
Building a second generation of World Water Scenarios

Driving force: Climate Change

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OVERVIEW

Climate change is by far the most significant driver affecting the world's supply of water, has a major influence on the demand for water, and on its use, and further has major consequences for the relationship between humanity and natural water, such as sea level rise and inland flooding. We can summarize the elements of the situation:

**Climate change**

Climate change is caused by Atmospheric changes
- Increased greenhouse gas (GHG) emissions
- Increased particulate matter
- Terrestrial reflectivity changes

Atmospheric changes are caused by Natural processes, e.g. in tundra, forests
- Energy production activities
- Other human activities, e.g. manufacturing, transportation, agriculture

may be modified by changes in those activities

mitigated
- Technological advances (e.g. pollution-free energy)

exacerbated
- Social and economic developments
  (e.g. growing and richer populations)

**Water supply**

Climate change raises global air temperatures selectively raises ocean temperatures
- Rising temperatures
- Melt frozen water storages (snow, ice, glaciers)
- Melting disrupts seasonal water distribution patterns
- Deplete water sources (rivers, lakes, wetlands, groundwater)

Climate change changes regional precipitation patterns, e.g. producing droughts

**Water demand**

Water demand will increase from growing global population
- Increased living standards and industrial development
  Need for more water to offset higher temperatures (e.g. evaporation)

The dire current and forecasted states of the global climate in The Fourth Assessment Report (AR4 or FAR) of the Intergovernmental Panel on Climate Change (IPCC) – “Climate Change 2007”¹ have only been confirmed and strengthened by subsequent research into climate change indicators.² (Bates et al., 2008)

The rate of global atmospheric warming continues to be about 0.19°C/decade, and in a November, 2009

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¹ [http://www.ipcc.ch/#](http://www.ipcc.ch/#) Although it is the largest and most comprehensive study of the subject yet produced, the Report had a few factual and typographic errors and has been criticized by some for having a bias toward the reality of anthropogenic and possibly catastrophic climate changes. The IPCC has set up a review body for its policies and procedures for preparing reports, an action that should lend more authority to its future analyses. There is talk of reorganizing or replacing the body.

A scenario developed by Climate Analytics at the request of Greenpeace Switzerland forecasts global warming by considering the Swiss climate policy model (reduce greenhouse emissions to at least 20% below their 1990 levels by 2020) at world level and linearly extending the policy trend up to 2020 to 2100. By these assumptions, global emissions peak at 60 Gt CO₂ in the 2050s, and drop below 50 Gt CO₂ by 2100. The best-estimate global warming in this scenario is 1°C by 2020, 1.8°C by 2050 and 3°C above pre-industrial by 2100. UNEP and Climate Interactive have reached even more pessimistic conclusions about 2100, up to a 3.9°C rise, a figure also derivable from the Copenhagen pledges. UNEP’s “Climate Change Science Compendium 2009” estimates that even in the best case scenario—if the world’s most ambitious targets are met—the planet will still warm by 3.5°C (6.3°F) by the end of the century, while a comprehensive MIT model over all policy options predicts a median probability of surface warming of 5.2°C. There are projections indicating precipitation increases in high latitudes and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions, but because of regional variability and measurement difficulties, there is not sufficient data available for substantial global precipitation descriptions or forecasts; it can be said only that there is a definite long-term trend toward decreasing amounts. (Bates et al., 2008, 2.3.1) Also extreme weather events—flooding, cyclones and droughts—are increasing in frequency. All these signs, which conform quantitatively with pollution-based models in spite of a counter-influence from solar forcing, leave no doubt as to the anthropogenic origin of climate change.

That anthropogenic origin is now almost certainly the enormously increased atmospheric level of the “greenhouse gasses” (GHG) - carbon dioxide (CO₂), mostly produced by the burning of fossil fuel for energy generation and vehicle propulsion, and, much more potent but with a much lesser role, methane (CH₄), coming from a variety of sources, livestock in particular. These gasses prevent the reradiation of solar heat back into space, thereby turning the earth into a virtual greenhouse. The Greenhouse Gas Bulletin of the World Meteorological Organization reveals that the global trend of rising atmospheric global greenhouse gases (GHG) continues. Global carbon dioxide emissions from fossil fuels in

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4 http://www.globalcarbonproject.org/carbonbudget/08/files/UniversityEastAnglia_UK.pdf
10 A detailed study of the anthropogenic aspect is contained in a paper by the UK Met Office at http://www3.interscience.wiley.com/cgi-bin/fulltext/123310513/HTMLSTART.
11 http://www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html
2008 were 40% higher than those in 1990, and average concentrations of carbon dioxide ($\text{CO}_2$), methane ($\text{CH}_4$) and nitrous oxide ($\text{N}_2\text{O}$) in the Earth’s atmosphere exceed those of pre-industrial times by 35%, 155%, and 18% respectively, reaching their highest-ever recorded levels. NOAA reports that in 2005, the $\text{CO}_2$ average atmospheric concentration reached 381 ppm, an increase of 2.6 ppm since 2004. While some halocarbons, such as chlorofluorocarbons (CFCs), are decreasing slowly as a result of the implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer, concentrations of their substitutes, such as HCFCs and HFCs, are increasing rapidly. The Global Carbon Project suggests that in order to limit global temperature rise to 2°C, average carbon emissions per capita for goods and services should be reduced to 0.3 metric tons by 2050, from 1.3 metric tons now. Twenty more years of emissions at these levels gives a 25% probability that warming will exceed 2°C. Effective action to reduce these emissions must be taken immediately, and must begin to take effect by 2020 if global warming is to be kept below 2°C, since it is vital that near-zero emissions be achieved well before 2100, say with a goal of the average annual per-capita emissions shrinking to well under one metric ton of $\text{CO}_2$ by 2050, 80-90% below the per-capita emissions in developed nations in 2000. If this remediation is not vigorously pursued, humanity runs a rapidly increasing risk in the next few decades of encountering a "tipping point" – inflicting irreversible damage on such vulnerable elements of the climate system as the continental ice-sheets, Atlantic thermohaline circulation, Amazon rainforest, and West African monsoon. A disturbing study suggests that hurricane-induced movement of warm ocean water could lead in turn to more warming, and even, possibly by 2040, to such a tipping point. The risk is even greater because the permanency of such damage is likely not to be realized until after it occurs. (Lenton, 2008; IARU, 2009, 12))

Megafarm manure is the US's most rapidly increasing source of methane, but burning that methane to produce electricity raises nitrous oxide pollution objections. Simultaneously, the first comprehensive study accounting for oceans’ intake of $\text{CO}_2$ over the past 250 years reveals that, since 2000, as the oceans’ acidity increases, their carbon-sequestration capacity is declining. The permafrost under the East Siberian Arctic Shelf, long thought to be an impermeable barrier sealing in methane, is perforated and is leaking an estimated 7 million metric tons of methane into the atmosphere annually, resulting in average methane concentrations in the Arctic averaging about 1.85 ppm, the highest in 400,000 years. Such methane release from permafrost melting thus produces a feedback effect of increased warming.

The World Resources Institute has prepared a chart and accompanying graphic, showing a breakdown by sectors of GHG emissions; these are the major components:

<table>
<thead>
<tr>
<th></th>
<th>%</th>
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<tbody>
<tr>
<td>Electricity and fuel</td>
<td>24.6%</td>
<td>Transportation</td>
</tr>
<tr>
<td>Land use change (e.g. deforestation)</td>
<td>18.2%</td>
<td>Other fuel consumption</td>
</tr>
<tr>
<td>Industry</td>
<td>13.8%</td>
<td>Fugitive emissions</td>
</tr>
</tbody>
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12 http://www.wmo.int/web/arep/gaw/ghg/ghg-bulletin-en-03-06.pdf
15 http://www.washingtonpost.com/wp-dyn/content/article/2010/02/28/AR20100228203978.html
16 http://www.latimes.com/business/la-fi-cow-power1-2010mar01,0,26949999.story
18 http://www.terr daily.com/reports/Arctic_Sealed_Methane_Stores_Destabilizing_And_Venting_999.html
The major targets of the multitude of efforts to reduce GHG emissions have been the electricity/fuel and transportation sectors, and, to a lesser degree, industry, probably because the causative chains to gas generation from land use change and agriculture are less apparent. There is also a much less prominent array of projects to remove existing GHGs from the atmosphere\(^ {20}\), by reforestation (somewhat offset, though, by solar reflectivity decrease), iron fertilization of ocean phytoplankton (efficacy put in doubt by experiment\(^ {21}\)), and changes in agricultural practices.

