrial sources to limit temperature change to below 2°C (with a success probability of >50%). Shown is that the emissions need to peak by around 2020 (or earlier) and decline toward zero during the following four to five decades. The later the peak occurs, the steeper the decline needs to be and higher the net "negative" emissions. The latter can be achieved through in the energy system through carbon dioxide capture and storage in conjunction with the use of sustainable biomass. Source: Chapter 17. For further details of the GEA pathways see the interactive web-based GEA scenario database hosted by IIASA: www.iiasa.ac.at/web-apps/ene/geadb.

Enhanced energy security for nations and regions is another key element of a sustainable future. Reduced global interdependence via reduced import/export balances, and increased diversity and resilience of energy supply have been adopted as key energy-related metrics. The targets for these goals were assessed ex-post through the GEA pathways analysis (Chapter 17), identifying the need for energy efficiency improvements and deployment of renewables to increase the share of domestic (national or regional) supply in primary energy by a factor of two and thus significantly decrease import dependency (by 2050). At the same time, the share of oil in global energy trade is reduced from the present 75% to below 40% and no other fuel assumes a similarly dominant position in the future.

The ***climate change mitigation*** goal is to contain the global mean temperature increase to less than 2°C above the preindustrial level, with a success probability of at least 50%. This implies global CO_2 emissions reductions from energy and industry to 30–70% of 2000 levels by 2050, and approaching almost zero or net negative emissions in the second half of the century (Figure SPM-2).

Health goals relating to energy systems include controlling household and ambient air pollution. Emissions reductions through the use of advanced fuels and end-use technologies (such as low-emissions biomass cookstoves) for household cooking and heating can significantly reduce human morbidity and mortality due to exposure to household air pollution, as well as help reduce ambient pollution. In the GEA pathways, this is assumed to occur for the vast majority of the world's households by 2030. Similarly, a majority of the world's population is also expected to meet the World Health Organization's (WHO) air quality guidelines (annual PM2.5 concentration < 10 µg/m^3 by 2030), while remaining populations are expected to stay well within the WHO Tier I-III levels (15–35 µg/m^3 by 2030). In addition, there needs to be a major expansion of occupational health legislation and enforcement in the energy sector.

Linkages between the energy system and the **environment** are at multiple levels and scales – from local to global. While the local environmental and ecological consequences of resource extraction, processing and energy conversion have been long recognized, attention is increasingly turning towards the growing evidence that humanity has reached a phase when anthropogenic pressures on Earth systems – the climate, oceans, fresh water, and the biosphere – risk irreversible disruption to biophysical processes on the planetary scale. The risk is that systems on Earth may then

Table SPM-1. | Global Burden of Disease, 2000 from Air Pollution and other Energy-related causes. These come from the Comparative Risk Assessment (CRA) published in 2004 by the World Health Organization (WHO). Estimates for 2005 in GEA for outdoor air pollution and household solid fuel use in Chapter 17 are substantially larger, but were not done for all risk pathways shown. Estimates for 2010 in the new CRA by WHO will be released in 2012 and will again include all pathways in a consistent framework.

	Total Premature Deaths – million	Percent of all Deaths	Percent of Global Burden in DALYs	Trend
Direct Effects [except where noted, 100% assigned to energy]				
Household Solid Fuel	1.6	2.9	2.6	Stable
Energy Systems Occupational*	0.2	0.4	0.5	Uncertain
Outdoor Air Pollution	0.8	1.4	0.8	Stable
Climate Change	0.15	0.3	0.4	Rising
Subtotal	2.8	5.0	4.3	
Indirect Effects (100% of each)				
Lead in Vehicle Fuel	0.19	0.3	0.7	Falling
Road Traffic Accidents	0.8	1.4	1.4	Rising
Physical Inactivity	1.9	3.4	1.3	Rising
Subtotal	2.9	5.1	3.4	
Total	5.7	10.1	7.7	

* One-third of global total assigned to energy systems.

Notes: These are not 100% of the totals for each, but represent the difference between what exists now and what might be achieved with feasible policy measures. Thus, for example, they do not assume the infeasible reduction to zero traffic accidents or air pollution levels.

Source: Chapter 4.

reach tipping points, resulting in non-linear, abrupt, and potentially irreversible change, such as destabilization of the Greenland ice sheet or tropical rainforest systems.

There are also a number of other concerns related to how energy systems are designed and operated. For example, activities need to be occupationally safe, a continuing concern as nano- and other new materials are used in energy systems. Other impacts such as oil spills, freshwater contamination and overuse, and releases of radioactive substances must be prevented (ideally) or contained. Waste products must be deposited in acceptable ways to avoid health and environmental impacts. These issues mostly influence local areas, and the regulations and their implementation are typically determined at the national level.

The world is undergoing severe and rapid change involving significant challenges. Although this situation poses a threat, it also offers a unique opportunity – a window of time in which to create a new, more sustainable, more equitable world, provided that the challenges can be addressed promptly and adequately. Energy is a pivotal area for actions to help address the challenges.

The interrelated world brought about by growth and globalization has increased the linkages among the major challenges of the 21st century. We do not have the luxury of being able to rank them in order of priority. As they are closely linked and interdependent, the task of addressing them simultaneously is imperative.

Energy offers a useful entry point into many of the challenges because of its immediate and direct connections with major social, economic, security and development goals of the day. Among many other challenges, energy systems are tightly linked to global economic activities, to freshwater and land resources for energy generation and food production, to biodiversity and air quality through emissions of particulate matter and precursors of tropospheric ozone, and to climate change. Most of all, access to affordable and cleaner energy carriers is a fundamental prerequisite for development, which is why the GEA places great emphasis on the need to integrate energy policy with social, economic, security, development, and environment policies.

Reaching the GEA goals simultaneously requires transformational changes to the energy system, in order to span a broad range of opportunities across urban to rural geographies, from developing to industrial countries, and in transboundary systems. The ingredients of this change are described in the following section.

Key Findings

The Global Energy Assessment (GEA) explored options to transform energy systems that simultaneously address all of the challenges above. A broad range of resources and technologies were assessed, as well as policy options that can be combined to create pathways[2] to energy for a sustainable future. 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.*

Humanity has the capacity, ingenuity, technologies and resources to create a better world. However, the lack of appropriate institutions, coordination mandates, political will and governance structures make the task difficult. Current decision making processes typically aim for short-term, quick results, which may lead to sub-optimal long-term outcomes. The GEA endeavors to make a compelling case for the adoption of a new set of approaches and policies that are essential, urgently required, and achievable.

The GEA highlights essential technology-related requirements for radical energy transformation:

- significantly larger investment in energy efficiency improvements especially end-use across all sectors, with a focus on new investments as well as major retrofits;
- rapid escalation of investments in renewable energies: hydropower, wind, solar energy, modern bioenergy, and geothermal, as well as the smart grids that enable more effective utilization of renewable energies;
- reaching universal access to modern forms of energy and cleaner cooking through micro-financing and subsidies;
- use of fossil fuels and bioenergy at the same facilities for the efficient co-production of multiple energy carriers and chemicals with full-scale deployment of carbon capture and storage; and
- on one extreme nuclear energy could make a significant contribution to global electricity generation, but on the other extreme, it could be phased out.

To meet humanity's need for energy services, comprehensive diffusion of energy and an increased contribution of energy efficiencies are required throughout the energy system – from energy collection and conversion to end use. Rapid diffusion of renewable energy technologies is the second but equally effective option for reaching multiple objectives. Conversion of primary energy to energy carriers such as electricity, hydrogen, liquid fuels and heat along with smart transmission and distribution systems are necessary elements of an energy system meeting sustainability objectives.

2 The GEA developed a range of alternative transformational pathways to explore how to achieve all global energy challenges simultaneously. The results of the GEA pathways are documented in detail at the interactive web-based GEA scenario database hosted by IIASA: www.iiasa.ac.at/web-apps/ene/geadb.

The GEA makes the case that energy system transformation requires an iterative and dynamic transformation of the policy and regulatory landscape, thereby fostering a buildup of skills and institutions that encourage innovation to thrive, create conditions for business to invest, and generate new jobs and livelihood opportunities.

A major finding of the GEA is that some energy options provide multiple benefits. This is particularly true of energy efficiency, renewables, and the coproduction of synthetic transportation fuels, cooking fuels, and electricity with co-gasification of coal and biomass with CCS, which offer advantages in terms of supporting all of the goals related to economic growth, jobs, energy security, local and regional environmental benefits, health, and climate change mitigation. All these advantages imply the creation of value in terms of sustainability. This value should be incorporated into the evaluation of these and other measures and in creating incentives for their use.

One implication of this is that nations and corporations can invest in efficiency and renewable energy for the reasons that are important to them, not just because of a global concern about, for example, climate change mitigation or energy security. But incentives for individual actors to invest in options with large societal values must be strong and effective.

The GEA explored 60 possible transformation pathways and found that 41 of them satisfy all the GEA goals simultaneously for the same level of economic development and demographic changes, including three groups of illustrative pathways that represent alternative evolutions of the energy system toward sustainable futures.[3] The pathways imply radically changed ways in which humanity uses energy, ranging from much more energy-efficient houses, mobility, products, and industrial processes to a different mix of energy supply – with a much larger proportion of renewable energy and fossil advanced fossil fuel technologies (see Figure SPM-3).

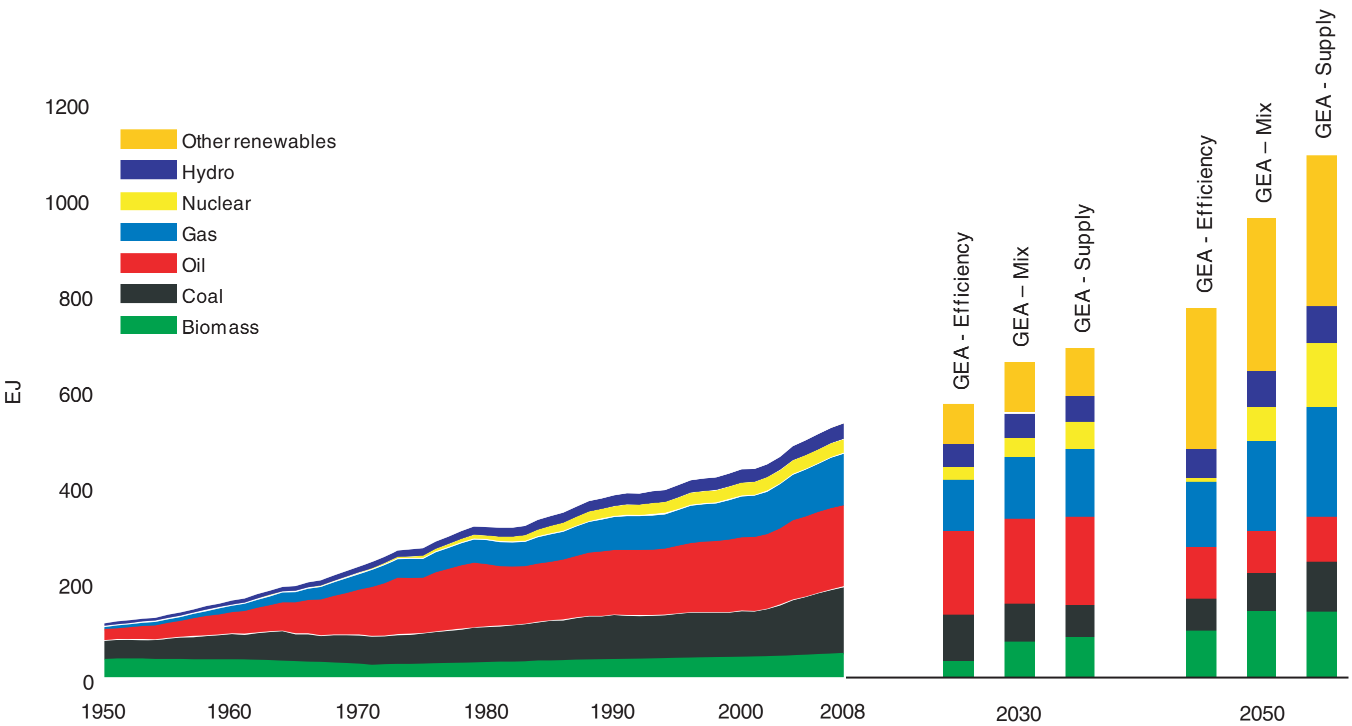

Figure SPM-3. | Development of primary energy to 2008 and in the three illustrative GEA pathways for the years 2030 and 2050. Source: based on Figures TS-24 and 17.13, Chapter 17. For further details of the GEA pathways see the interactive web-based GEA scenario database hosted by IIASA: www.iiasa.ac.at/web-apps/ene/geadb.

