ENVIRONMENTAL ISSUES IN ELECTRICITY ECONOMICS

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Abstract

- *The Nigerian electricity industry is currently experiencing and adapting to enormous change including concerns related to security, reliability, increasing demand, aging infrastructure, competition and environmental impacts.*

- *Decisions that are made over the next decade will be critical in determining how economically and environmentally sustainable the industry will be in the next 50 to 100 years.*

- *For this reason, it is imperative to look at investment and policy decisions from a holistic perspective, i.e., considering various time horizons, the technical constraints within the system and the environmental impacts of each technology and policy option from an economic and environmental life cycle perspective.*

- *Several promising options could satisfy our electricity demands. Other options remain unproven or too costly to encourage investment in the near term but show promise for future use (e.g. photovoltaic, fuel cells). Public concerns could impede the use of some desirable technologies (e.g. hydro, nuclear).*
- *Finally, less tangible issues such as intermittency of some renewable technologies, social equity and visual and land use impacts, while difficult to quantify, must be considered in the investment decision process.*

Electricity, the Economy and Environmental Sustainability-Environmental Issues

- Energy, which has always played a critical role in our country's national security, economic prosperity, and environmental quality, has over the last two years been pushed to the forefront of national attention as a result of several factors:

- World demand for energy has increased steadily, especially in developing nations. China, for example, saw an extended period (prior to the current worldwide economic recession) of double-digit annual increases in economic growth and energy consumption.

- Nigeria, a country with abundant oil resources now imports refined products thus pushing up prices of petroleum products domestically.

- The long-term reliability of traditional sources of energy, especially oil and natural gas, remains uncertain in the face of political instability and limitations on resources.

- Concerns are mounting about global climate change—a result, in large measure, of the fossil-fuel combustion that currently provides most of the world's energy.

- The volatility of energy prices has been unprecedented, climbing in mid-2008 to record levels and then dropping precipitously—in only a matter of months—in late 2008.

- Today, investments in the energy infrastructure and its needed technologies are modest; many alternative energy sources are receiving insufficient attention; and the nation's energy supply and distribution systems are increasingly vulnerable to natural disasters and acts of terrorism.

- **All of these factors are affected to a great degree by the policies of government, both here and abroad, but even with the most enlightened policies the overall energy enterprise, like a massive ship, will be slow to change course. Its complex mix of scientific, technical, economic, social, and political elements means that the necessary transformational change in how we generate, supply, distribute, and use energy will be an immense undertaking, requiring decades to complete.**

- **This paper evaluates current contributions and the likely future impacts, of existing and new energy technologies. It was planned to serve as a foundation for subsequent policy studies, at the academies and elsewhere, that will focus on energy research and development priorities, strategic energy technology development, and policy analysis.**

- The electricity industry is arguably the most polluting industry in the world economy. However, it is critical to modern society.
- Many decisions must be made over the next several decades about continued operation of existing generation and investment in new generation.
- The industry does not currently evaluate investments from a life-cycle perspective. However, life-cycle environmental impacts must be considered in order to understand the true environmentally preferred solutions.
- Further, these impacts must be integrated into economic considerations to ensure these solutions are relevant to the industry.
- The key policy questions facing the electricity industry today are graded into three time horizons (near-term - less than 10 years, mid-term - 10 to 25 years, and long-term - 25 to 50 years).

Near-Term

- What technologies exist today and how do policies, costs and impacts affect preferences for these technologies?
- What can be done to decrease the impact of current operations?

Mid-Term

- Are there opportunities in the near- to mid-term to improve efficiency and environmental impacts of new infrastructure investments and use?
- Specifically, are there alternatives to transportation of materials that improve the costs and/or environmental impacts?

Long-Term

- What would a future of high natural gas usage look like?
- How do choices in planning affect the impacts of this increased use?

- The hydrocarbon fuels in which Nigeria have hundreds of years of reserves at current prices are natural gas and coal. Currently, more than 50% of electricity is generated from natural gas.
- While many future energy scenarios are possible, natural gas is likely to play a large role for at least the next half-century, barring significant technological changes and large hydrocarbon discoveries.