Despite all of the work that has gone into conferences and agreements on climate change, so far no formula for compromise has been found among the conflicting objectives of the classic industrial nations, like the US, that want to continue thriving economies and a high (unreasonably high, say the other parties) standard of living; the ambitions of the BRIC (Brazil, Russia, India, and China) bloc, that wants progress toward that "place in the sun" too; and the needs of the developing world, that wants to stop developing, and become developed. It seems that the best that can be hoped for in the short, and regrettably perhaps medium, term are national and regional efforts to work for limited progress, and technological innovations and improvements that can at least slow the deleterious march toward a barren, hothouse, Earth. As an example, in a 30-month project, EU CO2 80.50, 21 European metropolitan regions aim to devise strategies for achieving an 80% reduction of greenhouse gases emissions by the year 2050.\(^ {22}\) Climate change legislation in the US is a goal of the current administration, but its eventual nature or fate is, at the moment, totally uncertain\(^ {23}\).

The effects of climate change on water resources and their use can be seen primarily in

- the disruptive timing changes that the higher air temperatures have on the acquisition and distribution of water by such water storage elements as glaciers, ice fields, and rivers and lakes
- widespread changes in the geographic distribution of precipitation, so that some regions are flooded and others are drought-stricken, and aquifers are lowered
- damage to littoral areas, in particular freshwater resources, from rising sea levels
- increased use of water to replace evaporative losses and to satisfy human needs in warmer weather

Humanity is reaching a point at which there is simply not enough water being collected in conventional places by conventional means to support six (all too soon to be nine) billion people\(^ {24}\). All over the world glaciers and ice-caps accumulate large amounts of frozen freshwater during the cold weather, and then gradually release it, thus representing the only freshwater source for millions of people, in particular during the growing season. "The cryosphere (consisting of snow, ice and frozen ground) on land stores about 75% of the world’s freshwater. In the climate system, the cryosphere and its changes are intricately linked to the surface energy budget, the water cycle and sea-level change. More than one-sixth of the world’s population lives in glacier or snowmelt-fed river basins." (Bates et al., 2008, 2.1.2) Over the past decade they have been melting and thinning at an accelerating rate, particularly in the subtropic zones, including parts of the Middle East, southern Africa, the U.S., South America, and the Mediterranean, with some disappearing entirely. When this happens, much of the water they normally channel is absorbed or runs off uselessly. Scientists estimate that most of the Andes’ glaciers will disappear within 20 years, and that the Pyrenees’

\(^{20}\) http://en.wikipedia.org/wiki/Carbon_sink (An excellent summary, with 50 references)
\(^{21}\) http://ipsnews.net/print.asp?idnews=33533
\(^{22}\) www.euco2.org/
\(^{23}\) http://www.fcnl.org/issues/item.php?item_id=3866&issue_id=102
\(^{24}\) (Bates et al., 2008) has an extremely thorough (219 pp.) description and analysis of climate change and its effects. (IARU, 2009) also has a shorter (36 pp.) but excellent summary.
and other European glaciers may vanish completely within a few decades. (McMullen, 2009) (WWDR-3, 2009) The Greenland ice cap reduction rate tripled over the past decade, while Antarctica, which seemed immune to global warming, now shows signs of net ice reduction on a similar scale to inland Greenland.\textsuperscript{25} The annual average Arctic sea ice extent has shrunk by 2.7\% per decade, with larger decreases in summer of 7.4\% per decade; the area of summertime sea-ice during 2007-2009 measured about 40\% less than the average prediction from IPCC AR4 climate models. (Bates et al., 2008, 2.3.2) These events have severe economic consequences – one estimate is up to $24$ trillion over the next 40 years.\textsuperscript{26} Ice-free water absorbs heat rather than reflecting it, creating a feedback effect. (IARU, 2009, 8) In some areas the melting problem is exacerbated by the snow or ice receiving a heat-absorbing cover layer of dust from drought-stricken areas or particulate pollution from industrial plants.\textsuperscript{27} Also, in fact, some dust may come from land exposed by shrinking glaciers and ice fields themselves.

In addition to reducing the supply of fresh water to needy populations, the worldwide melting of snow and ice has had another gravely serious effect: increasing sea levels. Sea level has been rising at an average of 3.4 mm/yr over the past 15 years, almost double the rate of the previous 50 years and 80\% above past IPCC predictions, and consistent with a doubling of ocean input from melting ice worldwide, augmented by thermal expansion. IPCC FAR projected that global mean sea level is expected to rise between 9 and 88 cm by 2100, with a 'best estimate' of 50 cm. A later study, taking ice melting more into account, indicated an 80 cm to 2 m rise.\textsuperscript{28} Sea-level will continue to rise for centuries after global temperatures have been stabilized and several meters of sea level rise must be expected over the next few centuries. (IARU, 2009, 8)

Rising sea levels have several deleterious effects:

Flooding of low lying land areas and partial or total destruction of islands, e.g. Tuvalu, coastal Bangladesh, and Vietnam’s deltas.

Intrusion of salt water into freshwater supplies and wetlands

Erosion of ocean front land, some possibly underlying built structures

A study based on ten years of daily global satellite images, showed 85\% of the world’s 33 largest delta regions experienced severe flooding due to sinking land and rising seas. The study warns that if ocean levels increase as projected under the moderate climate change scenarios, delta land vulnerable to serious flooding could expand by 50\% this century, Asia being the worst affected.\textsuperscript{29} The Egyptian government warns that a 30 cm rise in the Mediterranean would flood about 200 km\textsuperscript{2} and displace half a million people.\textsuperscript{30} There are concerns that ocean acidification from CO\textsubscript{2} absorption will have severe consequences for marine wildlife and ecosystems, causing a major die-off in the oceans that would affect birds and many land species and change the biology of Earth as a whole profoundly.\textsuperscript{31}

The bulk of the world’s freshwater supply comes from rivers and lakes. For many rivers around the world, however, only their upper reaches have reasonable flow, and, in some cases, they disappear before reaching their former mouths. (Bates et al., 2008, 2.3.6) A 2009 report\textsuperscript{32} from the National Center for

\textsuperscript{25} http://www.regieringen.no/upload/UD/Vedlegg/klima/melting_ice_report.pdf; Melting Snow and Ice: A Call for Action, a 51 pp report commissioned by Al Gore

\textsuperscript{26} http://www.time.com/time/business/article/0,8599,1977563,00.html

\textsuperscript{27} http://www.green-energy-news.com/arch/nrgs2010/20100009.html

\textsuperscript{28} http://www.scientificamerican.com/article.cfm?id=how-much-will-global-warming-raise-sea-levels

\textsuperscript{29} http://www.colorado.edu/news/r/b1535ed4a21c33f7de1d22d241bd5328.html

\textsuperscript{30} http://www.seeddaily.com/reports/Egypts_fertile_Nile_Delta_falls_prey_to_climate_change_999.html