3 The pathways encompass eleven world regions, grouped into five GEA regions and energy sectors, including supply and demand, with a full range of associated social, economic, environmental and technological developments.

On the demand side, the three groups of GEA pathways pursue the energy efficiency options to a varying extent. On the supply side, the GEA pathways highlight the broad portfolio of technologies that will be needed to achieve the energy system transformation. Particularly important options are low-carbon energy from renewables, bioenergy, nuclear power, and CCS. In aggregate, at least a 60–80% share of global primary energy will need to come from zero-carbon options by 2050; the electricity sector in particular will need to be almost completely decarbonized by mid-century (low-carbon shares of 75–100%). Getting to that point requires major progress in several critical areas:

- Renewables: Strong renewable energy growth beginning immediately and reaching a global share of 30–75% of primary energy by 2050, with some regions experiencing in the high case almost a complete shift towards renewables by that time;

- Coal: A complete phase-out of coal power without CCS by 2050;

- Natural Gas: Natural gas acting as a bridging or transitional technology in the short to medium term and providing 'virtual' storage for intermittent renewables;

- Energy Storage: Rising requirement for storage technologies and 'virtual' systems (e.g., smart grids and demand-side management) to support system integration of intermittent wind and solar;

- Bioenergy: Strong bioenergy growth in the medium term from 45 EJ in 2005 to 80–140 EJ by 2050, including extensive use of agricultural residues and second-generation bioenergy to mitigate adverse impacts on land use and food production, and the co-processing of biomass with coal or natural gas with CCS to make low net GHG-emitting transportation fuels and or electricity;

- Nuclear: Nuclear energy as a choice, not a requirement. The GEA pathways illustrate that it is possible to meet all GEA goals even in the case of a nuclear phase-out. Nuclear energy can play an important role in the supply-side portfolio of some transition pathways; however, its prospects are particularly uncertain because of unresolved challenges surrounding its further deployment, as illustrated by the Fukushima accident and unresolved weapons proliferation risks;

- Carbon Capture and Storage: Fossil CCS as an optional bridging or transitional technology in the medium term unless there is high energy demand, in which case CCS may be essential. CCS technology offers one potentially relatively low-cost pathway to low carbon energy. CCS in conjunction with sustainable biomass is deployed in many pathways to achieve negative emissions and thus help achieve climate stabilization.

New policies would be needed to attract capital flows to predominantly upfront investments with low long-term costs but also low short-term rates of return.

The pathways indicate that the energy transformations need to be initiated without delay, gain momentum rapidly, and be sustained for decades. They will not occur on their own. They require the rapid introduction of policies and fundamental governance changes toward integrating global concerns, such as climate change, into local and national policy priorities, with an emphasis on energy options that contribute to addressing all these concerns simultaneously.

In sum, the GEA finds that there are possible combinations of energy resources and technologies that would enable societies to reach all the GEA goals simultaneously, provided that government interventions accommodate sufficiently strong incentives for rapid investments in energy end-use and supply technologies and systems.

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 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.*

Given the longevity of the capital stock of energy systems and of the built environment, rates of change are slow and possible irreversibilities or 'lock-in' effects can have powerful long-lasting effects. Long-term transformations need to be initiated earlier rather than later. Therefore the time for action is *now.* Changes in current policies that are particularly critical in triggering longer-term transformations are technology, and urbanization.

Reflecting economic, social and environmental externalities in the market conditions is therefore a necessary first step to provide appropriate incentives for redirecting private sector investments. Such measures would include removal, or at least substantial reduction, of subsidies to fossil fuels without CCS and nuclear energy, stimulation of development and market entry of new renewable options, and emphasis on energy efficiency in all end-use sectors. According to the GEA pathway analysis, global energy systems investments need to increase to some US$1.7–2.2 trillion annually to 2050, with about US$300–550 billion of that being required for demand-side efficiency. This compares to about US$1 trillion supply-side investments and about $300 billion demand-side investments in energy components per year today. These investments correspond to about 2% of the world gross domestic product in 2005, and would be about 2–3% by 2050, posing a major financing challenge. New policies would be needed to attract such capital flows to predominantly upfront investments with low long-term costs but also low short-term rates of return.

Today about 3.5 billion people, about half the world population live in urban environments. Projections suggest that by 2050 an additional three billion people need to be integrated into the urban fabric. Housing, infrastructure, energy and transport services, and a better urban environment (especially urban air quality) are the key sustainability challenges for urban development.

Urban energy and sustainability policies can harness local decision-making and funding sources to achieve the largest leverage effects in the following areas:

- urban form and density (which are important macro-determinants of urban structures, activity patterns, and hence energy use, particularly for urban transport);
- the quality of the built environment (energy-efficient buildings in particular);
- urban transport policy (in particular the promotion of energy-efficient and 'eco-friendly' public transport and non-motorized mobility options); and
- improvements in urban energy systems through zero-energy building codes, cogeneration or waste-heat recycling schemes, where feasible.

There are important urban size and density thresholds that are useful guides for urban planning and policymaking. The literature review identified a robust density threshold of 50–150 inhabitants per hectare (5,000–15,000 people per square kilometer) below which urban energy use, particularly for transport, increases substantially and which should be avoided. There are also significant potential co-benefits between urban energy policies and environmental policies. However, they require more holistic policy approaches that integrate urban land use, transport, building, and energy policies with the more-traditional air pollution policy frameworks.

Policy coordination at an urban scale is as complex as potentially rewarding in sustainability terms. Institutional and policy learning needs to start early to trigger longer-term changes in urban form and infrastructures. A particular challenge is represented by small to medium sized cities (between 100,000 and 1 million inhabitants), as most urban growth is projected to occur in these centers, primarily in the developing world. In these smaller-scale cities, data and information to guide policy are largely absent, local resources to tackle development challenges are limited, and governance and institutional capacities are insufficient.

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 offers major opportunities;*
- *through a combination of increased enegry 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.

Progress in accelerating the rate of energy efficiency improvement worldwide is critical to an energy system for sustainability. Quickly improving energy efficiency through new investments and retrofits requires focused and aggressive policies that support rapid innovation through more stringent regulations of energy efficiency, fiscal incentives for new technologies, and pricing GHG emissions. Combined with higher energy prices, a culture of conservation among consumers and firms, and an increase in urban density societies can realize a dramatic increase in energy efficiency.

A major challenge is to resolve the issue of split incentives, that is, the situation where those who would be paying for efficiency improvements and other energy investments are more oriented toward short-term rates of return than to the long-term profitability of the investments and, likewise, they are rarely the beneficiaries of reduced energy costs and other public benefits.

Regulations are essential elements of energy policy portfolios to drive an energy transition. Standards for building codes, heating and cooling, appliances, fuel economy, and industrial energy management are one of the most effective policy tools for improving energy efficiency and should be adopted globally. These regulatory policies are most effective when combined with fiscal incentives and attention-attracting measures such as information, awareness, and public leadership programs.

The GEA analysis provides considerable evidence of the ability of such policy packages to deliver major change. However, the results from three decades of experiences with energy efficiency policies in industrial countries also show other effects.

These cost factors and rebound effects mean that subsidies to encourage acquisition of energy-efficient devices are unlikely, on their own, to cause the dramatic energy efficiency gains called for in the GEA analysis. For these gains to be realized, carefully targeted policies are needed. For example, strong efficiency regulations have proven effective. These are updated regularly and have incentives to reward manufacturers who push technology designs toward advanced efficiency by using electricity tariffs that reward efficiency investments and conservation.

In the buildings sector, new and existing technologies as well as non-technological opportunities represent a major opportunity for transformative change of energy use. Passive houses that reduce energy use for heating and cooling by 90% or more, for example, are already found in many countries. Increased investments in a more energy-efficient building shell are in part offset by lower or fully eliminated investments in heating/cooling systems, with energy costs for operation almost avoided, making these new options very attractive. Passive house performance is possible also

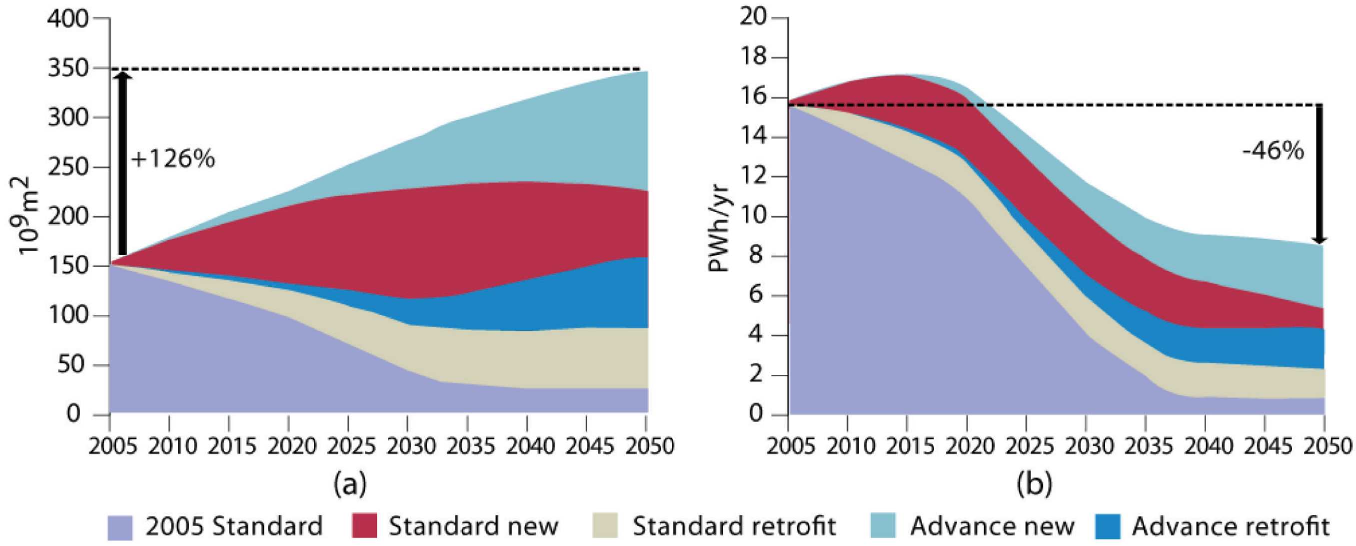

Figure SPM-4. | Global final thermal energy use in buildings (a) and global floor area (b) in the state-of-the-art scenario (corresponding approximately to the "GEA-Efficiency" group of pathways), 2005–2050. Source: Chapter 10.