- Advanced generation technologies can decrease air pollution emissions significantly, and even capture and sequester CO2. Thus, while the future is uncertain, it is prudent to investigate the possible impacts of a high natural gas use future. Since it is a non-renewable resource and currently causes environmental damage due to mining, transport, and electricity generation.

- Uncertainty about the price and availability of other fuels make their future contributions uncertain. For example, natural gas is more an environmentally desirable fuel than coal, but competition for use and uncertain prices make it’s future use in this industry uncertain.

- Expanding nuclear power is hampered by public opposition, high cost, lack of closure of the life cycle, and security concerns. Major expansion in hydroelectric output is unlikely because of environmental opposition and prior development of the best sites.
- Many renewable technologies are not yet economically competitive and their inability to supply power when needed raises cost and makes them less attractive. However, the potential for these technologies to contribute in the future shows promise.

Climate change and CO2 emissions

- Global climate change, a widely discussed topic in environmental studies, represents a potentially serious threat to natural ecosystems, and to the quality of human life on earth. Studies predict that the adverse consequences of climate change induced by human activities will include some of the following in the future [World Energy Assessment, 1999]:
- The average temperature of the global surface air will increase by 1.0~3.5°C during this century.
- The global mean sea level is likely to rise by about 6cm per decade during this century, mainly due to the thermal expansion of the ocean and the melting of some land ice.
- Even though food production may increase in some areas, the high likelihood of its decrease in other areas, especially in the tropics and subtropics, will bring hardship to large segments of population.
- Fast climatic changes may result in the instability of ecosystems, causing natural disasters such as floods and droughts.
- Some diseases currently contained within certain areas may spread further to threaten new populations.

- To minimize the impacts of climate change, it is important to pinpoint and eliminate factors responsible for this phenomenon.

- It is well-known that a number of gases, such as carbon dioxide, ozone, methane, nitrous oxide and CFCs in the atmosphere, induce the greenhouse effect that drives global climate change.
- The contribution of carbon dioxide is, however, dominant because of two reasons.
- First, the concentration of this gas is already higher than other greenhouse gases in the atmosphere, and, second, human activity on earth today is adding carbon dioxide to the atmosphere at historically unprecedented rates.
- The recent increase in the atmospheric concentration of carbon dioxide has resulted from the large scale utilization of fossil fuels in modern times.
- Since the onset of the industrial revolution, for instance, 296 gigatonnes of carbon from fossil fuels have been released to the atmosphere, raising carbon dioxide concentration from 280ppm to 360ppm [World Energy Assessment, 1999].

- At present, fossil fuels fulfill about 84.8% of the world's primary energy consumption needs [International Energy Annual 1999], and in the foreseeable future, fossil fuels will still be the major energy source.
- Estimates indicate that the world's fossil fuel reserves contain approximately 6600 gigatonnes of carbon, with 5200 gigatonnes of carbon in coal alone.
- In the absence of adequate measures to control the emissions of carbon dioxide from these sources, the atmospheric concentration of carbon dioxide could more than double by the end of this century [World Energy Assessment, 1999].
- Concerns about the greenhouse effect call for new strategies regarding the use of coal to reduce the emission of carbon dioxide into the atmosphere.
- The task of reducing carbon dioxide emissions without abruptly cutting off the utilization of fossil fuels, however, presents a serious challenge.
- The following section discusses some methods for facing this challenge.

- **CO_2 Mitigation in the Electric Power Sector**

There is no panacea for eliminating CO_2 emissions in the electricity sector. Because wind is a viable CO_2 emissions-free technology, a more accurate assessment of the cost of mitigating electric sector CO_2 emissions using wind is important to the economics of climate change mitigation.

Other renewable options include hydro, photovoltaics, and biomass. Non-renewable alternatives for reducing CO_2 emissions include fuel switching to less carbon-intensive fuels, improved efficiency (both demand- and supply-side), carbon capture and sequestration from fossil units, and nuclear.