\textsuperscript{32} http://www.ucar.edu/news/releases/2009/flow.jsp
Atmospheric Research says that rivers in some of the world's most populous regions are losing water, and suggests that in many cases the reduced flows are associated with climate change. "The scientists, who examined stream flow from 1948 to 2004, found significant changes in about one-third of the world's largest rivers. Of those, rivers with decreased flow outnumbered those with increased flow by a ratio of about 2.5 to 1. ... Several of the rivers channeling less water serve large populations, including the Yellow River in northern China, the Ganges in India, the Niger in West Africa, and the Colorado in the southwestern United States. ...the scientists reported greater stream flow over areas near the Arctic Ocean, where snow and ice are rapidly melting. ... Many factors can affect river discharge, including dams and the diversion of water for agriculture and industry. The researchers found, however, that the reduced flows in many cases appear to be related to global climate change, which is altering precipitation patterns and increasing the rate of evaporation. The results are consistent with previous research ...showing widespread drying and increased drought over many land areas." Vietnam's Mekong River presents a case in which the country is suffering its worst drought in 100 years, and still is trying to balance its meager water supply between the needs of hydropower and farming. In some places, sea water has crept 60 km inland, ruining farming areas. In the volatile Middle East, by 2100, the Euphrates might shrink by 30%, the Jordan River by 80%, while the Dead Sea is shrinking by 1 m per year due to overuse of its tributaries, and climate change. Israel has warned that its water supply may fall by 60% of 2000 levels by the end of the century. A similar situation exists in the Himalayan basins. (Arnell, 1999), though now rather out of date, has model-based geographically oriented 2050 predictions for water-based population stress. Adaptation to these changes may require that hydroelectric dams be converted to serve only water conservation ends, and that industries sharply reduce their water consumption. Higher temperatures and lower precipitation may not only shrink lakes, but also cause adverse changes in their biota, damaging the quality of their water. Climate-change-caused chemical and biological damage to water quality affects not only lakes but all sources of fresh water. (Bates et al., 2008, 3.2.1.4)

The International Association of Hydrogeologists has summarized the problem of climate change and groundwater as follows: "Groundwater is the world's largest accessible store of freshwater yet groundwater remains largely peripheral to current analyses and discussions of climate change and adaptation. ...groundwater is the primary source of drinking water to nearly half of the world's population and, as the dominant source of water to irrigated land, is critical to global food security. ... Under a warming atmosphere, precipitation intensities are predicted to increase, particularly in the tropics. This projected shift in the temporal distribution of rainfall itself results in more variable river discharge and soil moisture. The former exacerbates intra-annual freshwater shortages and the risk of flooding whereas the latter threatens food security through reduced crop yields. Projected changes in the spatial distribution of mean rainfall are substantial but remain highly uncertain for most of the world. Strategies to adapt to more variable freshwater resources will, in many environments, increase dependence upon groundwater."  

In addition to being important sources of water for the world's population, wetlands, including peatlands, store nearly 30 percent of all land-based carbon (550 GT carbon): this is 75% of all atmospheric carbon, and twice the carbon stock in the forest biomass of the world. They are also important elements of ecologies worldwide. In addition to sea level invasion of coastal wetlands, flooding and droughts wreak extensive damage on them and their constituent vegetation. Aquifers are suffering similar, but vertical, fates – they are retreating farther and farther into the earth, with some wells now descending to a depth of a mile. India is an example of the importance of groundwater. 60% of all aquifers in India could run dry in 20 years

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33 http://www.time.com/time/world/article/0,8599,1969630,00.html
34 www.iisd.org/publications/pub.aspx?id=1130
35 http://www.iah.org/gwclimate/gw_cc.html
or will be in a critical condition. 29% of groundwater blocks are semi-critical, critical, or overexploited, and the situation is deteriorating rapidly. India is the largest user of groundwater in the world, with an estimated use of 230 cubic kilometers of groundwater every year—more than a quarter of the global total. In fact, groundwater use has been steadily increasing in India over the last four to five decades. Today, groundwater supports approximately 60% of irrigated agriculture and more than 80% of rural and urban water supplies. Yemen’s water table is dropping about 6.6 feet per year, and in Sana’a water extraction rates are about four times that of replenishment. Saudi Arabia is the first country to acknowledge publicly how falling water tables are affecting harvests; over half the world’s population lives in countries where aquifers are being depleted faster than they can be replenished.

Changes in precipitation patterns have produced or increased desertification in many parts of the world. The UNDP’s 2009 Arab Human Development Report said desertification threatens about 2.87 million square kilometers of land -- a fifth of the Middle East and North Africa.

(Bates et al., 2008, 4.4.3 incl. refs.) summarizes the causes and effects of water availability problems:
- decreased flows in basins fed by shrinking glaciers and longer and more frequent dry seasons
- decreased summer precipitation leading to a reduction of stored water in reservoirs fed with seasonal rivers
- interannual precipitation variability and seasonal shifts in streamflow,
- reductions in inland groundwater levels,
- the increase in evapotranspiration as a result of higher air temperatures, lengthening of the growing season and increased irrigation water usage,
- salinisation

According to projections, the number of people at risk from increasing water stress will be between 0.4 billion and 1.7 billion by the 2020s, between 1.0 billion and 2.0 billion by the 2050s and between 1.1 billion and 3.2 billion by the 2080s, the range being due to the different SRES scenarios considered.

DEVELOPMENTS

The developments that may have a potential effect on climate change and therefore on its negative impact on water resources and use to 2050 can be categorized as

Political, social, cultural, and economic conditions and trends

Worldwide rise in living standards at both national and personal levels, causing increased demand for both water and consumable goods, resulting, much more significantly for climate change, in greatly increased demand for, and generation of, energy for transportation and manufacturing, causing higher GHG emissions

Increasing global population – more people making the above demands

Public attitudes and international agreements

The evolution of human interactions away from the physical/geographical toward the electronic/informational

Technological developments

Anti-GHG
Other measures to reduce the effect of solar radiation
Climate manipulation

An important area that one could call "meta-development" is effective international coordination of R/D activities in climate change analysis, mitigation, and adaptation, and the continual exchange of up-to-date data, knowledge, and experience about both those activities and climate change itself ("knowledge management"). There are a number of activities along these lines, the Climate and Development Knowledge Network has been funded for five years, the World Climate Research Programme is laid out for 2005-2015, and the Global Climate Change Situation Room at Gimcheon, Korea, is opening, but intensive coordination (perhaps even real centralization) and expansion of them is vital for the next two years, as climate change effects multiply and efforts for international agreement falter.

Social, cultural, and economic conditions and trends

1. Higher standards of living

Throughout the world nations are moving from developing to developed populations are upwardly mobile within each state people at any given socio-economic level are more consumption-oriented

The World Bank estimates that the output of the global economy will rise to $72 trillion in 2030 from $35 trillion in 2005, and that, although the incomes of developing countries will remain less than one-quarter of those in rich countries in 2030, the two groups will continue to converge. The impact that this will have on climate change is best visualized by noting that this increase in standards of living, together with the population rise, results in a projected world energy consumption of 510 quadrillion Btu in 2010, 563 quadrillion in 2015, 613 quadrillion in 2020, 665 quadrillion in 2025, and 721 quadrillion Btu in 2030—a total increase of 41 percent. Under present conditions this increased energy consumption, caused largely by correspondingly increased industrial production and accompanied by "necessary" deforestation, implies an equivalent rise in the production of GHGs and a diminution of CO₂ absorption by the environment.

2. Population growth rate

The most clearly significant factor in humanity's influence on climate change is the sheer size of the world's resource-consuming population, predicted to grow from its present 6.8 billion to reach 8.9 billion by 2050.