Key: Explanations of efficiency categories: standard: today's stock; new: new buildings built to today's building code or anticipated new building codes (without additional policies); advance new: new buildings built to today's state-of-the-art performance levels; retrofit: assumes some efficiency gains, typically 35%; advanced retrofit: retrofit built to state-of-the-art levels.

for existing buildings, if it is included as a performance goal when major renovations are done. Energy Plus houses, delivering net energy to the grid over a year, have been constructed even in high latitudes. Building-integrated solar photovoltaics can contribute to meeting the electricity demand in buildings, especially in single-family homes, and solar water heaters can cover all or part of the heat required for hot water demand. However, requiring buildings to be zero-energy or net-energy suppliers may not be the lowest-cost or most sustainable approach in addressing the multiple GEA goals and typically may not be possible, depending on location.

Analysis carried out under the GEA pathway framework demonstrates that a reduction of global final energy use for heating and cooling of about 46% is possible by 2050 compared with 2005 through full use of today's best practices in design, construction, and building operation technology and know-how. This can be obtained even while increasing amenities and comfort and simultaneously accommodating an increase in global floor area of over 126% (Figure SPM-4).

There is, however, a significant risk of lock-in. If stringent building codes are not introduced universally and energy retrofits accelerate but are not subject to state-of-the-art efficiency levels, substantial energy use and corresponding GHG emissions can be 'locked-in' for many decades. This could lead to a 33% increase in global energy use for buildings by 2050 instead of a decrease of 46% (Figure SPM-5).

Wide adoption of the state-of-the-art in the buildings sector would not only contribute significantly to meeting the GEA's multiple goals, such developments would also deliver a wide spectrum of other benefits. A review of quantified multiple benefits showed that productivity gains through reduced incidence of infections from exposure to indoor air pollution score particularly high in industrial countries. Other benefits included increases in productivity, energy security, indoor air quality and health, social welfare, real estate values, and employment. The approximately US$57 trillion cumulative energy cost savings until 2050 in avoided heating and cooling energy costs alone substantially exceeds the estimated US$15 trillion investments that are needed to realize this pathway. The value of the additional benefits has also been shown to be substantial, often exceeding the energy cost savings. In several cases the multiple benefits are so significant, and coincide with other important policy agendas (such as improved energy security, employment, poverty alleviation, competitiveness), that they provide easier and more attractive entry points for local policymaking than climate change or other environmental agendas.

Influencing energy use in the transport sector involves affecting transport needs, infrastructure, and modes, as well as vehicle energy efficiency. Policies for urbanization will have a large impact on transport needs, infrastructure, and

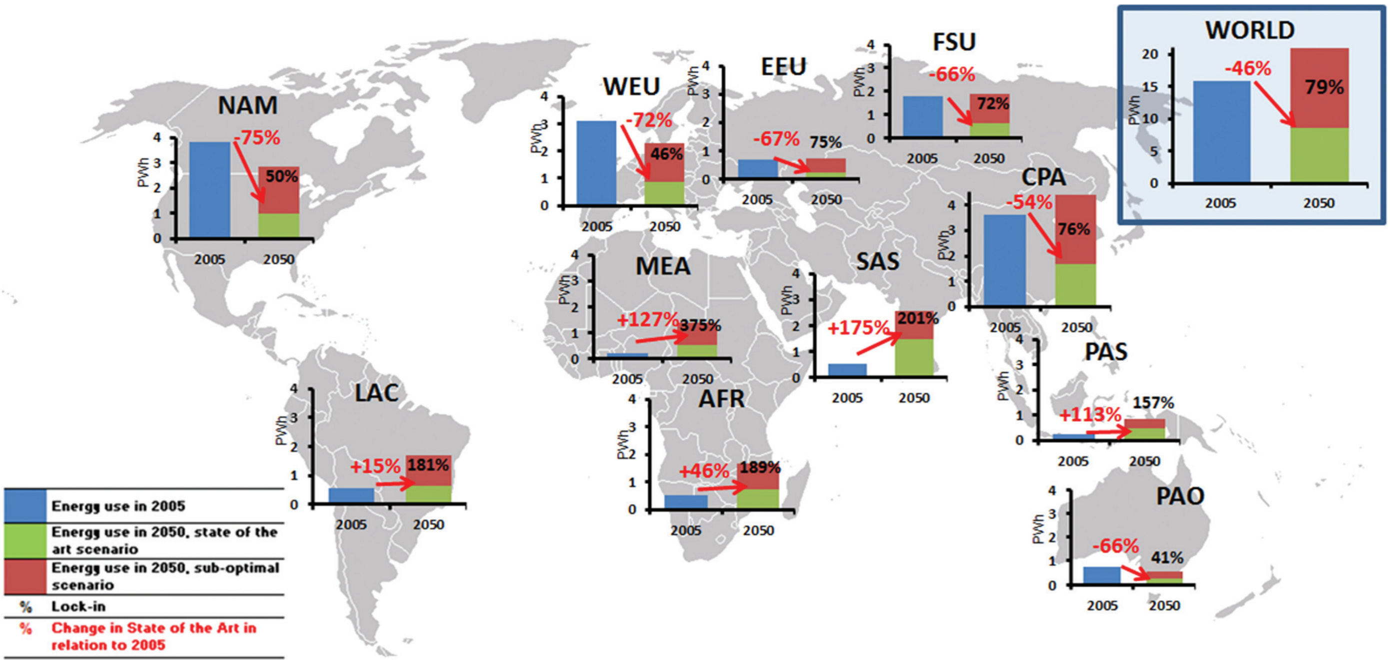

Figure SPM-5. | Final building heating and cooling energy demand scenarios until 2050: state-of-the-art (~corresponding roughly to the GEA-Efficiency set of pathways) and sub-optimal (~corresponding roughly to the GEA-Supply set of pathways scenarios, with the lock-in risk (difference). Note: Green bars, indicated by red arrows and numbers, represent the opportunities through the state-of-the-art scenario, while the red bars with black numbers show the size of the lock-in risk (difference between the two scenarios). Percent figures are relative to 2005 values. Source: Chapter 10.

the viability of different transport modes on the local scale. Both the decision to travel and the choice of how to travel affect fuel consumption. With a focus on urban road transport, a transition to sustainable transport can follow the framework known as 'avoid-shift-improve'. This considers three major principles under which diverse policy instruments are grouped, with interventions assuming different emphasis in industrial and developing countries. They need to focus on technological options, ('improve'), not only with respect to climate mitigation but also with respect to local environmental conditions and social concerns. The other two components – modal shift and avoiding travel influence the level of activity and structural components that link transport to carbon emissions.

A major transformation of transportation is possible over the next 30–40 years and will require improving vehicle designs, infrastructure, fuels and behavior. In the short term improving overall sector energy efficiency, introducing alternative low-carbon fuels and electricity, enhancing the diversification, quantity and quality of public modes of transport is necessary. Medium term goals require reducing travel distances within cities by implementing compact urban design that improves accessibility to jobs and services and facilitates use of non-motorized modes, and replacing and adopting vehicle and engine design (for trucks, airplanes, rail, and ships) following the best available technological opportunities for increasing efficiency and societal acceptability.

Transport policy goals for urbanization and equity include the adoption of measures for increasing accessibility and the affordable provision of urban mobility services and infrastructure that facilitates the widespread use of non-motorized options Cities can be planned to be more compact with less urban sprawl and a greater mix of land uses and strategic siting of local markets to improve logistics and reduces the distances that passengers and goods need to travel. Urban form and street design and layout can facilitate walking, cycling, and their integration within a network of public transport modes. Employers in many sectors can enhance the job-housing balance of employees through their decisions on where to be located and can provide incentives for replacing some non-essential journeys for work purposes with the use of information technologies and communication.

Modal share could move to modes that are less energy-intensive, both for passenger and freight transport. In cities, a combination of push and pull measures through traffic demand management can induce shifts from cars to public transit and cycling and can realize multiple social and health benefits. In particular, non-motorized transportation could be promoted everywhere as there is wide agreement about its benefits to transportation and people's health. Parking policies and extensive car pooling and car sharing, combined with information technology options can become key policies to reduce the use of cars. Efficient road capacity utilization, energy use and infrastructure costs for different modes could be considered when transport choices are made.

There are still many opportunities to improve conventional vehicle technologies. The combination of introducing incremental efficiency technologies, increasing the efficiency of converting the fuel energy to work by improving drive train efficiency, and recapturing energy losses and reducing loads (weight, rolling, air resistance, and accessory loads) on the vehicle has the potential to approximately double the fuel efficiency of 'new' light-duty vehicles from 7.5 liters per 100 km in 2010 to 3.0 liters per 100 km by 2050.

The emergence of electric drive technologies such as plug-in hybrid electric vehicles allows for zero tailpipe emissions for low driving ranges, up to around 50 kilometers in urban conditions. All-electric battery vehicles can achieve a very high efficiency (more than 90%, four times the efficiency of an internal combustion engine vehicle but excluding the generation and transmission of the electricity), but they have a low driving range and short battery life. If existing fuel saving and hybrid technologies are deployed on a broad scale, fleet-average specific fuel savings of a factor of two can be obtained in the next decade.

The aggregate energy intensity in the industrial sector in different countries has shown steady declines due to improvements in energy efficiency and a change in the structure of the industrial output. In the EU-27, for instance, the final energy use by industry has remained almost constant (13.4 EJ) at 1990 levels; 30% of the reduction in energy intensity is due to structural changes, with the remainder due to energy efficiency improvements.

In different industrial sectors, adopting the best achievable technology can result in savings of 10–30% below the current average. An analysis of cost-cutting measures in 2005 indicated energy savings potentials of 2.2 EJ for motors and 3.3 EJ for steam systems. The economic payback period for these measures ranges from less than nine months to four years. A systematic analysis of materials and energy flows indicates significant potential for process integration, heat pumps, and cogeneration.

Nevertheless, such a transformation has multiple benefits. Improved energy efficiency in industry results in significant energy productivity gains as a result, for example, in improved motor systems; compressed air systems; ventilation, heat recovery, and air conditioning systems; and improvements in comfort and the working environment through better lighting, thermal comfort, and reduced indoor air pollution from improved ventilation systems, and, in turn, improved productivity boosts corporate competitiveness.

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.

The GEA pathways show that renewable energies can exceed 90% of projected energy demand for specific regions. The GEA pathways analysis indicates that a significant increase in renewable energy supplies is technically feasible and necessary in order to meet the GEA goals.

Table SPM-2. | Renewable energy flows, potential, and utilization in EJ of energy inputs provided by nature.[a]

	Primary Energy 2005[b] [EJ]	Direct Input 2005 [EJ]	Technical potential [EJ/yr]	Annual flows [EJ/yr]
Biomass, MSW, etc.	46.3	46.3	160–270	2200
Geothermal	0.78	2.3	810–1545	1500
Hydro	30.1	11.7	50–60	200
Solar	0.39	0.5	62,000–280,000	3,900,000
Wind	1.1	1.3	1250–2250	110,000
Ocean	-	-	3240–10,500	1,000,000

[a] The data are direct energy-input data, not primary energy substitution equivalent shown in the first column. Considering technology-specific conversion factors greatly reduces the output potentials. For example, the technical 3150 EJ/yr of ocean energy in ocean thermal energy conversion (OTEC) would result in an electricity output of about 100 EJ/yr.

[b] Calculated using the GEA substitution method (see Chapter 1, Appendix 1.A.3).

Source: Chapter 7.

