The structure of the global energy system has undergone major transitions over the past two centuries. The energy triangle in Figure-1 offers a useful tool for visualizing these grand transitions.

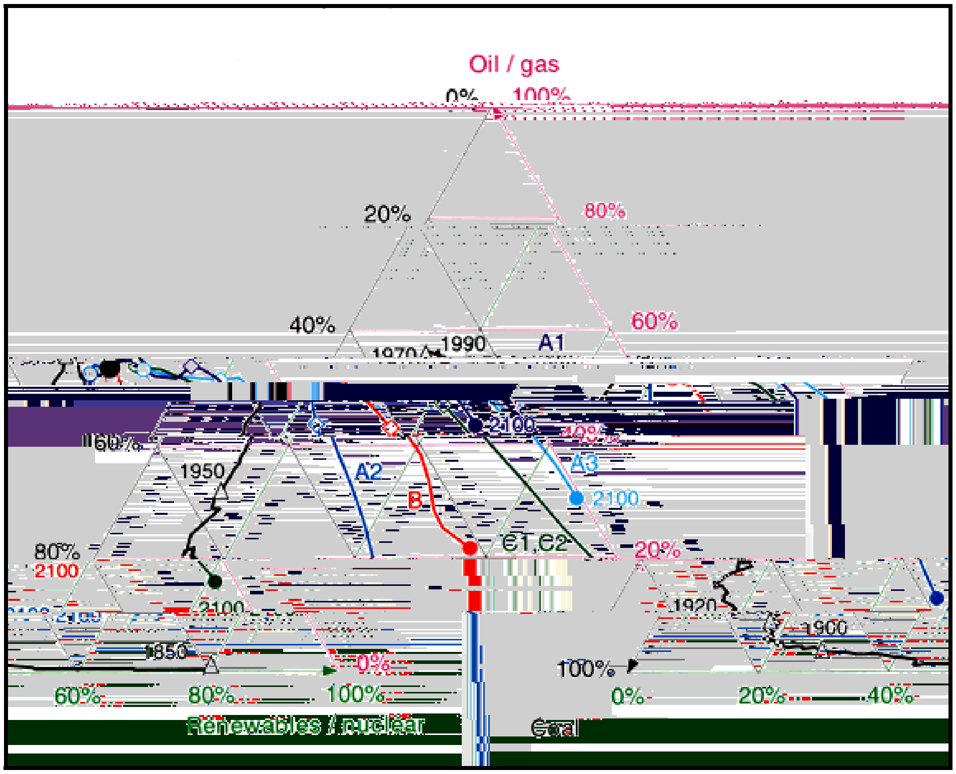

Figure 1: Evolution of Global Primary Energy Structure. (Nakicenovic et al., 1998). *The figure may be interpreted by focusing on the 3 vertices of the triangle, each representing a situation in which one of the 3 kinds of primary energy has a 100% share, with no contributions from the other two. nce the triangle does not have a time dimension, selected points in time are marked on the curves. For example, looking at the end point at 2100 for scenario A1, one sees a projection of roughly 42% oil/gas (reading across the horizontal pink lines to the pink scale), roughly 48% renewables/nuclear (reading down the green diagonals to the green scale), and roughly 10% coal (reading up the black diagonals to the black scale).*

In this diagram, the primary energy structure has evolved clockwise as coal replaced traditional renewable energy between 1850 and 1920, while oil and gas largely replaced coal between 1920 and 1990. Dramatic further change can be anticipated in the period up to the end of the present century. Very different possible pictures of the future role of coal as an energy source might be entertained, for example, depending on the expectations one might have for hydrocarbon supplies and the viability of new technologies for 'clean coal' through carbon management. The end-points at 2100 shown in Figure-1 highlight just five such different pathways for energy system change over the 21st century.

Two qualitative features of these pathways to date and into the future might be noted. The first is the long time scales involved, due to the very long lifetimes of the power plants, refineries, grids, distribution systems and other energy infrastructure and capital. This inertia means that policy decisions made in the next decade or two regarding the orientation of research and development and the turnover of capital will largely dictate our trajectory for the rest of the century. On the other hand, the dramatic structural change observed from 1850 to 2000 suggests that similar transformations are likely over the coming century, also plausibly within the adjustment capacity of the economy and society.

Discussion: Characteristics of Scenarios Reviewed

This section provides a summary of results for global primary energy consumption and associated carbon emissions to 2100, based on a range of projections of the two principal drivers or determinants, population and economic output, for the most recent scenarios published in the literature, since the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) in 2001. Linking these drivers to energy demand and associated emissions requires assumptions as to trends in energy intensity and carbon intensity; these are reviewed briefly below. The discussion in this section focuses mainly on longer term projections (up to 2100) however the tables below also provide near-term projections to 2020 and mid-term projections to 2050.