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40 http://www.eia.doe.gov/IEA/pdf/ieoreftab_1.pdf
The current growth rate is 1.17% annually. Estimates for the future rate differ; the UN Population Div. suggests 0.34% by 2050 (UN, 2008). These estimates have decreased over the past few years largely because of decreases in the human fertility rate, but also, for the near term, because of HIV/AIDS mortality. Exact figures are almost irrelevant for future planning – the bottom truth is that there will be several billion more people consuming energy by 2050. The most likely reason for a downward departure from that conclusion would be unexpectedly severe consequences from unchecked global warming, resulting in large-scale migrations of peoples, civil disorder and resource-driven wars, and mass starvation and other mortalities. A study is in progress on the impact of demographic change on carbon emissions. "Wild card" possibilities for a lower-than-expected population are the development of a cheap, effective, and semi-permanent male contraceptive, reducing the fertility rate still further; or a severe global pandemic of an untreatable disease, possible stemming from a biowarfare source.

3. Public attitudes and international agreements

"Green" may be the "word of the year", and its prominence reflects a growing generalized public concern for the environment, particularly with regard to global warming. A strong, effective, universally binding international agreement to combat climate change is undoubtedly the most significant development that could affect this driver. Unfortunately, "Climate-gate" delivered a severe blow to the climate change movement. The most probable future course is a very slow recovery in public opinion on the issue, and in support for the sacrifices and expensive measures needed for effective remediation. A pessimistic but realistic view is that people and organizations will continue a "culture of consumption"; will feel more guilty about it, and will engage in a variety of minor acts of conservation – turning off lights, biking, or walking short distances rather than driving – but will not be amenable to making major behavioral or financial sacrifices. This, of course, affects the actions of governments. There is a desperate need to change this fundamental attitude toward climate change, and to fully enlist the world’s population in the cause of climate environmentalism. This needs to take place during 2010-2013, particularly in order to affect international regulatory efforts. Despite all of the work that has gone into conferences and agreements on climate change, so far no formula for compromise has been found among the conflicting objectives of the classic industrial nations, like the US, that want to continue thriving economies and a high (unreasonably high, say the other parties) standard of living; the ambitions of the BRIC (Brazil, Russia, India, and China) bloc, that wants progress toward that "place in the sun" too; and the needs of the developing world, that wants to stop developing and become developed.

There is no way of predicting the future nature and chronological course of these negotiations (e.g. carbon tax vs. cap and trade), depending as they do on a complex of political and economic developments in at least a score of countries and regions. A "wild card" is a major diplomatic or conceptual breakthrough in possible solutions. It seems that the best that can be hoped for in the short, and regrettably perhaps medium (five-year), term are national and regional efforts to work for limited progress. As an example, in a 30-month project, EUCO2 80.50, 21 European metropolitan regions aim to devise strategies for achieving an 80% reduction of greenhouse gases emissions by the year 2050. An international opinion poll indicated that generally less than half of the public in a variety of countries was willing to pay as much as 1% of their

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http://www.globalchange.umich.edu/globalchange2/current/lectures/human_pop/human_pop.html#future
42 http://www.wilsoncenter.org/events/docs/ONeill_WilsonCtr_2010_popclimate.pdf
43 (IARU, 2009. pp. 16-19) has discussions of some of these elements.
44 www.euco2.org/
share of GDP more to fight climate change. It is highly likely that much of this feeling is the result of the well-financed anti-control campaign waged by the petroleum industry. Until a firmer degree of public backing and a sense of urgency has been achieved, most governments in the world can be expected to continue to be unwilling to risk opposition by instituting stringent but effective anti-GHG measures. Some governments around the world are averse to public discussion of the effects of climate change, fearing that they will be interpreted as signs of high-level mismanagement. Unfortunately, it is very likely that, by 2015-2020, the strongest factor working toward reviving that needed public backing and speeding up international agreement will be the appearance of indisputable global temperature and precipitation changes, with disruptive ill effects. The best hope for avoiding this negative prospect for the decades to come would seem to lie in the establishment of an immediate well-planned intensive and extensive multinational campaign of public education on the facts, causes, effects, and costs of climate change. Since 2002, UNEP and the UNFCCC Secretariat and COPs have engaged in the UNFCCC New Delhi Work Programme, which has that general charter, but the sad course of climate change negotiations over the years shows no signs of its having been effective. Research is needed on these public attitudes and the best ways to change them. (IARU, 2009, 31-32).

4. The evolution of human interactions

It is with reason that this is called the "information age". Only 8% of the US labor force is involved in "making things". Business meetings and social gatherings are now more and more taking place in virtual worlds, consuming megabyte bandwidth rather than gasoline, and people are watching events remotely rather than attending them. Physical (and therefore resource- and energy-consuming) information media are vanishing, replaced by e-books and blogs. Fuel-saving telecommuting is rising rapidly - the number of Americans who worked from home or remotely at least one day per month increased from approximately 12.4 million in 2006 to 17.2 million in 2008, a 74% increase since 2005, and 40% of US employees hold jobs that that could be done at home. A consulting firm estimates that the number will increase to 63 million by 2016. Telecommuting saves not only the energy required for transportation, but also that needed to build and support the central working facilities. This movement from the physical to the electronic will not balance out the effects of 1. and 2. above, but will temper them.

Technological developments

It has been established that the only really significant causative factor in climate change is the presence in the atmosphere of greenhouse gasses, of which almost 65% are energy-related, i.e. arise from burning carbon-based fuels for transportation and electricity production. The remainder is attributable to land use change, such as deforestation, and emissions from industrial processes, both of which are more "diffuse" problems than fuel burning. Therefore efforts to ameliorate the effects of climate change concentrate on energy, and the significant technological developments will be in the areas of:

- Replacement of current GHG-producing fuels by other, non-polluting fuels
- Generation of electricity by means other than burning fuels
- with less extensive efforts oriented toward

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Preventing generated GHGs from reaching the atmosphere (carbon sequestration)
The technologies described in this section illustrate the possibilities for eliminating the major cause of climate change.

In the consideration of these possibilities, it is important to keep in mind the overwhelming importance of renewable energy sources. The ever-growing world population is running out of burnable material! A new study demonstrates how the opportunity exists to power Europe and North Africa exclusively by renewable electricity by 2050, if this is supported by a single European power market united with a similar market in North Africa, all linked by a "smart grid".50

The US Dept. of Energy’s International Energy Outlook 200951 provides an excellent introductory summary of the current state and future prospects for the world’s climate-affecting energy production technologies. The following is taken directly from the Highlights section of that document. [Other text is in brackets.]

Total world energy use rises from 472 quadrillion British thermal units (Btu) in 2006 to 552 quadrillion Btu in 2015 and then to 678 quadrillion Btu in 2030. [Figure 2 ] projects increased world consumption of marketed energy from all fuel sources over the 2006 to 2030 projection period. World use of liquids and other petroleum grows from 85 million barrels per day in 2006 to 91 million barrels per day in 2015 and 107 million barrels per day in 2030. Absent significant technological advances [the possibilities for which are discussed in detail in the following section of this document], liquids will continue to be the primary energy source in the world’s transportation sector. Biofuels, including ethanol and biodiesel, will be an increasingly important source of unconventional liquids supply, reaching 5.9 million barrels per day in 2030. Natural gas consumption [with its lower emissions] worldwide increases ... from 104 trillion cubic feet in 2006 to 153 trillion cubic feet in 2030. In the absence of ... [policy restrictions] world coal consumption is projected to increase from 127 quadrillion Btu in 2006 to 190 quadrillion Btu in 2030, an average annual rate of 1.7 percent. The non-OECD Asia region accounts for nearly 90 percent of the total world increase in coal use from 2006 to 2030. For example, installed coal-fired generating capacity in China is projected to nearly triple from 2006 to 2030.