Each of these technological alternatives possess a unique set of benefits, limitations, and costs.

- This section focuses on the potential efficacy of these options and is briefly discussed below.

Renewable Technologies

- Today, there is a nexus of concerns about the energy portfolio: concerns about the environment, principally arising from climate change issues; concerns about energy security, principally due to the large amounts of vandalization of oil facilities in the volatile parts of Nigeria; and concerns about the economy, principally because of sharp increases in the price of oil, natural gas, and basic construction commodities.
- Collectively, these concerns beg the question of whether it is time for reevaluating and redesigning our electric infrastructure to extend energy efficiency to a much greater extent and use domestic, non-polluting, economically attractive energy sources. Thus, this provides the motivation for the continued but growing interest in renewable-based electric power.

- Among renewable technologies – most notably wind, biomass, solar, and hydro –wind and biomass show the most potential for growth.
- Despite continued growth in hydroelectric installations in the developing world (EIA, 2003a, 105), limited resources and growing environmental concerns are likely to severely limit the long-term role that hydro can play in climate change mitigation.
- Even if installed hydroelectric capacity were to double worldwide, it would still only make a small contribution to CO2 mitigation.
- The direct use of solar energy to generate electricity is currently confined to small off-grid applications because the cost of electricity from photovoltaic panels is roughly 20 ¢/kWh (Bull, 2001), and projections for advanced solar thermal systems are still higher than the current cost for wind (Dracker and De Laquil, 1996).
- Despite the current high costs, advances in materials science make the long-term potential of photovoltaics a realistic possibility.

- Biomass, unlike hydro and solar, has the potential to play a leading role in the reduction of carbon emissions in the electric power sector.
- According to Metz et al. (2001), the technical potential for global biomass energy crop production in 2050 could reach 12.5 TW from 1.28Gha of available land, a land area that is slightly less than the amount of currently cultivated land worldwide.
- Capital investment in a high pressure, direct gasification combined-cycle plant for electricity production is expected to be roughly 1000 $/kW by 2030, with operating costs, including fuel supply, reaching 3.12 ¢/kWh (*ibid.*).
- If this projection proves accurate, biomass gasification would become an inexpensive carbon-neutral technology.
- In the near term, biomass cofiring in existing coal plants can reduce electric sector carbon emissions by 5% at a low cost of 25±20 $/tC (Robinson et al., 2003), and a biomass-IGCC system with a carbon capture and sequestration can produce net negative emissions at projected costs of 7-8 ¢/kWh (Rhodes and Keith, 2008).

Hydro

- Until recently, hydroelectric power was considered the most environmentally benign source of electricity. In recent years, however, the major adverse impacts of hydro power, through flooding large areas and disrupting fish migration have challenged this idea (Collier, 1996). A few dams have been breached for environmental reasons and many more are being investigated (ARFE, 1999).

- However, projects involving retrofitting current dams as well as smaller scale diversion structures are possible. Outside the U.S. major construction of new hydropower is expected in the next few decades. (Sharp, 2000; Acreman, 1996; Zutshi, 1994; Masjuki, 2002; Bhutta, 2002)

- Hydropower's fuel source is renewable, it is available on site (no mining, transporting etc. required), and no combustion is required. It also has the large disadvantage that generation depends on precipitation, which varies from year to year. These environmental implications are different from fossil fuel cycles.

- The main implications to be considered with hydro-electricity are the land and water ecosystem impacts associated with constructing and operating hydro-electric dams, the cost of power, and the renewable nature of the fuel supply. Hydro power releases no CO_2 directly, but is less reliable than fossil fuel plants due to droughts.
- The range of emissions in various literature show that different results are obtained based on different assumptions and boundaries drawn for analysis. For example, the ORNLRFF study did detailed calculations to assess emissions from the dam construction and manufacture. Other studies investigated an upgrade to an existing hydro plant (Pacca, 2002), run-of-river vs. reservoirs (Gagnon, 2002) and various sizes of hydro projects (Roth, 2004).