It is essential to emphasize that scenarios are not forecasts. One should not attempt to draw conclusions about likely future developments from a review of scenarios. The purpose of scenario exercises is to provoke reflection on feasible institutional or societal responses to alternative possible developments in an uncertain future.

What can be drawn from a review such as that sketched here is a sense of the range of alternative futures that have been considered sufficiently plausible as to warrant exploration. In that sense, the features of the paths described below can be considering as bracketing a likely range of plausible values and indeed identifying some scenarios that must be considered as suggesting implausibly extreme outlying values.

Global Primary Energy Consumption

Historically primary energy consumption has increased at a rate of more than 2% per year since 1900. However, recent scenarios (post-2001) assume growth rates between -0.29 to 1.77 per year, with a median value of 1.2% per year. This drop in overall growth rates, generating a major downward shift in projected levels of primary energy consumption in recent scenarios compared to earlier, reflects more optimistic assumptions as to improvements in energy intensity. As a result there has been a 35% reduction in the upper bound for the primary energy estimates for 2100 – from 3783 EJ in scenarios prior to 2001 compared to approximately 2500 EJ in post-2001 scenarios (see Table-1).

It should be noted that these estimates of primary energy consumption at the end of this century range from 250EJ to 2500EJ, a factor of 10. The lower tail of the distribution of estimates (near the low end at 250EJ) includes relatively few scenarios compared to a long tail at the higher end which consists of more than half the scenarios. As one would expect, those around 800 EJ and lower for 2100 represent mostly intervention scenarios, but the long tail from 1500-2500 EJ includes both intervention and non-intervention scenarios. The median for the entire distribution in 2100 is at 1275 EJ.

Table 1: Global Primary Energy projections for recently published scenarios (post-2001).

Year	**Range [EJ] ***	**Number of Scenarios**	**Distribution**	**Modes [EJ]**
2020	400-1000	178	Asymmetrical	90% between 475-575 EJ
2050	300-1500	159	Bi-modal with long tail at high end	550, 750 (long tail extends to 1500)
2100	250-2500	117	Bi-modal with long tail at high end	800, 1300 (long tail from 1500-2500)

* 1 Exajoule (EJ) is equivalent to 278 Billion Kilowatt Hours, or 160 million barrels of oil

What are the assumptions with respect to the central drivers and intensities—population growth, economic growth, energy intensity and carbon intensity—that give rise to these results? The following sub-sections offer brief summaries.

Global Population Projections

Population is an important driving force of future energy demand and carbon emissions. Most population projections used for the various emissions and mitigation scenarios are taken from one of three main research groups: United Nations, World Bank or IIASA (International Institute for Applied Systems Analysis). An interesting feature of the more recent scenarios is that the upper end of the population projection for 2100 (~ 15 Billion) is markedly lower compared to the highest projections (19 Billion) prior to the publication of the IPCC TAR in 2001. Although a wide range exists for the population distribution both in 2050 and in 2100, as shown in Table-2, the population projections used in the scenarios tend to cluster around certain values, creating multi-modal distributions. Nevertheless the median projection for 2100 (over 117 scenarios) suggests a more than 50% increase from today's population of 6.4 billion.

Despite the large range in global population projections in 2100, the ratio between highest and lowest projections is only about 3.5, compared to 10 for primary energy demand and 20 for global economic output, as discussed later.

Table 2: Global population projections for recently published scenarios (post-2001).

Year	**Range [Billions]**	**Number of Scenarios**	**Distribution**	**Modes [Billions]**

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An interesting relationship has been demonstrated in the Special Report on Emissions Scenarios (SRES scenarios) prepared for the Third Assessment Report (2001) (TAR) of the Intergovernmental Panel on Climate Change (IPCC) between carbon intensity and energy intensity for various post-SRES stabilization scenarios. The authors of these stabilization scenarios assume that more opportunities will be found to reduce energy intensity in the near term, and more opportunity to shift to non-carbon primary sources after 2050. A regional

increases faster than carbon intensity improvements, then emissions and atmospheric concentrations of greenhouse gases will continue to rise. If a desirable future is one in which atmospheric concentrations of CO_2 (equivalents) stabilize or decline, then much more stringent policies (e.g., aggressive carbon policies) will be needed to guide a transition in that direction.

Given the shorter turnover rates for end-use applications (1-2 decades) compared to energy supply technologies and infrastructures (5 decades or more) changes in end-use applications can be implemented rather quickly and the effects are also more pervasive. The power to influence the direction of change in tomorrow's energy systems is with us today, but given the long lead times for energy infrastructure and supply technologies, the choices we make over the next decade or so will decide the nature and direction of our energy systems and their global impacts in the second half of this century. Initiating long-term changes therefore requires aggressive but adaptive actions sooner rather than later.