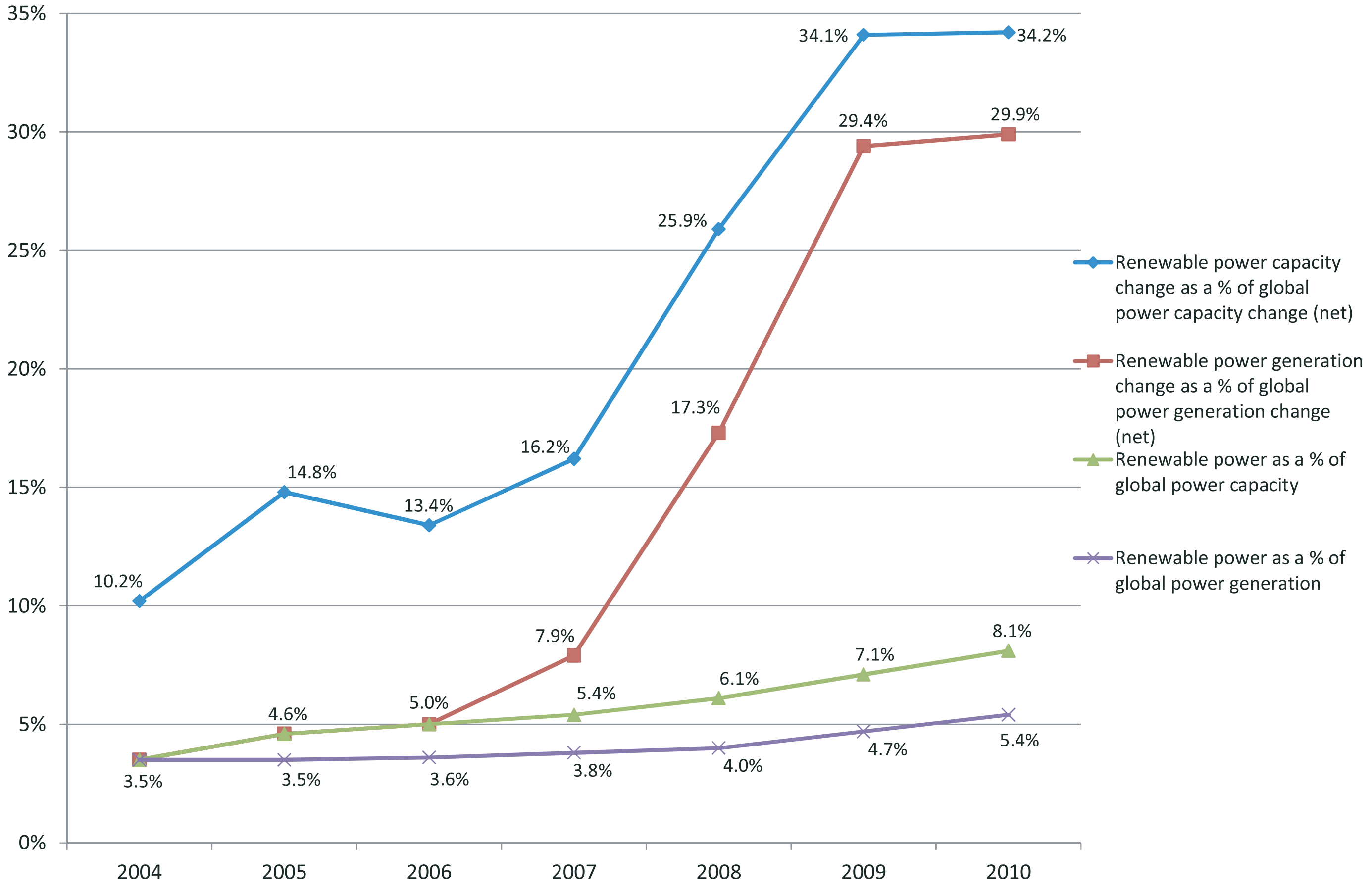

Figure SPM-6. | Renewable power capacity and generation (excluding large hydro) as a percentage of global capacity and generation, respectively, and their rates of change also in percent; 2004–2010. Source: UNEP and BNEF, 2011, see Chapter 11.[4]

The resource base is sufficient to provide full coverage of human energy demand at several times the present level and potentially more than 10 times this level (see Table SPM-2). Starting in 2007 renewable power generating capacity has grown fast in the world (see Figure SPM-6), and is now over 30% of total capacity expansion, excluding large scale hydropower. Figure SPM-7 shows a regional breakdown of the investments.

4 **UNEP and BNEF, 2011:** *Global Trends in Renewable Energy Investment 2011: Analysis of Trends and Issues in the Financing of Renewable Energy*. United Nations Environment Programme (UNEP), Nairobi, Kenya and Bloomberg New Energy Finance (BNEF), London, UK.

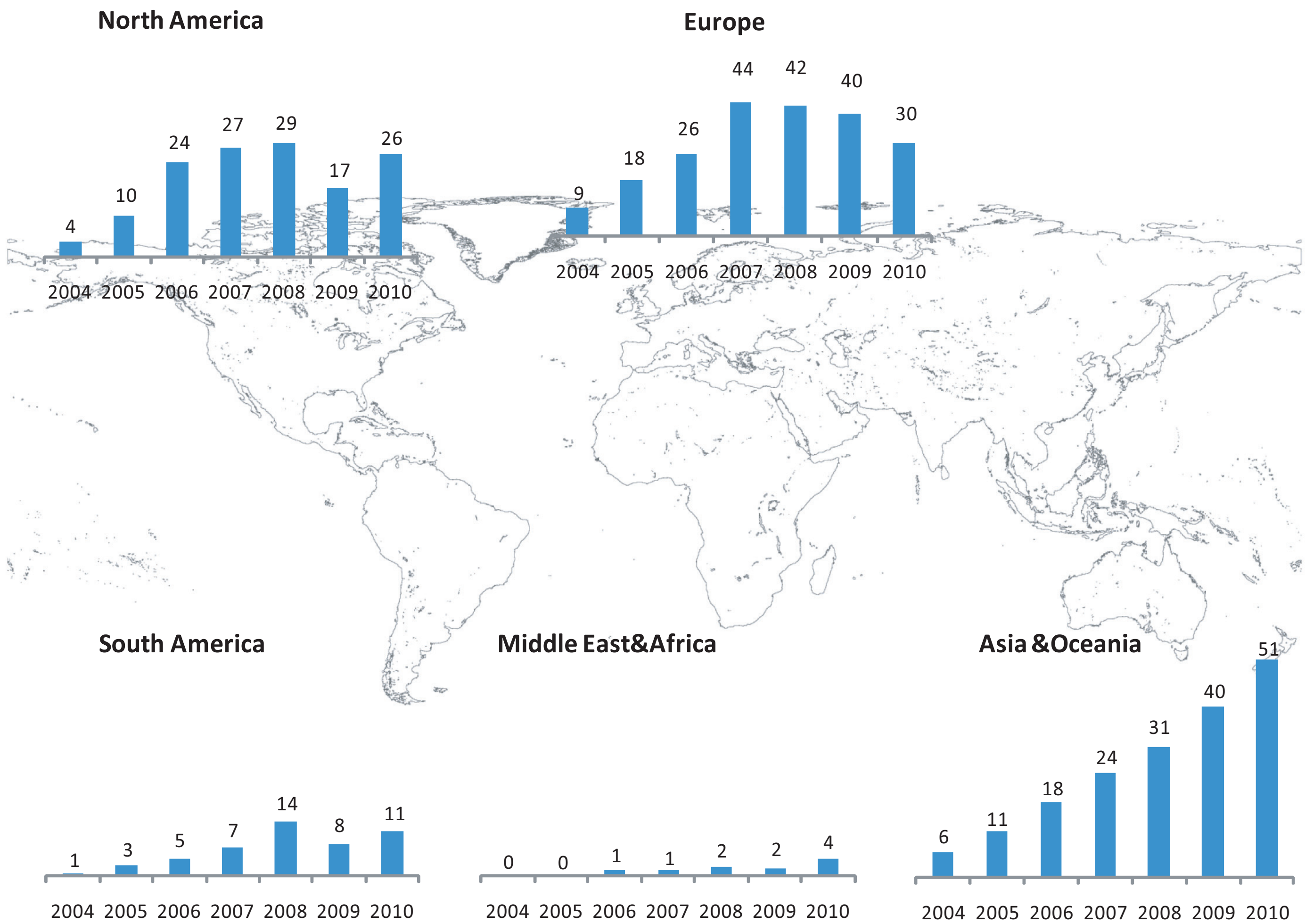

Figure SPM-7. | New financial investments in renewable energy, by region, 2004–2010 (US$$_{2005}$bn). New investment volume adjusts for reinvested equity; total values include estimates for undisclosed deals. This comparison does not include small-scale distributed energy projects or large-scale hydropower investments. Source: Chapter 11.

The rapid expansion in renewables, which has largely taken place in only a few countries, has usually been supported by incentives of different types or driven by quota requirements. Especially successful have been the feed-in tariffs used in the majority of EU countries, China, and elsewhere. Global investments in 2009 were slightly lower as a result of the financial crises (although with less reduction than for most other energy technologies), and in 2010 they rebounded. Both wind and solar PV electricity are nowadays cost-competitive in some markets and are projected to become so in many markets in the next 5–10 years without any public subsidy. However, renewables face resistance due to lock-in to conventional energies and substantial market barriers in the majority of markets.

The intermittent and variable generation of wind, solar and wave power must be handled within an electricity system that was not designed to accommodate it, and in which traditional base load-power from nuclear, geothermal and fossil power stations with restricted flexibility limit the system's ability to follow load variations. Energy systems have historically been designed to handle loads that vary over seconds, days, weeks, and years with high reliability. These systems are becoming increasingly able to accommodate increased quantities of variable generation through use of so-called smart systems with advanced sensing and control capabilities. With support from accurate and timely load forecasting, capacity management, and overall intelligent load and demand-side management, experience has shown that at least 20%, perhaps up to 50%, of variable renewable generation can be accommodated in most existing systems at low costs and that it is feasible to accommodate additional intermittent generation with additional investment in grid flexibility, low capital cost fuel-based generation, storage, and demand-side management (smart grids).

Safe and reliable improvements of interconnections between nations and across geographical regions will facilitate the compensation due to fluctuations in electricity generation from rapidly increasing shares of variable renewable energies in the system. Wind and solar PV and most hydrokinetic or ocean thermal technologies offer the unique additional attribute of virtually complete elimination of additional water requirements for power generation. Other renewable options, including bio-based options, geothermal, concentrating solar, and hydropower on a life-cycle basis, still require water for cooling of a steam turbine or are associated with large amounts of evaporation.

The development of high-voltage direct current (HVDC) transmission cables may allow the use of remote resources of wind and solar at costs projected to be affordable. Such cables have been installed for many years in sub-marine and on-shore locations, and demand is increasing (in the North Sea, for example). This is significant, as some of the best renewable energy resources are located far from load centers. In conjunction with energy storage at the generation location, such transmission cables can be used to provide base load electricity supply.

The GEA pathways analysis indicates that a significant increase in renewable energy supplies is technically feasible and necessary in order to meet the GEA objectives.

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.

Table SPM-3. | Fossil and uranium reserves, resources, and occurrences.[a]

	Historical production through 2005 [EJ]	Production 2005 [EJ]	Reserves [EJ]	Resources [EJ]	Additional occurrences [EJ]
Conventional oil	6069	147.9	4900–7610	4170–6150	
Unconventional oil	513	20.2	3750–5600	11,280–14,800	> 40,000
Conventional gas	3087	89.8	5000–7100	7200–8900	
Unconventional gas	113	9.6	20,100–67,100	40,200–121,900	> 1,000,000
Coal	6712	123.8	17,300–21,000	291,000–435,000	
Conventional uranium[b]	1218	24.7	2400	7400	
Unconventional uranium	34	n.a.		7100	> 2,600,000

[a] The data reflect the ranges found in the literature; the distinction between reserves and resources is based on current (exploration and production) technology and market conditions. Resource data are not cumulative and do not include reserves.