- **Wind**
- The main advantages of wind are that the generation phase does not emit environmentally harmful pollutants and the fuel is renewable. The number of attractive sites for wind turbines is limited since they must have high wind during most hours of the year.
- Humans cannot control wind speed, requiring backup power when the wind does not blow. While wind turbines emit no pollutants, the life cycle of these turbines does require materials and emit pollutants, as well as use land. The most important current objection seems to be objections to placing the turbines in their best locations, highly visible places such as the tops of ridges or mountains or in the ocean.

- The structure and technology of most modern wind turbines is very similar around the world. They are considered a mature technology.
- The results of life cycle assessments conducted are very different due to variability in each study’s assessment of the contents of materials, national fuel mixes chosen, and the method and scope of each study (Lenzen, 2002).
- For example, one study compared the material requirements for offshore versus onshore wind farms (Schleisner, 2000).
- This study found that the emissions of CO_2, SO_2 and NO_x associated with the offshore project were greater by 50 – 70%.
- This was primarily due to the additional material production and manufacturing required for the offshore project.
- The full life cycle of renewable fuels is extremely important for determining the environmental impact of such systems.
- Wind is a good example as 68-99% of the external costs of the system are from emissions related to material production and manufacturing (Schleisner, 2000). Also, even the windiest sites in do not experience consistently high wind speeds the entire year.
- One method to compensate for this intermittency is to use natural gas plants as a source of backup power.

- The point of showing this simplified analysis is to demonstrate that the life cycle emissions increase dramatically if natural gas is used to deal with the intermittency of wind.

- There are many other methods of backing up intermittent sources. These include storage of the energy in batteries, compressed air, chemical bonds (e.g. hydrogen, methanol), or fly wheels.
- However, none of these technologies have been proven to be cost effective to-date (Decarolis, 2005).

- A recent study evaluated the life cycle emissions of wind for base load with temporary compressed air storage but did not evaluate the costs (Denholm, 2005).
- The main tradeoffs to be considered for wind powered electricity systems are the reduction of greenhouse gas (and other) emissions versus the intermittency problem (and the potential non-renewable backup required).
- In addition, the distance between where the wind blows and where the electricity is demanded is often large, requiring long transmission lines.

- Currently, wind receives a subsidy of 1.8 cents/KWh in the U.S. and many states have renewable portfolio standards that encourage wind power.
- If the costs of air pollution and CO_2 emissions were added to the cost of electricity generated from fossil fuels, and if the depletion of these fuels were considered, wind generated electricity might be less expensive than electricity from fossil fuels (Kennedy, 2005).
- However, very large-scale wind deployment could affect climate by removing energy from the lower boundary layer of the atmosphere (Keith et al., 2004; Decarolis, 2004).

Solar

- The sun is the earth's greatest source of energy and the source of most renewable energy.
- Solar energy that is currently being used to generate electricity is either solar thermal or photovoltaic.
- Solar thermal technology uses the radiation directly to heat water or other materials, focusing the radiation to generate steam.
- Photovoltaic technology converts the sun's rays directly to electrical energy.
- One of the advantages of solar radiation is that the conversion of electromagnetic radiation to electricity occurs without environmentally harmful emissions.
- However, other stages of the fuel cycle do contribute to environmental damage.
- Examples of the toxic and flammable/explosive gases that are used in making photovoltaic power systems are silane, phosphine and germane; cadmium is often used in production.
- Recycling the cell materials is possible but the environmental consequences of that must be considered first.
- The use of hazardous compressed gases in PV manufacturing could lead to health and safety concerns.

- Since the sun does not always shine, electricity storage or back up is required; this increases costs significantly and can lead to additional environmental problems.
- One of the major environmental concerns for this fuel cycle is the manufacture (particularly the process energy) and disposal of solar cells and other equipment.
- A recent study showed that a photovoltaic array produces a global warming effect which is 9 times less than that of a coal plant over the course of an assumed 20 year lifetime when both are built to produce 5.55 TWh/year (Pacca et al., 2002).
- The emissions associated with this PV system are higher than other studies have shown since the method of dealing with intermittency in this study was to scale the size of the PV array up to over 4,000 MW whereas the coal plant requires a capacity less than 1,000 MW to produce the same amount of electricity.
- Energy use in the manufacturing stage is the largest contributor to conventional emissions. In addition, greenhouse gases can be used (and emitted) in PV manufacturing such as SF_6 and CF_4.
- The cost of this technology is not competitive with fossil technologies (even with the current level of subsidies). As such, commercial application of photovoltaic arrays is currently restricted to remote applications and other niche applications.