ANNEX

Global Energy Scenarios to 2030, 2050 and 2100:

Summary results from diverse scenarios

As observed at the beginning of this note, the discussion above is based on an examination of hundreds of scenarios released since 2001 carried out by Nakicenovic and his colleagues and reported in their 2006 paper cited in the references below. In that study they attempted to ensure consistency of treatment across those scenarios, and reported results for 2020, 2050 and 2100 based on the same collection for each date.

In this annex are presented summary results from a review of several bundles of scenarios from diverse sources. For the near and medium-term horizons, only a handful of scenarios are reviewed; these relate to 2030 and 2050. For the long term scenarios to 2100, a larger number of examples was available. It should be emphasized, therefore, that the results reported here are not based on consistent sets of assumptions either over time or across scenarios for a specific horizon. They provide merely an illustration of the range of conclusions drawn from scenarios reported over the last decade.

Global Energy Scenarios to 2030 - Near Term

Summary

1. **World population**

production is expected to come from advanced gas and coal-powered turbines. The share of nuclear power in electricity production is expected to decline.

9. The cumulative investment in the energy sector is estimated to be $US 17 Trillion up to 2030. Of this, more than 70% will be related to power generation, transmission and distribution; 40% is to provide energy and fuels to OECD countries.
10. Energy intensity improvements are expected to be between 1.5% to 1.9% between 2003 and 2030.
11. There are large regional differences in carbon intensities worldwide. India and China are expected to increase their carbon intensities, while all industrialized countries except North America show a drop in their carbon intensities.
12. Even with alternative policies that curb energy consumption by 10% over the typical reference case, global energy con

to converge toward higher quality fuels such as electricity, natural gas or hydrogen, primary energy supply trends are likely to diverge globally.

7. Environmental concerns, financing and technological needs are considered to be more likely sources of future limits to global energy systems than the unequal distribution of fossil resources, regional shortages and resulting price increases.
8. Given the shorter turnover rates for end-use applications (1-2 decades) compared to energy supply technologies and infrastructures (5 decades or more) changes in end-use applications can be implemented rather quickly and the effects are also more pervasive. Given the long-lead times for energy infrastructure and supply technologies, 'betting on the wrong horse may have serious, possibly irreversible consequences'. RD&D and investment decisions made now and in the immediate future will determine which options become available or foreclosed in the long-term. Therefore, initiating long-term changes requires actions sooner rather than later.

Global Energy Scenarios to 2100 – Long Term

Summary

1. All major driving forces of primary energy demand have been revised downward in global energy scenarios published since 2001, compared to those published by 2001.
2. Projections of global population in 2100 range from 4-15 billion with a median of around 10 billion. The vast majority of this population is expected to be urbanized.
3. The projected GDP range in 2100 is between US$ 25 Trillion and US$ 550 Trillion. This range as well as the upper-bound projection has been revised down substantially in the post-2001 scenarios.
4. The median projections for energy intensity (EI) improvements are between 0.7%-1.3%/year up to 2100. Factors other than GDP growth seem to affect EI improvements in the latter half of this century, when EI improvements are also expected to be less than prior to 2050.
5. The factor range or ratio between highest and lowest projections (uncertainty range) is greatest in 2100 for global economic output at 20, lowest for population range at 3.5 and 10 for primary energy demand. (It should be emphasized that these broad ranges reflect the large number of disparate long-range scenarios reviewed, not the uncertainty within each. They also illustrate well the challenge of policy-making in the absence of any confident expectations about the evolution of critical features into the future.)
6. The demand for primary energy in 2100 is projected to be between 243 EJ and 2447 EJ across 178 scenarios.
7. Long-term energy scenarios to 2100 point to a possible transition in the global energy system as we move toward more non-fossil energy sources, although to varying degrees and directions.
8. Even with the assumed median 0.6% rate of decarbonisation (above the historical average of 0.3%), the median CO2 emissions projections are expected to rise to 9 GtC (50% over today's emissions) in 2100. Even with the median emission projections, atmospheric CO_2 levels are expected to rise to 750 ppmv.
9. In OECD countries carbon emissions can potentially be reduced through a combination of advanced energy technologies as well as fuel switching with comparable effectiveness.

10. The effect of various levels of carbon tax on GDP ranges from losses of about 22% to gains of about 5 in 2100. Although no regional trend appears, generally larger GDP losses are more prevalent in developing regions than in developed regions.
11. Sector-specific carbon policies increase the cost of emissions reductions and reduce

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