World net electricity generation increases by 77 percent, from 18.0 trillion kwh in 2006 to 23.2 trillion kwh in 2015 and 31.8 trillion kwh in 2030. Much of the world increase in renewable electricity supply is fueled by hydropower and wind power. Of the 3.3 trillion kwh of new renewable generation added over the projection period, 1.8 trillion kwh (54 percent) is attributed to hydropower and 1.1 trillion kwh (33 percent) to wind. Except for these two sources, most renewable energy technologies are not economically competitive with fossil fuels over the projection period, outside a limited number of niche markets. Solar power, for instance, typically is uneconomical but can be economical where electricity prices are high and government incentives are available. In fact, government incentives or policies typically provide the primary support for construction of any renewable generation facilities. The mix of renewable fuels consumed differs between the OECD and non-OECD regions in the projection. In the OECD nations,[hydropower is widely used] and there are few large-scale hydroelectric power projects planned for the future, .... [so] most of the growth in renewable energy... is expected for other sources, led by wind and biomass. In the non-OECD nations, hydropower is the predominant source of renewable energy growth. Wind-powered electricity generation also is expected to grow significantly in the non-OECD countries, including substantial additions of wind electricity to the grid in China. Electricity generation from nuclear power is projected to increase from about 2.7 trillion kwh in 2006 to 3.8 trillion

50 www.supersmartgrid.net
51 http://www.eia.doe.gov/oiaf/ieo/index.html
kwh in 2030. Higher fossil fuel prices [and higher capacity utilization rates] allow nuclear power to become economically competitive with other generation types.

(IARU, 2009, 24-28 and especially Box 11) has useful discussions of the following developments and their effects.

1. Fuel-oriented developments

Any discussion of GHGs and their effect is hampered by the lack of accurate and wide-coverage information on the state of the atmosphere. There is hope for improvement, however. In 2009 the UN and Japan launched the first satellite that could track greenhouse gases, the US has budgeted for one for early 2013, and Brazil and India plan to launch satellites in the next two years that will monitor their domestic emissions.

Petroleum and methane
There are very large quantities of petroleum locked in shale deposits, but they can be recovered only at the risk of severe environmental damage, e.g. from fracking (the forcible injection of a liquid into the oil-bearing formations to break them apart and allow more of their contents to be recovered) which at times has resulted in the contamination of underground water supplies by the injected liquid. Oil sands are an even more prominent secondary source of petroleum, and an even more controversial target of environmental damage claims, one in particular being the very large amount of energy needed to extract the product from its packed granular matrix. It can be expected that these exploitative methods will have a prominent and probably even somewhat increasing role until alternative sources and public opinion begin to force their decline, probably not before 2020. Similarly there are vast stores of methane gas in the form of methane hydrate in frozen deposits under ocean beds and permafrost areas, but to the difficulty of exploiting them is added the fact that methane is an enormously more damaging greenhouse gas than CO₂, raising grave dangers of leakage and other environmental disasters. Those hazards and the enormous
investment required are likely to prevent any development of this source, although China has announced plans to bring its stores into production in 10-15 years.

Biofuel, with its allegedly lower carbon footprint, is currently the leading contender as a replacement for petroleum-based fuel for vehicles, but developers are turning away from corn and other crops because of CO₂ associated with the growth and processing of the original plants, and other severe negative social and environmental effects, including food shortages and destruction of virgin jungle. A study found that "corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%." A report from ActionAid warns that if all present global biofuels targets were to be met in this way, food prices could rise by an additional 76% by 2020 and force an extra 600 million people into hunger. Instead, about 150 companies worldwide are working to commercialize algae-based products, which do not require agricultural land, and can be transformed into substitutes for diesel fuel, aviation fuel and gasoline, with production targeted for the 2013-2018 range. Cost factors are still uncertain. Other possibilities being explored at stages too early for prediction are cellulosic ethanol, derived from wood and miscellaneous organic waste; halophytic plants, that can grow in soils too brackish for conventional crops; and replacing algae by genetically engineered organisms or equivalent artificial enzymes. Once these fuels are generally available, an equipment transition period of five years can be expected, the duration depending on the availability of local replacement/modification capital.

Batteries and hydrogen are proposed as providing motive power for vehicular transportation. A point often ignored in energy discussions is the fact that these are not energy sources, in the sense that oil is, but rather are energy storage means – some other form of energy is required to charge the battery or split off the hydrogen from water. A study indicates that the battery-powered fully electric car is very unlikely to have a substantial share of the market by 2020 because of the cost of the battery and the recharging question, problems that can be solved only by the possible development at some unknown time in the future of a battery priced at well under $500, capable of running a small car for several hundred miles, and chargeable in no more than six hours from a 110V home outlet. Hydrogen fuel cells are another, and, in the long run, probably more likely, possibility for powering private autos. Hydrogen can be produced by electrolysis of water, but only with the expenditure of a corresponding amount of electrical energy, but early research is underway on less energy-consuming techniques (e.g. sun-driven catalyzed photosynthesis) for its generation. These methods would almost certainly require five years or more to come to production. Fuel cells can also use petroleum or natural gas as the energy source, with the advantage of producing only 50% as much CO₂ per kwh as an engine/generator.

2. Electricity generation

About one-fifth of GHG emission comes from electric power plants, so an important trend in the fight against global warming is increasing use of non-polluting technologies, like wind power, solar, hydroelectric, and nuclear, for generating electricity. A complement to that effort is the reduction of emissions from existing fuel-burning polluters.

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54 http://online.wsj.com/article/SB1000142405274870475904575077460652052760.html
56 http://www.aepi.army.mil/IESIR/IESIR-2010-03.pdf, Item 6.3.3
Nuclear fission power has been losing its initial attractiveness for decades because of two as yet unsolved problems: safety and waste disposal. The world in general is not entirely convinced of the safety of nuclear plants, and construction is almost universally opposed by a plant's would-be neighbors. Continuing reports of radioactive leakages keep the flames of protest alive; the Associated Press has reported that at least 27 of the US's 104 nuclear plants have leaked tritium at some point. On the second problem, the US has tried for years to put in place an acceptable radioactive waste disposal site at Yucca Mtn. NV; that effort is now slated for abandonment, with no good solution in sight for the US's 120 million pounds of high-level leftovers. Other concerns interfering with the progression of this trend are the global presence of that much fissile material that might fall into the hands of extremists, and the escalating cost of plant construction, now running around $10 billion. Nuclear power itself is a drain on the water resources it is trying to preserve; a 3 GW plant proposed in Utah would require 50,000 acre-feet of water annually, enough for 100,000 homes.57 However, in spite of the envisioned difficulties, there are plans to build the first new reactors in the US since the 1970s, in Georgia. The worldwide view is more favorable, with 53 plants now under construction, double the total of just five years ago. Poland, the UAE, and Indonesia are seeking to build their first reactors; China plans to build more than 100 plants. Sweden has selected a waste repository site that is expected to be built by 2020; the location was chosen on purely technical grounds, without the political/geographic overtones of the process elsewhere.58 However, at the current rate, only about 10 GW of new nuclear power is likely to come online by 2020 – about ten plants, with the first new plants in the US becoming operational around 2017. (a typical U.S. nuclear plant can produce 500 to 1,300 megawatts ) There is about 370 GW of capacity installed; one estimate puts total current world energy demand at 15,000 GW.59 If present U-235 plants were expanded to replace 40% of today's fossil fuel power, the reserve of uranium would be exhausted in about 30 years.60 Countering this, there is one something of a "wild card" in the traveling wave reactor, which the originator, TerraPower, claims increases the energy output from low-grade uranium by a factor of 100, can be demonstrated in less than ten years, and begin deployment in less than fifteen.

Wind power

Wind power is a widely adopted substitute for GHG-producing fuel burning power generation. The Global Wind Energy Council estimates that wind power capacity grew by 31 percent worldwide in 2009, with 37.5 additional gigawatts installed, bringing global wind power capacity to 157.9 Gw. The Chinese market experienced more than 100 percent growth, and in the EU, 39% of all new capacity installed in 2009 was wind power. US capacity rose nearly 10,000 megawatts, or 39%, last year.

