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Summary for Policymakers

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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

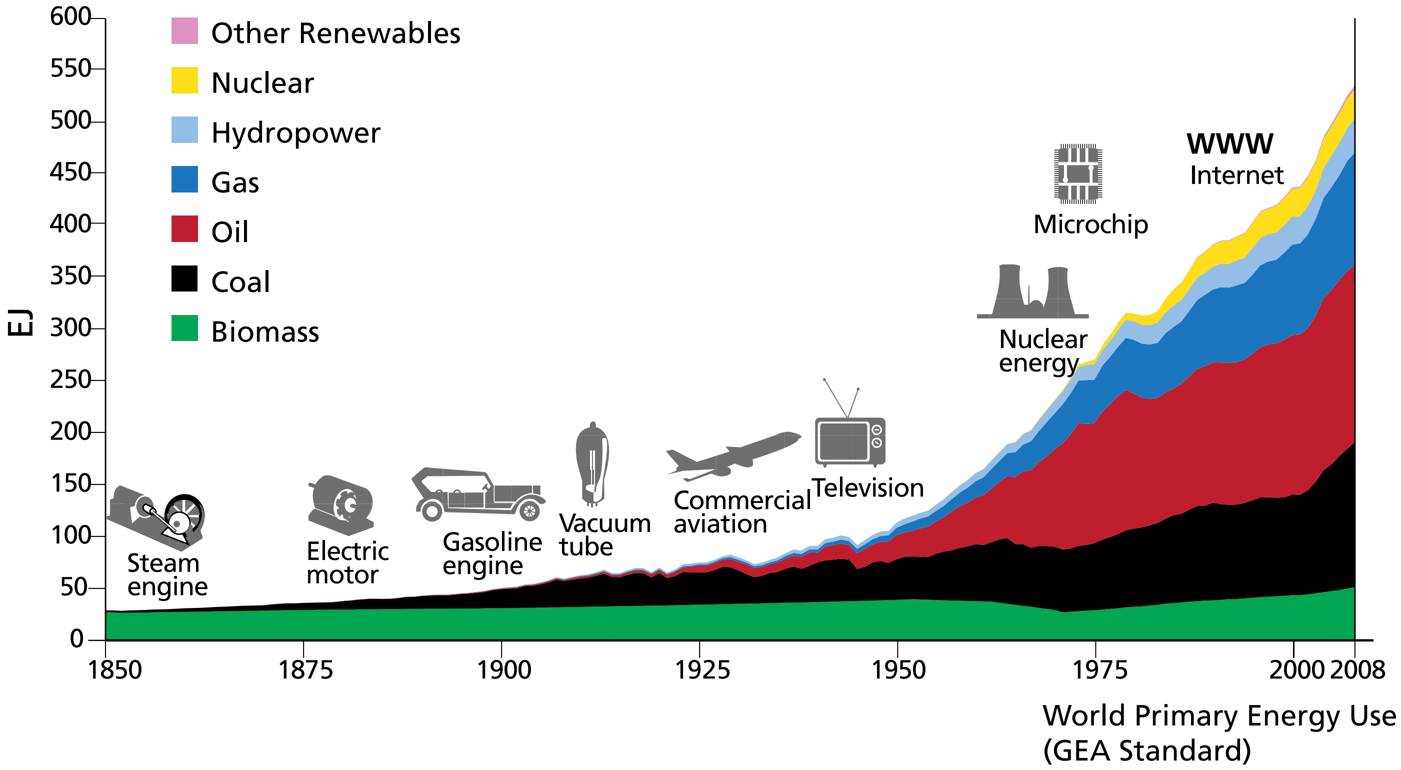

Figure SPM-1. | Evolution of primary energy shown as absolute contributions by different energy sources (EJ). Biomass refers to traditional biomass until the most recent decades, when modern biomass became more prevalent and now accounts for one-quarter of biomass energy. New renewables are discernible 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.