[b] Reserves, resources, and occurrences of uranium are based on a once-through fuel cycle operation. Closed fuel cycles and breeding technology would increase the uranium resource dimension 50–60 fold. Thorium-based fuel cycles would enlarge the fissile-resource base further.

Source: Chapter 7.

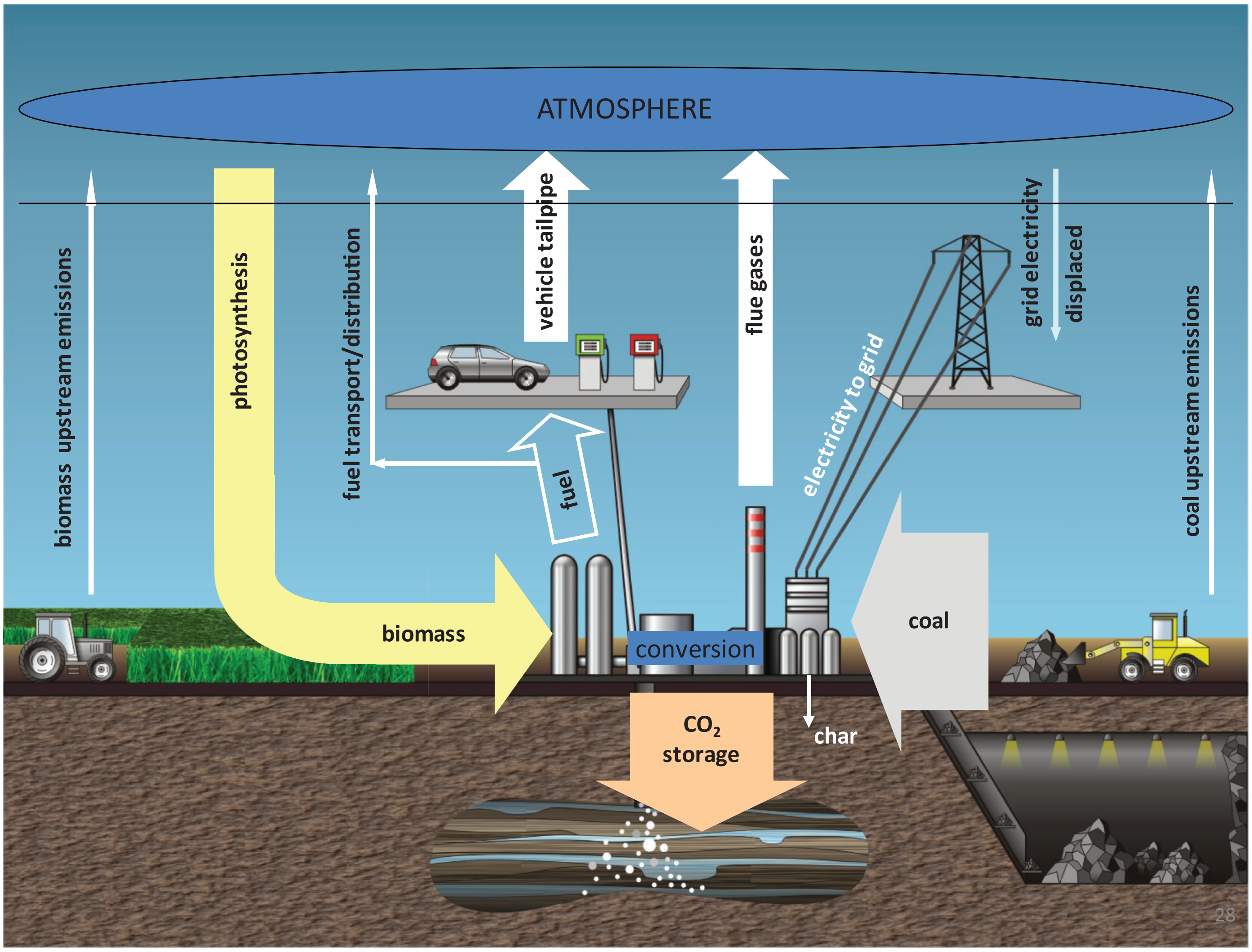

Figure SPM-8. | Carbon flows for conversion of coal and biomass to liquid fuels and electricity. For this system, when biomass is approximately 30% of the feedstock input (on a higher heating value basis), the net fuel cycle GHG emissions associated with the produced liquid fuels and electricity would be less than 10% of the emissions for the displaced fossil energy. Source: Larson et al., 2010, see Chapter 12.[5]

Continued use of coal and other fossil fuels in a carbon-constrained world requires strategies that deal with this reality. For industrial and developing countries, these strategies would differ in the short term but converge in the long term. For developing countries, the emphasis could be on increasing access to energy services based on clean energy carriers, building new manufacturing and energy infrastructures that anticipate the evolution to low-carbon energy systems, and exploiting the rapid growth in these infrastructures to facilitate introduction of the advanced energy technologies needed to meet sustainability goals. In industrial countries, where energy infrastructures are largely already in place, a high priority could be overhauling existing coal power plant sites to add additional capabilities (such as co-production of power and fuels) and CCS. Simply switching from coal to natural gas power generation without CCS will not achieve the needed carbon emission reductions.

Among the technologies that use fossil fuels, co-production strategies using coal plus biomass and CCS have the greatest ability to address all the major energy-related societal challenges. In the long term, hydrogen made from fossil fuels with CCS is an energy option, but infrastructure challenges are likely to limit this option in the near

5 **Larson, E. D., G. Fiorese, G. Liu, R. H. Williams, T. G. Kreutz and S. Consonni, 2010:** Co-production of Decarbonized Synfuels and Electricity from Coal + Biomass with CO_2 Capture and Storage: an Illinois Case Study. *Energy – Environmental Science*, **3**(1):28–42.

term. Co-production with CCS of electricity and carbon-based synthetic transportation fuels such as gasoline, diesel and jet fuel represent low-cost approaches for simultaneously greatly reducing carbon emissions for both electricity and transportation fuels and providing multiple benefits (Figure SPM 8): enhancing energy supply security, providing transportation fuels that are less polluting than petroleum-derived fuels in terms of conventional air pollutants, providing super-clean synthetic cooking fuels as alternatives to cooking with biomass and coal (critically important for developing countries), and greatly reducing the severe health damage costs due to air pollution from conventional coal power plants.

No technological breakthroughs are needed to get started with co-production strategies, but there are formidable institutional hurdles created by the need to manage two disparate feedstock supply chains (for coal and biomass) and provide simultaneously three products (liquid fuels, electricity, and CO_2) serving three different commodity markets.

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.*

Access to affordable modern energy carriers and cleaner cooking, improves well-being and enables people to alleviate poverty and expand their local economies. Enhanced access to modern energy carriers and cleaner cooking can become an effective tool for improving health for example, by reducing air pollution and can also help combat hunger by increasing food productivity and reducing post-harvest losses. Modern energy carriers and end-use conversion devices could improve education and school attendance by providing better lighting, heating, and cooling services. Electrifying rural health centers enables medical services to be provided at night, medicines to be preserved and more-advanced medical equipment to be used. Reduction of the proportional cost of energy services, particularly for rural poor people who spend a significant part of their time and disposable income on energy, is also important. This can liberate financial and human, especially women's, resources for other important activities or expenses, such as education, purchasing more and better-quality food, and expanding income-generating activities.

Several challenges exist to improving access to modern forms of energy and cleaner cooking. These include low income levels, unequal income distribution, inequitable distribution of modern forms of energy, a lack of financial resources to build the necessary infrastructure, weak institutional and legal frameworks, and a lack of political commitment to scaling up access. Even among households that have physical access to electricity and modern fuels, a lack of affordability and unreliable supplies limit their ability to use these resources, particularly for productive purposes. In addition to access to modern forms of energy, there must be access to end-use devices that provide the desired energy services. Those who can afford modern energy carriers may still not be able to afford the upfront costs of connections or the conversion technology or equipment that makes that energy useful.

While the scale of the challenge is tremendous, access to energy for all, electricity for all, and modern fuels or stoves for all by 2030 is achievable. This will require global investments of US$36–41 billion annually – a small fraction of total energy infrastructural investments required by 2030. It is expected that as households with public sector support gain access to modern energy and end-use devices and start earning incomes, their standard of living and ability to pay for the energy services utilized would successively expand.

Between 1990 and 2008 almost two billion people gained access to electricity, more than the corresponding population increase of 1.4 billion people over that time period (see Figure SPM-9). By 2030, the 1.4 billion people currently without access to electricity plus the projected population increase to 2030 of 1.5 billion people need to be connected to meet the GEA goal on electricity access (see Figure SPM-10). To achieve this, a multitrack approach is needed, combing grid extension with microgrids and household systems. Grid extension is currently the lowest cost per kWh delivered and also the preferred delivery form by most customers because of the capacity to deliver larger quantities of power for

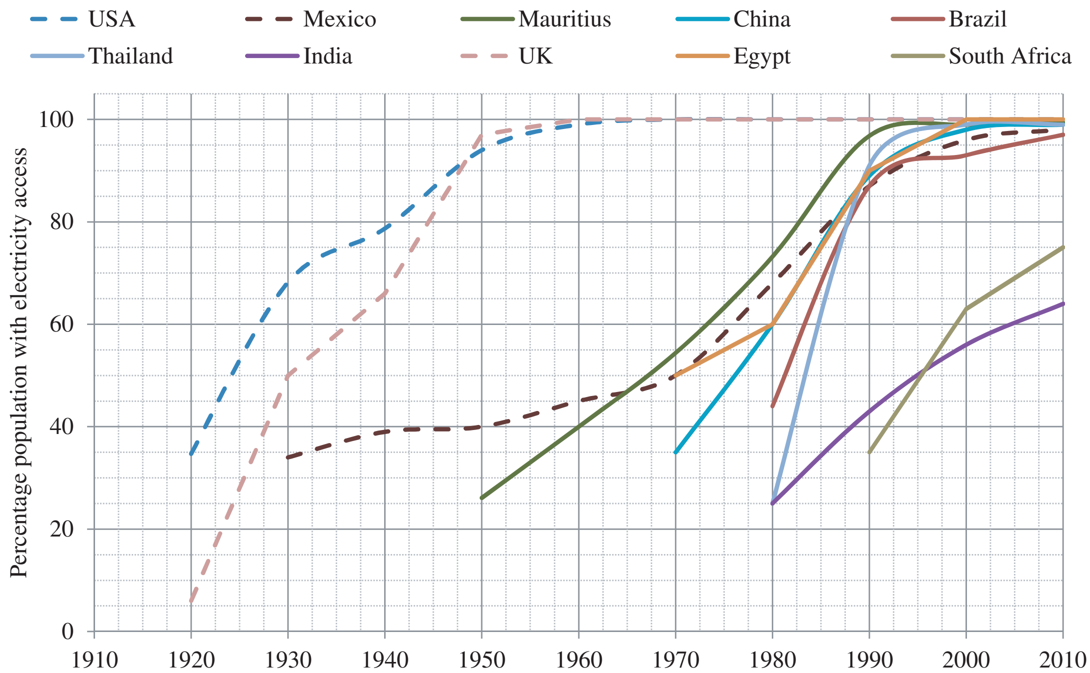

Figure SPM-9. | Historical experience with household electrification in select countries. Source: Chapter 19.