Existing installations provide, in Gw:61

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<td>2009</td>
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In the U.S., wind produced about 73 billion kilowatt-hours of electricity last year, about 2% of total generation. A report states that on-shore wind turbines in the continental U.S. could generate 37 PWh (petawatt-hours) per year — far more than the 3.8 PWh per year currently required to power the nation, as

57 http://www.hcn.org/issues/42.4/water-fallout
61 http://www.smartplanet.com/technology/blog/thinking-tech/us-holds-wind-power-lead-but-china-coming-on-fast/3042/
estimated in 2005. The world's largest wind farm, being built on the Oregon-Washington border, will produce 400 MW for about $0.04/kwh, compared to about $0.20/kwh for natural gas. to a total of about 35,000 megawatts. [For comparison, a typical U.S. nuclear plant can produce 500 to 1,300 megawatts.] The U.S. Department of Energy has laid out a scenario for how wind could meet 20% of total electricity demand by 2030—about 300 gigawatts—displacing half of natural gas-powered and 18% of coal-fired generation.

A recent report by the National Renewable Energy Laboratory found that the Eastern US, which isn't blessed with substantial onshore wind resources, could hit the 20% target by 2024, but with a price tag as high as $93 billion, including a transmission "superhighway" to carry electricity from parts of the country with lots of wind to places where demand is highest. Offshore generation is more reliable but is about twice as expensive as onshore wind power and faces opposition from coastal property owners. Power from the first of a handful of proposed US offshore wind projects is expected by 2012.

On the other hand, the European wind industry has a target of 40 GW of offshore wind in the EU by 2020. Wind power is also finding a niche as an on-site power source, given suitable energy storage facilities.

Solar

Solar-based electricity generation may be accomplished by photovoltaic (PV) cells that directly convert light into electrical power; or by solar thermal installations in which the infrared radiation from the sun is focused on a vessel containing water, molten salt, or some other liquid medium that is then used to drive a "steam" turbine, or on a Sterling engine, to run a generator. Large arrays of reflectors in various configurations are used to concentrate the sun's rays on the vessel, to create temperatures in the 200°-1200°C range. It projects that, by 2030, overnight capacity costs for new generating plants using solar photovoltaics will be 37 percent lower than the 2009 costs. In addition, the efficiency of solar photovoltaic applications is expected to improve as the technology continues to be developed. As a result, US solar photovoltaic generating capacity is projected to increase from 30 megawatts in 2006 to 381 megawatts in 2030, and total U.S. installed solar thermal capacity, currently 400 megawatts, is projected to increase to 859 megawatts in 2030. These are very small capacities compared to other technologies. Now being discussed for the 2020-2025 timeframe is space-based solar power generation (SBSP), in which a satellite carries a PV array (or, in a few proposals, a thermal system) and transmits the resultant energy to earth via a microwave beam (or, less often proposed, a laser).

Hydroelectric

In 2006, hydroelectric plants had a total capacity of 777 GW and, provided 2998 TWh of power, about 20% of the world's consumption of electricity, and 88% of its renewable supply. Hydroelectric dams cause minimum damage to the atmosphere (from decaying vegetation around them), but they are notorious despoilers of the environment, often flooding unspoiled lands, dislodging populations, and threatening aquatic life. Also, because of silting behind them, they generally have limited lives – the Chinese Academy of Science gives Three Gorges as little as 70 years. Finally, hydroelectric power depends on healthily flowing rivers, not constricted by decreased precipitation or increased water diversion for other purposes. 32 dams with capacities greater than 2 MW (most in the range 3-7MW) are planned or under construction, but in the light of their negative aspects, and the increasing availability of other renewable energy sources, the

References:
64 http://www.20percentwind.org/20percent_wind_energy_report_revOct08.pdf
66 http://online.wsj.com/article/SB10001424052748704757904575077470940114744.html
67 http://www.eia.doe.gov/oiaf/ieo/solar.html
building rate will decline over the next decade and it is likely that by 2050 much of their 20% role in the world's electricity supply will have been taken over by other renewable sources.

**Nuclear Fusion**

Nuclear fusion as an energy source has been under study since the 1970s, and is a very active field of current research. The engineering difficulties are enormous, though, and the outlook is well-conveyed by a quotation from the World Nuclear Association, "A 2 GWt Demonstration Power Plant, known as Demo, is expected to demonstrate large-scale production of electrical power on a continual basis. The conceptual design of Demo is expected to be completed by 2017, with construction beginning in around 2024 and the first phase of operation commencing from 2033." A "wild card" is the discovery (possibly via the LHC) of a new physical principle that would bring this source closer than 20 years.

**Geothermal**

More than 8,900 MW of large, utility-scale geothermal capacity in 24 countries now produce enough electricity to meet the annual needs of nearly 12 million typical U.S. households. Geothermal plants produce 25 percent or more of electricity in the Philippines, Iceland, and El Salvador. A new technique, Enhanced Geothermal Systems (EGS), that circulates water through hot dry rock far underground, is the subject of R/D in several countries. The US DOE hopes to have EGS ready for commercial development by 2015 and is currently funding several demonstration projects.

**Distribution and usage**

Much current research is being devoted to the concept of the "smart grid", a complex of intelligent systems that would monitor the flow of electricity from the generating plant to the wall outlet, and control that flow in such a way as to conserve power at all levels in the network, by, for example, routing wind power to overcast places and solar power to calm areas, and turning on building lights only when it's dark. It could decrease annual electric energy use and utility sector carbon emissions at least 12 percent by 2030. A "wild card" is the development of high-temperature superconductivity that could be applied to the grid.

**3. Carbon sequestration and coal**

Rather than reducing the GHGs produced by fuel burning or other basic process, one approach, carbon capture and storage (CCS), seeks to capture the gas before it reaches the atmosphere. Doing this for a new coal-fired power plant is estimated to add 21-91% to its cost, but the industry claims that by 2025 improvements in the overall process would bring the cost of "clean coal" energy down to its present value — scant compensation for 15 more years of pollution, since world coal consumption is predicted to increase by 49 percent, from 127.5 quadrillion Btu in 2006 to 190.2 quadrillion Btu in 2030, generally reflecting the growth trends for both world GDP and world primary energy consumption. There is increasing environmental opposition to coal-fired power plants, but it cannot be expected to have much influence until alternative sources become more available after 2020. Experts warn that 2030 is the absolute deadline for the cessation of emitting greenhouse gases from coal if we are to avoid a catastrophic tipping

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68 http://www.world-nuclear.org/info/inf66.html
point. CCS can be applied to the emanation of GHGs from general industrial processes, which is responsible for almost 14% of the total release. Storage of the captured gas is also a problem. It has been reported that North America has enough storage capacity in its geological formations for more than 900 years worth of carbon dioxide at its current rate of production, but such long-term predictions are very difficult and uncertain, and CO₂ might leak from the storage into the atmosphere. In the most-advanced current test, the next stage is building and operating a commercial-scale demonstration plant. Designing the facility can overlap with the current pilot, but construction of the plant is expected to take several years; the goal is to have it online by fall of 2015. It would then have to be operated for several years to test its reliability and efficiency. The operator expects that commercial versions of the technology could begin by 2020. Ultimately, commercial adoption also will depend on whether Congress decides to impose a price on carbon and what that price is. Carbon capture is expensive; most experts agree that it is going to take a carbon price of at least $50 a ton to make carbon capture economically feasible.