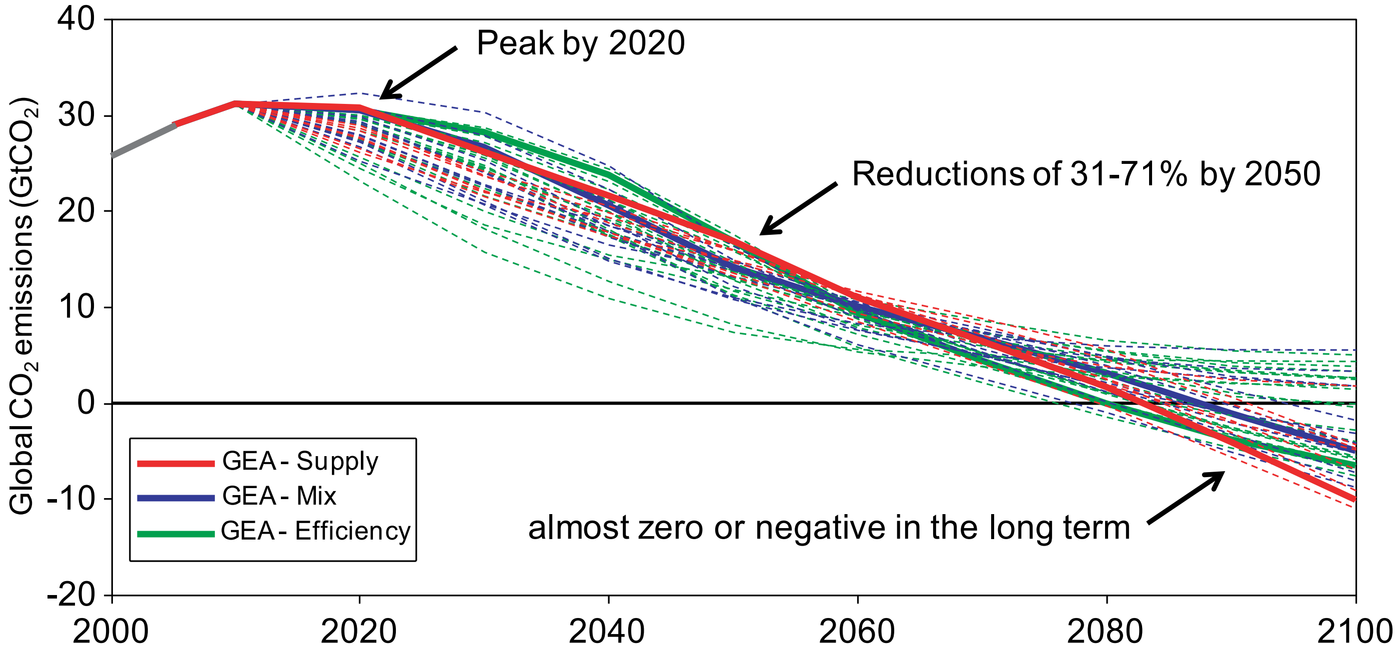

Figure SPM-2. | Development of global CO_2 emissions from energy and industrial sources to limit temperature change to below 2°C (with a success probability of >50%). Shown is that the emissions need to peak by around 2020 (or earlier) and decline toward zero during the following four to five decades. 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

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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).

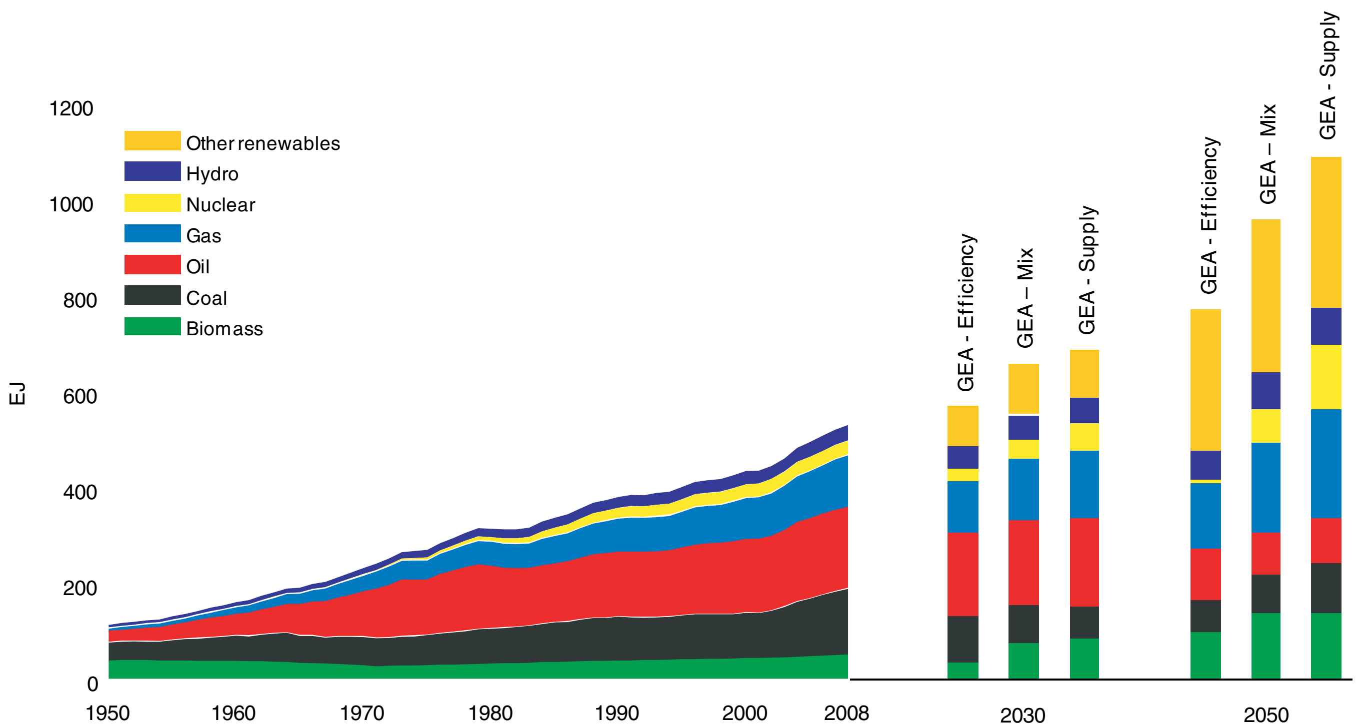

Figure SPM-3. | Development of primary energy to 2008 and in the three illustrative GEA pathways for the years 2030 and 2050. Source: based on Figures TS-24 and 17.13, Chapter 17. For further details of the GEA pathways see the interactive web-based GEA scenario database hosted by IIASA: www.iiasa.ac.at/web-apps/ene/geadb.

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.*