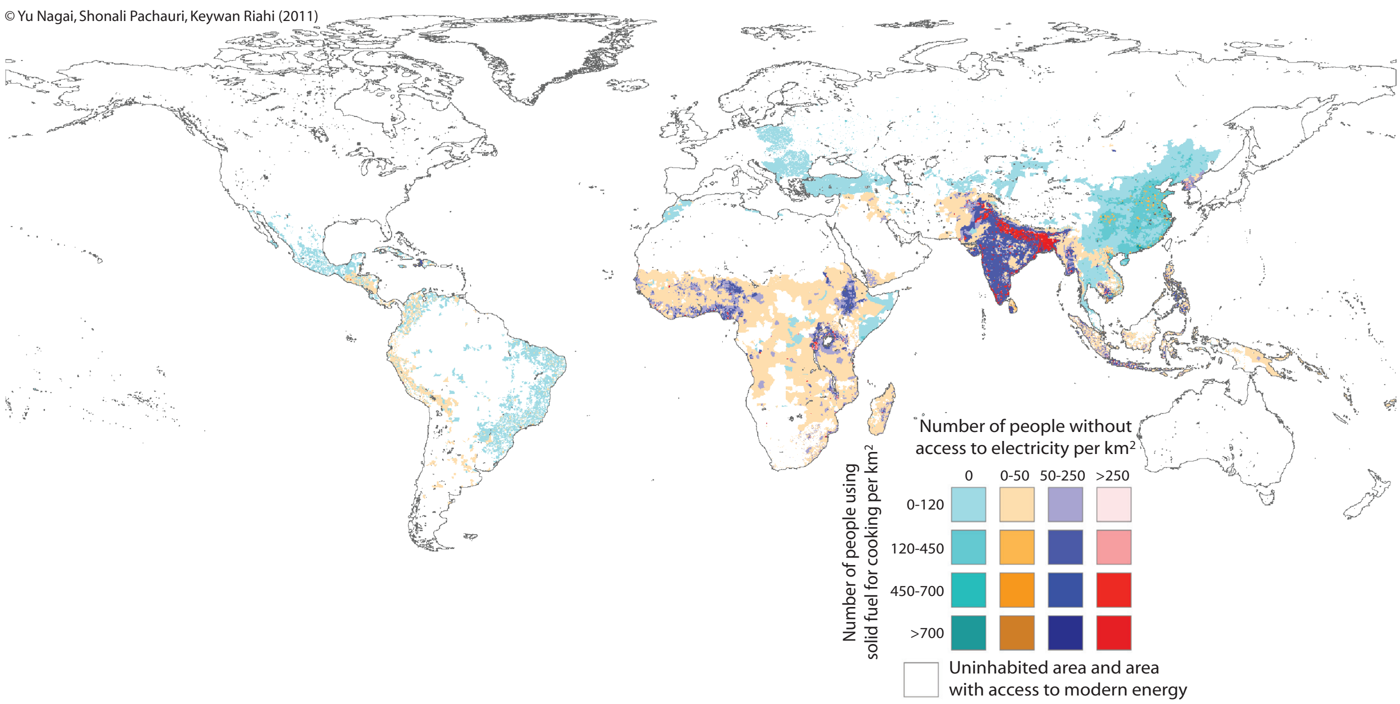

Figure SPM-10. | Density of population lacking access to modern energy carriers in 2005. Colored areas show people per km^2 without access to electricity and those that use solid fuels for cooking, e.g., dark blue and red areas show where people do not have access to electricity and cook predominately using solid fuels. Source: Chapters 17 and 19.

productive purposes. For many remote populations grid extension by 2030 will be highly unlikely and microgrids offer an alternative, based on local renewable energies or imported fossil fuels. An interesting approach to providing modern energy and development in remote villages is the multifunctional platform beginning to gain hold in West Africa. Household electrification is expanding rapidly in some countries, based on solar PV that are financed by micro-credits that has been done without increasing household expenses for energy (replacing candles and kerosene).

About 3 billion people rely entirely, or to a large degree, on traditional biomass or coal for cooking and heating. This number has not changed appreciably over the last decades, particularly among households in rural areas. Indeed, more people rely on these fuels today than any time in human history. Improving the cooking experience for these populations will require access to cleaner liquid or gaseous fuels, especially biogas, liquid petroleum gas (LPG), and ethanol, or alternatively access to advanced biomass stoves with efficiency and pollutants emissions similar to those of gas stoves. Transitioning to such fuels or stoves is not likely to have negative implications for climatic change. This is because transitioning to modern fuels (even in the case that these are fossil based) will displace large quantities of traditional biomass use. Current technologies that use traditional biomass are a factor 4–5 times less efficient than cooking with modern fuels such as LPG, and are associated with significant emissions of non-CO_2 Kyoto gases (e.g., CH_4, N_2O) and aerosols (e.g., BC, OC) due to incomplete combustion.

Providing universal and affordable access to electricity and cleaner cooking is possible if timely and adequate policies are put in place. Overall, and on the basis of successful experiences of increasing access to modern energy, no single approach can be recommended above the others. What is clear, however, is that the current institutional arrangements and policies have met with mixed success, at best. Reforms are needed, at global and country level, to strengthen the feasibility of energy projects for poor people, expand the range of players involved, open up the regulatory system, and allow for innovation. In the specific case of access to cleaner cooking, fuel subsidies alone will be neither sufficient nor cost-effective in terms of achieving ambitious energy access objectives (see Figure SPM-11). Financial mechanisms, such as micro-credit, will need to complement subsidies to make critical end-use devices such as cleaner cookstoves affordable for poor people.

A paradigm shift is needed in the approach to energy planning and policy implementation in order to facilitate access to modern forms of energy and cleaner cooking. Current supply-side approaches that simply take as their starting point the provision of electricity, petroleum, or gas, or of equipment of a particular type (solar technology, improved cookstoves, biogas, and other forms of bioenergy) are unable to reap the full potential of social and economic improvements that

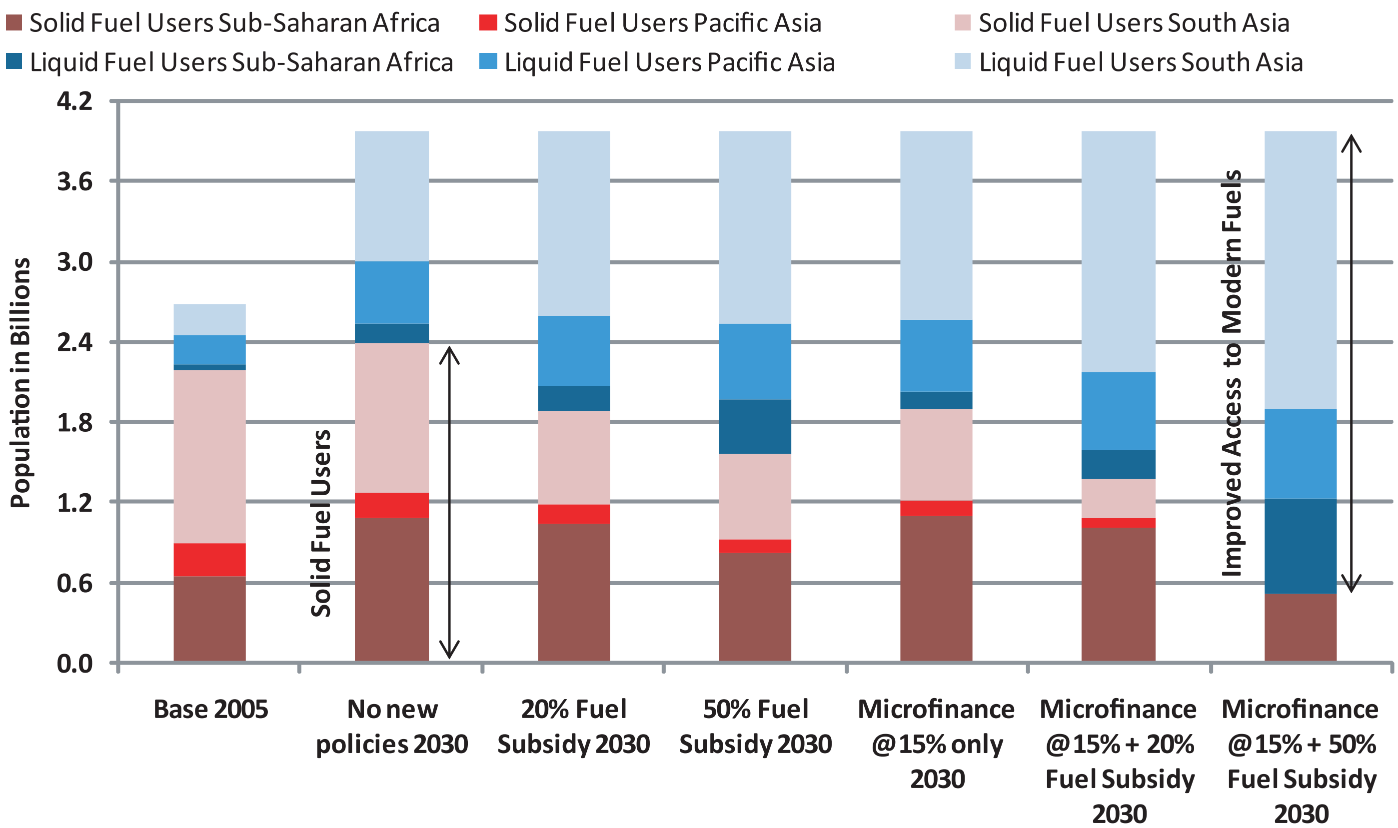

Figure SPM-11. | Impact of alternative policy scenarios on access to cleaner cooking fuels in three developing regions. Subsidies are relative to consumer price levels and are additional to existing subsidies. Source: Chapter 17.

follow from improved energy access and cleaner cooking. Leveraging funding and access to capital from public and private sources – for needed investments at the macro level and, at the micro level, for meeting costs for low-income households – is crucial in efforts to expand access to energy services for the poorest people. Creative financing mechanisms and transparent cost and price structures will be critical to achieving the required scale-up and quick roll-out of solutions to improve access.

Policy recommendations in the form of general ideas or guidelines are provided below. Regional and national contexts should be considered in defining strategies, instruments, and measures.

- A better understanding and a clearer diagnosis of the structure and functioning of energy systems, along with the needs (energy services) to be supplied, is needed. It has often been absent in the discussion of proposals and the role of public policies. Good policies need good diagnoses. Support and funds for diagnosis and information should be part of the strategies.

- Subsidies are generally justified as a response to inequality and social expectations in energy provision. However, their net effect can be positive or negative depending on the intended goals of the subsidy, and the way a subsidy is implemented. An effective tariff and subsidy regime has to be transparent and minimize administrative costs to avoid gaming of the system and to maximize the benefits that accrue to the intended recipients. Subsidies to energy should be complemented with funds toward solving the first-cost capital financing problem since up-front costs of equipment are, usually, the key barrier.

- Financing mechanisms are needed for every scale of energy intervention. Mobilizing affordable and genuine international, regional, national, and local funds is crucial.

- Energy access policy is part of a wider development policy and should be aligned with other sector policies and objectives. If these policies are misaligned, they can reduce the effectiveness of any given policy. Policy misalignments can occur when different energy policies work at cross-purposes or when government priorities that could benefit from an effective energy policy are not aligned. In particular, there is a need to link rural and peri-urban energy supply more closely with rural development. This would shift the focus from minimal household supply to a more comprehensive approach to energy that includes productive activities and other welfare-enhancing uses of energy. Ideally, the linkages between energy and other policy priorities, such as health, education, gender equality and poverty alleviation, should be recognized explicitly and local solutions that address these needs be encouraged and supported.

- Capacity development is needed, especially for the design and implementation of public policies oriented to poor people.

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.*

Energy-focused policies must be coordinated and integrated with policies addressing socioeconomic development and environmental protection in other sectors. Effective policy portfolios will require a combination of instruments, including regulatory frameworks and investment policies, as well as measures for strengthening capacity development, which stimulate innovation.