4. Land use change

A 2002 paper documents that "land-use change impacts regional and global climate through the surface-energy budget, as well as through the carbon cycle. The surface energy budget effects may be more important than the carbon-cycle effects". This is not only due to global radiative forcing by surface albedo change from agricultural or forestation activities, but changes in vegetation cover can also modify the surface heat fluxes directly. (FAO predicts meat consumption will double from current levels by 2050, so converting land to meet a growing demand for meat is a big factor here; the movement for "animal-free" meat, if it is successful technically and eventually with the public, could reverse this, but even backers admit, only "after many years"). That type of change pales in comparison with the climatic havoc wrought by worldwide tropical deforestation, which not only halts CO₂ absorption by the destroyed trees but whose associated fires dump enormous amounts of the gas into the atmosphere, in four years pumping more CO₂ into the atmosphere than every flight in the history of aviation to at least 2025. It has also been shown that deforestation decreases precipitation in the affected region, causing water scarcity and making reforestation difficult. Another deleterious land use practice is agricultural tilling, which causes the carbon naturally held in the soil to be oxidized, resulting in CO₂ release. No current statistics or forecasts were available, but the practice of "conservation" or "no till" farming is being widely promoted (including its benefit of reducing tractor emissions). On the positive side, thought is being given and research is beginning to be conducted on the idea of an admittedly time-wise far-distant (maybe by 2050) total and rational re-allocation of the earth's land resources to achieve sustainability for the projected 9 billion people. "Analyses ... also indicate that 12 billion people with 1995 dietary habits could be nourished on less than one third of the present agricultural area – if the best sites were used for the most appropriate crops and if world food trade would operate undistorted by protectionism." (IARU, 2009, 33)

5. Climate modification (geoengineering)

Geoengineering has so far been only discussed, not put into practice in any substantial way. Some proposed techniques are aimed at directly reducing greenhouse gases in the atmosphere, while others attempt to reduce impinging heat-creating solar radiation. The former type includes removal of CO₂ from the air chemically or by biological consumers (e.g. iron-stimulated phytoplankton in the ocean), while the latter proposes such techniques as stratospheric sulfur aerosols, giant sunshades, and cloud seeding, which
however leave the CO₂ in the atmosphere, and therefore do not mitigate such ill effects as ocean acidification. Geoengineering planning is very difficult because of the lack of a safe "laboratory" in which to try out techniques that could have catastrophic worldwide or regional consequences. Studies of these possibilities have been initiated, but it would be surprising if any of them were applied before 2020.

**Water Adaptation to Climate Change**

Much of the text in this section is taken directly from *Climate Change Adaptation: The Pivotal Role of Water – Policy Brief from UN-Water, March 2010*

Since climate change can only be mitigated, but cannot be eliminated or reversed in the short or medium term, the world must adapt to it and its impacts on the human population and its institutions and activities. Such adaptation is especially important in the context of the sustainable development in which the world hopes to engage over the next few decades. The less developed countries will be experiencing even more water stress than at present, and improved water resource management is critical in such areas as health, food production and security, environmental sustainability, domestic water supply and sanitation, and energy and industry. If it is inadequate, progress in poverty reduction and sustainable development will be jeopardized.

It will be necessary to implement measures to deal with climate change, building on existing land and water management practices to create resilience to climate change and enhance water security. Innovative technological practices are also needed for adaptation as well as for mitigation. The government and business communities do not recognize the pivotal role that water plays in climate adaptation, and adaptation measures in water management are often underrepresented in national plans or in international investment portfolios. Shifts in those undertakings are needed, and should be guided by the following principles, applied in joint efforts and local-to-global collaboration among sectoral and multisectoral as well as multidisciplinary institutions:

- Mainstream adaptations within the broader development context;
- Strengthen governance and improve water management;
- Improve and share knowledge and information and invest in data collection;
- Build long-term resilience through stronger institutions, and invest in infrastructure and in well-functioning ecosystems;
- Invest in cost-effective and adaptive water management as well as in technology transfer;
- Leverage additional funds through increased budgetary allocations and innovative funding.

Climate change comprises not only gradual changes in conditions, but also makes inevitable increased water-related risks from such extreme events as droughts, floods, storm surges, and landslides that will put additional strain on water resources management and increase uncertainty about quantity and quality of water supplies. Sustainable management and development of water resources will play a pivotal role in preparing societies’ ability to adapt to climate change in order to increase resilience and achieve development goals. Water management, based on integrated and system-wide approaches, is the key to climate change adaptation.

**Climate change impacts**

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75 http://www.aepi.army.mil/IESIR/IESIR-2010-01.pdf, Item 4
Even though there may be some mitigation, temperature and precipitation changes and their effects will vary widely over the globe, with some areas having to cope with a scarcity of water, others with ocean incursions and flooding, and some facing changes in the quality of their supply. Damages from severe weather events will be widespread. Climate change will directly affect the demand for water; for instance, changes in demands will derive from industrial and household use, or from irrigation.

**Water Resources Management**

Those responsible for water resource management will have to ensure that their planning is adequate to deal with all of these impacts – gradual or sudden, mild or severe, in all their variations. They must also recognize that decision-makers and policymakers in other disciplines have the solution to many water management problems. They need to recognize that all major decisions should take into account the potential impact on water, recognizing water as the lifeblood. While tackling these issues, decision-makers should think beyond their own sectors and consider the wider ramifications of their decisions on water availability and the forces affecting it, and should adopt a balanced, integrated and coherent approach. Improved integrated management of water and land resources is critical to sustainable development, especially in the context of the following scenarios: worsening food security and malnutrition; increased energy shortages; spread of diseases; humanitarian emergencies; growing migration; increased risk of conflict over scarce land and water; and escalating ecosystem degradation. The establishment of new institutions, networks, and better coordination and exchange of information will be necessary.

Long-term, sustainable adaptation to climate change will require the integration of infrastructure, policy and economic instruments, as well as behavioral changes in national development strategies. Adaptation programs should consider structural and non-structural measures, and the potential offered by natural and physical infrastructure and “soft” programs that comprise incentives and sanctions. Measures should also be evaluated from the mitigation perspective and for their likely impact on the ecosystem and on human health. Adaptation measures should be built on learning-by-doing principles, particularly those being introduced locally, which draw upon traditional and indigenous know-how that could enrich and widen scientific knowledge.

Adaptation measures can be categorized in the following five ways that could ultimately serve as the foundation for adapting to climate change:

1. Planning and applying new investments (including possibly extended water storage facilities)
2. Adjusting operation, monitoring and regulation practices of existing systems to accommodate new uses or conditions (for example, ecology, pollution control, climate change, population growth).
3. Working on maintenance and major rehabilitation of existing systems
4. Making modifications to processes and demands for existing systems and water users.
5. Introducing new efficient technologies

Measures should be designed with full attention paid to coping with the uncertainties, both of climate change itself (short-term, long-term, and extreme events) and of mitigation effort effectiveness, as well as with climate-change-induced changes in overall development projects and other sectors.

**Other aspects**

Adaptation calls for coherent measures to address water security for all major users with priority given to the basic needs of human hygiene and sanitation, consumption and subsistence. Stormwater and wastewater infrastructures will have to be designed for, and operated under, conditions caused by changing water availability, water demand and water quality. Climate change is likely to worsen the living
conditions of rural populations who live in fragile environments and depend on agriculture for their livelihood. Aids could include better water management, more storage (surface water and groundwater), watershed development, rainwater harvesting, water conservation and community initiatives that better integrate land and water management. Rising temperatures or other effects of climate change may damage the quality of drinking water for some populations; adaptation measures should be sure to consider safe water a necessary goal. The impacts of climate change on water may degrade ecosystems whose services support livelihoods and economic development, reducing such benefits as clean water supply, and fisheries and coastal preservation. Remedial actions include upper watershed management to maintain water storage; allocation of water to ecosystems through the application of environmental flows; and restoration of flood plains and mangroves.

Water-related risk assessment, forecast services, and early warning systems should take climate variability into account in their planning and operation.

**Guiding principles**

**Mainstreaming Adaptation Within the Broader Development Context**
Cross-sectoral, integrated and system-wide approaches to climate change adaptation must be developed, placing water management at the center of any development plan.

**Strengthening Water Governance and the Integration of Land and Water Management**
A combination of bottom-up and top-down, land and water, decision-making, where all major players – at community, national and regional levels – can agree, should be the goal.

**Improving and Sharing Knowledge and Information**
Better access to information promotes more rational decision-making. More information needs to be collected and shared across jurisdictional boundaries.

**Building Long-term Resilience**
New systems, structures, procedures, and operating cadres need to be built up as quickly as possible in both the hard and soft environments.

**Cost-effective, Adaptive Water Management and Technology Transfer**
Natural infrastructure (watershed, wetlands) rather than dams and canals; Cost-benefit analysis of measures should consider all potential benefits, especially those related to health. Technological advances for conserving water.

**Additional and Innovative Funding**
Any adaptation funding must be new and must supplement Official Development Assistance (ODA) funds, Climate change adaptation should be integrated into existing funding for water management, and adaptive water management should be considered a funding priority for other water-reliant sectors.

**Causal Links With Other Drivers**

**Governance** (Strongly important)

The most essential role of governance in climate change lies in the formulation and implementation of measures or projects to reduce or eliminate such causative factors as greenhouse gas emissions. Efforts in that role begin with support for the invention and continued development of remedial technologies, something which in general only national governments have the financial resources to accomplish. Most of the work involved in the alternative energy techniques described earlier in this paper was carried out with the aid of government grants. Government’s unique task in remedying climate change is the use of its
coercive power to require that people and institutions apply the solutions as widely as needed. Considering the lack of progress in climate change control at the international level, a 2007 paper, *Conceptualizing climate change governance beyond the international regime,* makes an important contribution when it notes that "over the past five years, there has been an explosion of parallel initiatives, at a variety of scales, by non-state actors, seeking to reduce emissions of green house gases – in cities, at the regional level, through corporations, voluntary offset schemes and so on", and goes on to analyze these efforts. This document pointed out earlier the importance of public opinion, and a most important governance task for the next few years is, to put it bluntly, extensive propaganda at national and international levels for effective climate change control. Another area of governance responsibility arises from the requirements for governments to prevent, limit or repair damage from such climate-change-caused effects as sea water incursions into deltas or aquifers and to properly prepare for the extreme weather events of climate change – storms, flooding, droughts – by strengthening vulnerable parts of the infrastructure and establishing emergency response systems. Other responsibilities of government lie in the area of information systems, where it must make sure that the severe current quantitative and qualitative deficiencies in the collection and processing of local and regional data on climate change and its effects are rapidly corrected. (Bates et al., 2008, 8.1)*76, and in supporting climatological and related research (Bates et al., 2008, 8.2) This is already happening: The US DOE, NSF, and Department of Agriculture have announced the launch of a joint research program to produce high-resolution models for predicting climate change and its resulting impacts.

**Water Resources and Ecosystem** (Strongly important)

The [draft] Driver Report on ecosystems sometimes understates the importance of climate change as a major factor in the supply of water to support ecosystems worldwide. This is especially true in its section on rivers, lakes, and wetlands, where most of the described changes in, and damages to, water resources have climate change as a principal contributing element. That report does point out the effects that climate change may have on flora and fauna, and discusses the damaging or catastrophic effects floods and droughts can have on ecosystems of all kinds. As an element of water quality, eutrophication is strongly affected by atmospheric composition, which in turn depends on the success of climate control measures. Also, according to the Report, "IPCC scenarios modified in Ramsar COP8-Doc.11 predict lower water quality due to higher temperature by 2025, which is further altered by changes in water flow volume. By 2100, water quality effects are amplified."

**Technology** (Strongly important)

Besides the technologies that are involved with controlling climate change and that are covered in the Climate Change Driver Report, the principal links between the two aspects are:

- The emissions, and therefore climate change effects, produced by facilities, like desalination plants, devoted to remedying the effects of climate change itself
- Protection, in both design and operation, of the components of the water production and distribution system from the effects, both gradual and extreme, produced by climate change

Other relationships are:

- Remote sensing – Very important for continuously collecting worldwide data on climate change indicators

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77 US NOAA is setting up a Climate Service, analogous to the National Weather Service.
Desalination – Important tool for adapting to climate change shortage of fresh water
Nanotechnology – Important in the engineering of all the Climate Change technologies
Saltwater Agriculture – Important for biofuel production and for overcoming ocean intrusions
Meat without Animals – Reduces methane emissions and harmful land use changes
Information Technology – Water management data collection needs to be sure to include climate-change indicators and climate-change-related water parameters

**Economy and Security** (Strongly important)

Along with energy usage patterns and technology, a major driver in climate change is the size and "climate conscientiousness" of the world's economy – the Economy Report states "carbon intensity of the global economy would need to be reduced by 95% by 2050 compared to 2002, in order to stabilize emissions at 350ppm by 2050" – moving to a "green economy". Every industrial action must be examined in the light of its effect on the causative factors of climate change. The world’s economy, including the water production and distribution sector itself, will also have to take account in all its planning and activities of the effects of climate change on resources, populations, and the state of the environment. The grave security implications caused by areas becoming uninhabitable, or at least less desirable, because of climatic changes are well recognized, with the world facing crises of national rivalries and population shifts in the Middle East, central and southeast Asia, and elsewhere.

**Agriculture** (Strongly important)

In addition to its connection with irrigation, climate change has a profound effect on the success or failure of the rainfed agriculture that covers 80 percent of agricultural land worldwide, and of course all crops, and in fact all vegetation, depends on a certain ambient temperature range. "No till" farming, fertilizer limitation, and other soil management techniques contribute substantially to the mitigation of climate change. Increase in agricultural land, because of the population growth or for biofuels, or decrease, because of urbanization or "animal-free meat", is likely to affect climate change.

**Infrastructure** (Strongly important)

The water-related consequences of climate change must be thoroughly determined and analyzed to ensure that all necessary changes to the world's infrastructure are scheduled for conservatively calculated timely implementation. Thus adaptation to the effects of climate change will be the motivating force behind many infrastructure projects, like dam destruction or modification, littoral protection structures (e.g. breakwaters), and changes (improvements and expansions) to the water collection, processing, and distribution systems (e.g. canals). Infrastructure planning and project implementation must maintain a strongly "green" outlook, with the consequences for climate change kept in mind in carrying out all design and construction (e.g. green bulldozers). Infrastructure components will have to be built to cope with the effects of climate change (cooling for rising temperatures, strength for extreme storms). The EU 'PREPARED: Enabling Change' Project, linking the adaptation efforts of a number of cities, is an example of the kind of large-scale cooperative effort that is needed.

**Demography** (Strongly important)
The energy demands created by population growth and changes in socioeconomics-related behavior have already been cited as a major cause of climate change. In the inverse causal direction, climate change is already bringing about population shifts in various parts of the world, as people leave regions that have been made nearly uninhabitable, e.g. rising sea levels are beginning to force populations to move from low-lying areas. The rigors of its effects on temperature and water supply are tending to increase infant mortality and decrease life expectancy, and are beginning to produce localized areas of high mortality from starvation and disease.

Ethical, Social, and Cultural (Strongly important)

This driver relates closely to climate change in the area of public support for measures and techniques to mitigate climate change, an aspect whose importance was emphasized in the discussion above of non-technological developments. As this driver points out, water is a central component of human existence, but the dependence of its availability on climatic conditions is a less viscerally felt element. Increasing the level of societal awareness of that connection must be a vital objective of the international effort for control of climate change. A proper division of resources must be established between attitude reform efforts related to the production and distribution of water itself, and those associated with the mitigation of climate change, mainly through emission control. A usually overlooked aspect of this struggle is the necessity of increasing the public's appreciation (in both senses) of science. Climate-gate would not have been such a catastrophe had it not built on an underlying ignorance of, and hostility toward, science. In addition to supporting "external" steps to mitigate climate change, like emission controls, society needs to "behave green" in its consumer habits – this tendency may be increasing in developed regions, and decreasing in LDC - this driver report points out that China is going in that materialistic direction.

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