The main conclusion from the GEA pathways analysis is that energy efficiency improvements are the most important option to increase the flexibility of regional and sectoral energy end use and supply systems. In pathways with high rates of efficiency improvements, it was possible to achieve the GEA normative goals under any of the assumed supply portfolio restrictions and even without including nuclear energy and CCS technologies.

Energy systems differ between regions, between major economies, and between developing and industrial countries. Approaches to the necessary transitions to create energy systems for a sustainable future therefore vary, and policies that work successfully in one region may fail in another. Nevertheless, there are lessons to be learned from shared experiences. The evolution of energy systems will depend on how well technologies are implemented and how well policies are instituted to bring about the required changes.

Prevailing market and institutional structures in the energy sector have a significant influence on investments in different end-use and supply-side options. In countries with well-developed energy markets, spot-market energy trading is common and long-term contracts are becoming less frequent; and it is now more difficult to ensure long-term returns on large-scale investments. This is the main impediment to financing of large capital-intensive energy-supply projects.

Governments must recognize that policies promoting competition in the electricity sector must also prevent the short-term exercise of market power that results in unjustified excessive profits for some producers and speculators as well as price volatility for consumers, requiring continued regulation and public sector involvement in energy system planning and long-term contracting.

A regulatory framework is essential as it facilitates the creation and modernization of physical infrastructure and capital investments in energy end-use and supply systems. It is also necessary for economic development and poverty reduction.

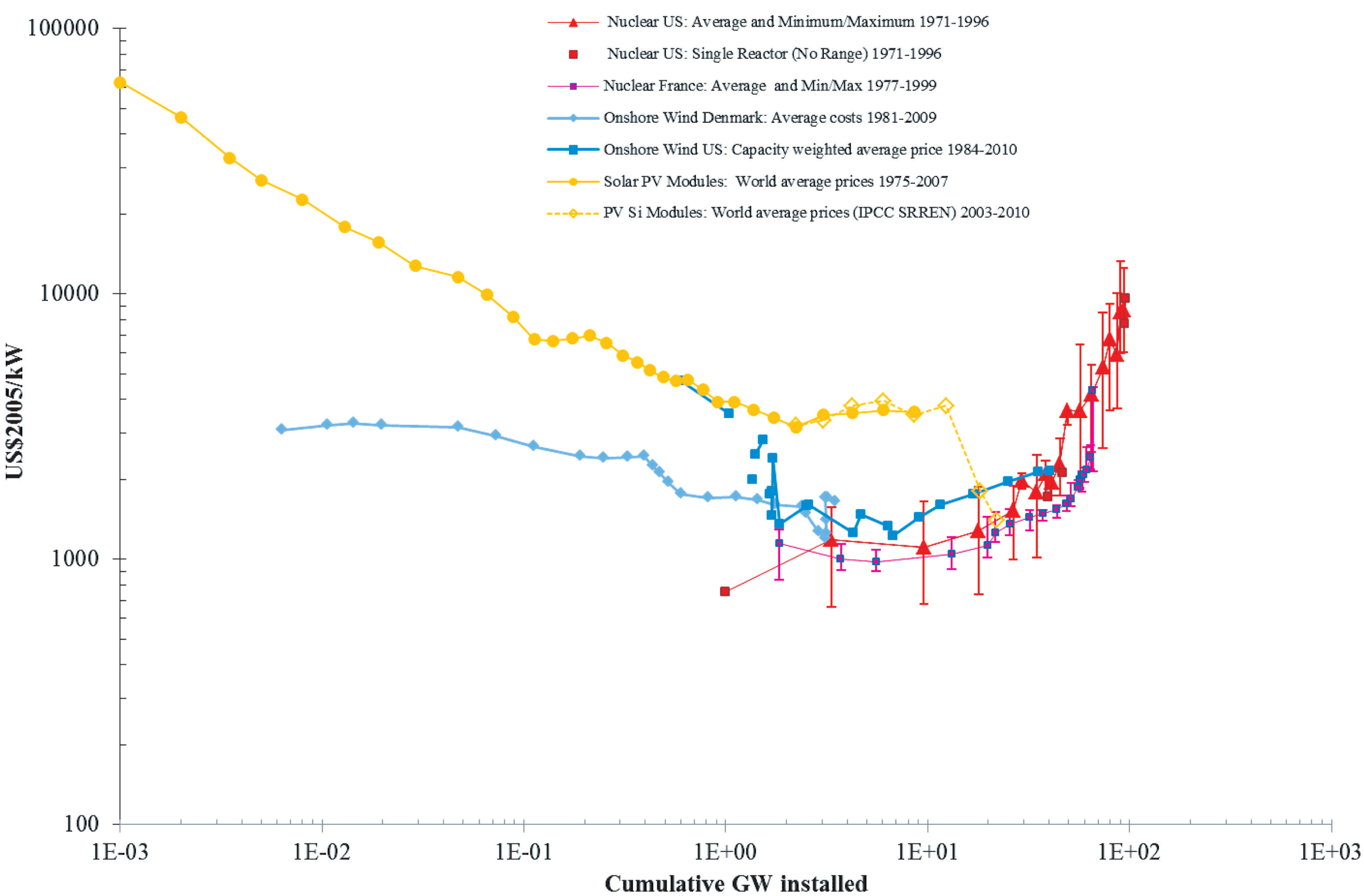

Figure SPM-12. | Cost trends of selected non-fossil energy technologies (US$2005/kW installed capacity) versus cumulative deployment (cumulative GW installed) Chapter 24 data have been updated with most recent cost trends (2010) available in the literature for PV Si Modules and US onshore wind turbines. Note that the summary illustrates comparative cost trends only and is not suitable for direct economic comparison of different energy technologies due to important differences between the economics of technology components (e.g. PV modules versus total systems installed), cost versus price data, and also differences in load factors across technologies (e.g., nuclear's electricity output per kW installed is three to four times larger than that of PV or wind turbine systems). Source: Chapter 24.

Success will depend on the implementation of robust public and private partnerships that can achieve unprecedented cooperation and integration between and among the public and private sectors, civil society, and academia.

A multiplicity of policies is required to address the potential impacts of the energy system on human health and the environment. A mix of regulations, information programs, and subsidies are needed, for example, to stimulate the rapid adoption of household energy-using devices that have virtually zero indoor emissions. Ambient air quality requires regulations on emissions from fuel combustion. Similarly, regional air quality must be protected by technology and emissions regulations or by direct emissions pricing.

Policies to foster energy from biomass should seek to minimize the trade-offs between biomass for food and biomass for fuel by encouraging the use of biomass residues and sustainable feedstocks as well as efficient conversion processes. Many developing countries import all or most of their current liquid fuels (in the form of oil and diesel) at increasingly higher costs and have at the same time large areas that are off-grid.

Greenhouse gas pricing policies will be essential in shifting energy systems toward low-carbon emission technologies, fuels, and activities. While there is disagreement on which pricing method is best – carbon taxes or cap and trade – the two approaches can be designed so that their effects are quite similar. The price certainty of a carbon tax can be approximated with cap and trade by setting a price floor and ceiling for permit prices. The revenues generated by a carbon tax can also be obtained by auctioning permits in the cap and trade approach

It is important to complement GHG pricing with a portfolio of other regulatory and market mechanisms. This is because different instruments are more effective in different sectors, geographic and cultural regions, as well as for different options. For instance, due to the magnitude and diversity of market barriers prevailing in the building sector, different regulatory and market-based instruments and their packages needed to be tailored to overcome specific barriers.

Strategic alliances and strong coordination among various policy fields will be able to lead to the realization of a larger share of technological potential by improving the economics of efficiency investments through the addition of further benefits to cost-efficiency considerations, such as security, employment, social welfare, and regional development. For example, policies for urban planning that encourage high density development with investments in public transport are likely to lead to lower long-term energy demand. Similarly, policies for renewable energy technologies could emphasize positive spillover effects on new venture and job creation. By actively seeking opportunities for such cross-sectoral integration; the required changes in the energy system may be accelerated. For example, a shift to clean cooking may be regarded as much a required change in the energy system, as an intervention to improve maternal and child health.

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 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 perpectives and at multiple levels of governance.*

The energy systems illustrated by the GEA pathways meet the sustainability goals by design while generating substantial economic, environmental, and social benefits. For example, achieving near-term pollution and health objectives is furthered by investing in the same energy technologies that would be used to limit climate change. Policies to control emissions of greenhouse gases, or to increase access to cleaner cooking fuels could, in turn, bring significant improvements in pollution related health impacts. For example as the GEA pathways indicate, a saving of 20 million disability adjusted life years (DALYs) from outdoor air pollution and more than 24 million DALYs from household air pollution. In addition, universal access to electricity and cleaner cooking fuels opens up opportunities for education, for income generating activities, and significantly improved well-being.

This synergy is crucial and advantageous, given that measures which lead to local and national benefits (e.g., improved health and environment) may be more easily adopted than those measures that are put forward solely on the grounds of global goals. Many energy efficiency and renewable energy options enjoy such synergies and generate benefits across multiple objectives. Some of these advantages can be so substantial for certain investments and measures that they may offer more attractive entry points into policymaking than the climate or social targets alone. This is particularly the case where benefits are local rather than global. Seeking local benefits and receiving global benefits as a bonus is very attractive, and this is often the case for investments in energy efficiency and renewable sources of energy.

Therefore, even if some of these multiple benefits cannot be easily monetized, identifying and considering them explicitly may be important for decision-making. Cost-effectiveness (or cost-benefit) analyses evaluating energy options may fare differently when multiple benefits are considered.

The enhancement of end-use efficiency in buildings, transport and industry offers many examples of benefits across multiple environmental, social, and economic objectives:

- *inter alia* improved social welfare as a result of very high efficiency and thus very low fuel-cost buildings;
- reduced need for public funds spent on energy price subsidies for people living in poverty; health benefits through significantly reduced indoor and outdoor air pollution, often translating into commendable productivity gains;
- productivity gains and general improvements in operational efficiency in industry translate into strengthened competitiveness; and
- enhancing efficiency by increasing the rate of building retrofits can in addition be a source of employment and know-how.

Other benefits that are difficult to quantify include improved comfort and well-being, reduced congestion, new business opportunities, and better and more durable capital stock.

Rapid decarbonization of the energy system for climate protection also reduces the need for subsidies presently given to carbon-intensive petroleum products and coal. Subsidies for these fuels amount to approximately US$132–240 billion per year, and only 15% of this total is spent directly towards those with limited access to clean energy. However, GHG mitigation in the GEA pathways would, at the same time, reduce consumption of carbon-intensive fossil fuels, leading to a reduction in the need for subsidies for petroleum products and coal in the order of US$70–130 billion per year by 2050 compared to today.

Whether an impact is a benefit or a liability depends on the baseline and specific local situation. For example, while LPG causes major environmental and climate impacts in itself, it still has major advantages in many areas when it replaces traditional biomass as a fuel. Thus a unique novelty of the analysis is that it provides a new, additional framework for a well-founded assessment for individual decisions to choose among various energy alternatives, which complement financial appraisals. For example, in regions where access to modern forms of energy is a major energy policy goal, evaluations of "energy security" will play an essential role in ranking the different options available at comparable costs. In other areas, access or employment may be key secondary objectives of energy policy and these can play an important role in additional prioritization of options with comparable local costs.

There is a broad array of different benefits in the spectrum of policy target areas, which represent many potential entry points into policy-making. However, some options can have a wider range of multiple benefits than others, in particular renewable energies and improved energy end-use efficiency.

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 system, 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.*

The complexity, magnitude, and speed of the changes envisaged in this transformation will necessitate a major shift in the way that societies analyze and define the concept of 'capacities' and the way in which they go about the important task of developing these capacities to meet the challenges of energy transitions. Different from some of the linear approaches to capacity development and to technology transfer and deployment used today, which often fail to appreciate the complexity of change processes, the concept of capacity development advanced by the GEA is intimately linked to the energy transitions perspective based on multilayered processes of system change.

In these processes, special attention is paid to the informal institutions that arise out of historically shaped habits, practices, and vested interests of players in the system already in place and to the tendency for path dependence, where past choices constrain present options. They are given special attention because they constitute potential impediments to needed change. In the transitions perspective, both learning and unlearning such habits, practices, and norms in the course of change are important.

Traditional habits, practices, and norms also shape the styles of communication in societies. Evidence shows that the more successful change processes take place in environments that tend to move away from top-down communication and consultation to more active and continuous dialogue practices. Capacity development has an important role to play in building mechanisms of support and capacities for interactive feedback, flexibility, and adaptive management and change. And because these traditional habits, practices, and norms are embedded in a broader social context, building capacities for dialogue at the local level is essential.

Market development and the role of feedback and flexibility at the local and project level are also essential in support of the diffusion of new energy technologies, but they are usually ignored in the design of capacity building initiatives. Also important is the need to build and strengthen capacities for local manufacture, repair, and distribution of new energy-related technologies, whether related to improved cookstoves, solar home systems, or other forms of early energy access initiatives, or to the introduction of more modern and decentralized forms of energy. Successful examples of energy technology development and diffusion also point to the need to develop and strengthen local research capacities, participating in collaborative research and development efforts and coordinating across sectors and disciplines.

But these new and emerging forms of knowledge networking, coupled with new and innovative forms of finance and technology research collaboration and development, require new and enhanced capacities for effective participation on the international level that many countries, particularly developing ones, do not have or are not well developed today. The increasingly complex and fast-paced world of energy and climate change finance is a good example of an area where present capacities fall far short of the need. The recent climate change negotiations alone have generated pledges of fast-start finance up to 2012 of some US$30 billion and promises to work collaboratively so that this funding can grow to some US$100 billion by 2020.

This is only a small part of the overall investment projections needed to meet the high growth in energy demand – some US$1.7–2.2 trillion per year are needed to 2050. The world of energy finance has always been a large and complex market. The difference today is that it is becoming even more complex, with new and innovative instruments of finance, including the carbon market, and with countries demanding more attention to the need to develop, introduce, and diffuse new technologies. Under these conditions, a multi-goal approach can both speed the diffusion of new energy technologies as well as stimulate the development and energy transition processes in developing countries.

10. Policies, 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 fuels. 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 fuels 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 GEA analysis has identified pronounced asymmetries in current incentive structures for the development, early deployment, and the widespread diffusion of energy end-use and supply technologies that need rebalancing. Current technology policy frameworks are also often fragmented and contradictory instead of integrated and aligned. Nowhere is this more apparent that in the continued subsidies for fossil fuels that amount to close to US$500 billion and are in direct contradiction with policy initiatives that promote increasing energy end-use efficiency and deployment of renewables. This assessment has also identified a marked mismatch between the critical needs for vastly improved energy efficiency and the under-representation of energy efficiency in publicly funded energy research and development and deployment (RD&D) and incentives for early market deployment of new technologies which are presently characterized by a distinct supply-side over-emphasis.

A first, even if incomplete, assessment of the entire global investments into energy technologies – both supply and demand-side technologies – across different innovation stages suggests RD&D investments of some US$50 billion, market formation investments (which rely on directed public policy support) of some US$150 billion, and an estimated range of US$1–5 trillion investments in mature energy supply and end-use technologies (technology diffusion). The GEA pathways estimate the current annual energy investments at about US$1.3 trillion per year. The difference to the estimated range up to US$5 trillion is related mostly to the magnitude of demand-side investments that is not included in the pathways. Demand-side investments are of critical importance, particularly because the lifetimes of end-use technologies can be considerably shorter than those on the supply side. Demand-side investments might thus play an important role in achieving pervasive and rapid improvements in the energy system.

Major developing economies have become significant players in global energy technology RD&D, with public- and private-sector investments approaching some US$20 billion – in other words, almost half of global innovation investments – which are significantly above OECD public-sector energy RD&D investments (US$13 billion).

Policies now need to move toward a more integrated approach, stimulating simultaneously the development as well as the adoption of efficient and cleaner energy technologies and measures. RD&D initiatives without simultaneous incentives for consumers to adopt the outcomes of innovation efforts risk not only being ineffective but also precluding the market feedbacks and learning that are critical for continued improvements in technologies.

Another area of near-term technology policy focus is the domain of enhancing the international cooperation in energy technology research and development as well as in the domains of technology standards. Through dynamic standard setting and international harmonization, predictable and long-term signals are provided to innovation players and markets. Ambitious efficiency standards are of particular urgency for long-lived capital assets such as buildings. Other end-use technologies such as vehicles or appliances turn over much more quickly, offering the possibility of more gradually phased in technology standards as long as clear long-term signals are provided.

Table SPM-4. | Energy investments needed between 2010 and 2050 to achieve GEA sustainability goals and illustrative policy mechanisms for mobilizing financial resources. GEA pathways indicate that global investments in combined energy efficiency and supply have to increase to about US$1.7–2.2 trillion per year compared with the present level of some US$1.3 trillion (2% of current gross world product). Given projected economic growth, this would be an approximately constant fraction of GDP in 2050.

Times	Investment (billions of US$/year)		Policy mechanisms			
		2010–2050	Regulation, standards	Externality pricing	Carefully designed subsidies	Capacity building
Efficiency	n.a.[a]	290–800[b]	*Essential* (elimination of less efficient technologies every few years)	*Essential* (cannot achieve dramatic efficiency gains without prices that reflect full costs)	*Complement* (ineffective without price regulation, multiple instruments possible)[c]	*Essential* (expertise needed for new technologies)
Nuclear	5–40[d]	15–210	*Essential* (waste disposal regulation and, of fuel cycle, to prevent proliferation)	*Uncertain* (GHG pricing helps nuclear but prices reflecting nuclear risks would hurt)	*Uncertain* (has been important in the past, but with GHG pricing perhaps not needed)	*Desired* (need to correct the loss of expertise of recent decades)[e]
Renewables	190	260–1010	*Complement* (feed-in tariff and renewable portfolio standards can complement GHG pricing)	*Essential* (GHG pricing is key to rapid development of renewables)	*Complement* (tax credits for R&D or production can complement GHG pricing)	*Essential* (expertise needed for new technologies)
CCS	<1	0–64	*Essential* (CCS requirement for all new coal plants and phase-in with existing)	*Essential* (GHG pricing is essential, but even this is unlikely to suffice in near term)	*Complement* (would help with first plants while GHG price is still low)	*Desired* (expertise needed for new technologies)[e]
Infrastructure[f]	260	310–500	*Essential* (security regulation critical for some aspects of reliability)	*Uncertain* (neutral effect)	*Essential* (customers must pay for reliability levels they value)	*Essential* (expertise needed for new technologies)
Access to electricity and cleaner Cooking[g]	n.a.	36–41	*Essential* (ensure standardization but must not hinder development)	*Uncertain* (could reduce access by increasing costs of fossil fuel products)	*Essential* (grants for grid, micro-financing for appliances, subsidies for clean cookstoves)	*Essential* (create enabling environment: technical, legal, institutional, financial)

[a] Global investments into efficiency improvements for the year 2010 are not available. Note, however, that the best-guess estimate from Chapter 24 for investments into energy components of demand-side devices is by comparison about US$300 billion per year. This includes, for example, investments into the engines in cars, boilers in building heating systems, and compressors, fans, and heating elements in large household appliances. Uncertainty range is between US$100 billion and US$700 billion annually for investments in components. Accounting for the full investment costs of end-use devices would increase demand-side investments by about an order of magnitude.

[b] Estimate includes efficiency investments at the margin only and is thus an underestimate compared with demand-side investments into energy components given for 2010 (see note a).

[c] Efficiency improvements typically require a basket of financing tools in addition to subsidies, including, for example, low- or no-interest loans or, in general, access to capital and financing, guarantee funds, third-party financing, pay-as-you-save schemes, or feebates as well as information and educational instruments such as labeling, disclosure and certification mandates and programs, training and education, and information campaigns.

[d] Lower-bound estimate includes only traditional deployment investments in about 2 GW capacity additions in 2010. Upper-bound estimate includes, in addition, investments for plants under construction, fuel reprocessing, and estimated costs for capacity lifetime extensions.

[e] Note the large range of required investments for CCS and nuclear in 2010–2050. Depending on the social and political acceptability of these options, capacity building may become essential for achieving the high estimate of future investments.

[f] Overall electricity grid investments, including investments for operations and capacity reserves, back-up capacity, and power storage.

[g] Annual costs for almost universal access by 2030 (including electricity grid connections and fuel subsidies for cleaner cooking fuels).

Some of the policies for energy for sustainability described above simply involve an improvement of existing policies, such as better management of the electricity sector or more responsible use of fossil fuel resource rents. But the dominant message of the GEA is that the global energy system must be rapidly modified and expanded to provide energy access to those who have none, and must quickly transform to an energy system more supportive of sustainable development. This transition will require considerable investments over the coming decades. Table SPM-4 indicates the necessary investments to achieve this as estimated by the GEA, and links these to the types of policies needed. It also assesses these policies in terms of their necessity and their ability to complement or substitute for each other. Although considerable, these investment levels can be compared to estimates of global fossil fuel subsidy levels on the order of US$500 billion a year, of which an estimated US$100 billion goes to producers.

Table SPM-4 compares the costs and policies for different technology options to those of promoting energy access. Different types of technologies and objectives will require different combinations of policy mechanisms to attract the necessary investments. Thus, the Table identifies 'essential' policy mechanisms that must be included for a specific option to achieve the rapid energy system transformation, 'desired' policy mechanisms that would help but are not a necessary condition, 'uncertain' policy mechanisms in which the outcome will depend on the policy emphasis and thus might favor or disfavor a specific option, and policies that are inadequate on their own but could 'complement' other essential policies.

GEA findings indicate that global investments in combined energy efficiency and supplies have to increase to about US$1.7–2.2 trillion per year compared with the present level of some US$1.3 trillion (2% of current gross world product). Given projected economic growth, this would be an approximately constant fraction of GDP in 2050.

For some objectives, such as energy access, future investment needs are comparatively modest. However, a variety of different policy mechanisms – including subsidies and regulation as well as capacity building programs – need to be in place. Regulations and standards are also essential for almost all other options listed in the Table, while externality pricing might be necessary for capital-intensive technologies to achieve rapid deployment (such as a carbon tax to promote diffusion of renewables, CCS, or efficiency). The GEA estimates that the investment requirements to transform energy systems are in the range of US$1.7–2.2 trillion per year through 2020. Capital requirements for energy infrastructure are only a small part of the overall investment projections, but among the highest priorities of the options listed. A multi-goal approach can both speed the diffusion of new energy technologies as well as stimulate the development and energy transition processes in developing countries.

Increasing investments in the energy system as depicted by the GEA pathways requires the careful consideration of a wide portfolio of policies in order to create the necessary financial incentives, adequate institutions to promote and support them, and innovative financial instruments to facilitate them The portfolio needs to include regulations and technology standards in sectors with, for example, relatively low price elasticity in combination with externality pricing to avoid rebound effects, as well as targeted subsidies to promote specific 'no-regret' options while addressing affordability. In addition, focus needs to be given to capacity development to create an enabling technical, institutional, legal, and financial environment to complement traditional deployment policies (particularly in the developing world).

In sum, the GEA finds that attainment of a sustainable future for all is predicated on resolving energy challenges. This requires the creation of market conditions, via government interventions, that invite and stimulate investments in energy options that provide incentives for rapid investments in energy end-use and supply technologies and systems.