- Therefore, the main tradeoffs to consider for solar powered electricity are cost and environmental impacts of backup power generation or other method to handle the intermittency issue, as well as the manufacturing and disposal of solar cells, depletion of scarce resources, and use of hazardous materials versus the reduction in greenhouse gas emissions.

Biomass

- Biomass is a renewable fuel that could be a partial or total replacement for coal. When biomass is co-fired with coal, most pollutant and net CO_2 emissions fall in proportion to the biomass used. The most significant environmental impacts from this fuel cycle are caused by the use of chemicals and fertilizers, as well as land use issues.
- A recent study compared an integrated gasification combined cycle plant fired by dedicated energy crops (poplar short rotation forestry) to a conventional power plant (Rafaschieri, 1999).
- For almost all of the eco-indicators and normalized effects considered in this study, biomass had less environmental impact than coal.
- Another study concluded that the use of crops to generate electricity is preferred to their use as transport fuels from both an ecological and socio- economical criteria (Hanegraaf, 1998).
- However, the average private costs of biomass were found to be almost double that of coal power generation (Faaij, 1998).

- There are also significant differences in damages, and thus externalities, among different sites (for example, benefits from erosion reduction differ by a factor of three) for different biomass technologies (ORNL, 1996).
- The use of advanced biomass conversion technologies could reduce NOx emissions significantly compared to conventional wood burners.
- The biomass fuel cycle has near-zero net emissions of CO_2 since CO_2 is fixed by the plants as they grow.
- The land area required to replace a significant portion of the electricity currently generated by coal limits the use of biomass.

- *Environmental Impacts of Renewables*
- Renewable electricity technologies have inherently low life-cycle CO_2 emissions as compared to fossil-fuel-based electricity production, with most emissions occurring during manufacturing and deployment.
- Renewable electricity generation also involves inherently low or zero direct emissions of other regulated atmospheric pollutants, such as sulfur dioxide, nitrogen oxides, and mercury.
- Biopower is an exception because it produces NO_x emissions at levels similar to those associated with fossil-fuel power plants.
- Renewable electricity technologies (except biopower, high-temperature concentrated solar power, and some geothermal technologies) also consume significantly less water and have much smaller impacts on water quality than do nuclear, natural-gas-, and coal-fired electricity generation technologies.
- Because of the diffuse nature of renewable resources, the systems needed to capture energy and generate electricity (i.e., wind turbines and solar panels and concentrating systems) must be installed over large collection areas.
- Land is also required for the transmission lines needed to connect this generated power to the electricity system.
- But because of low levels of direct atmospheric emissions and water use, land-use impacts tend to remain localized and do not spread beyond the land areas directly used for deployment, especially at low levels of renewable electricity penetration.

- Moreover, some land that is affected by renewable technologies can also be used for other purposes, such as the use of land between wind turbines for agriculture.
- However, at a high level of renewable technologies deployment, land-use and other local impacts would become quite important.
- Land-use impacts have caused, and will in the future cause, instances of local opposition to the siting of renewable electricity-generating facilities and associated transmission lines.
- State and local government entities typically have primary jurisdiction over the local deployment of electricity generation, transmission, and distribution facilities. Significant increases in the deployment of renewable electricity facilities will thus entail concomitant increases in the highly specific, administratively complex, environmental impact and siting review processes.
- While this situation is not unique to renewable electricity, nevertheless, a significant acceleration of its deployment will require some level of coordination and standardization of siting and impact assessment processes.

Deployment

- Policy, technology, and capital are all critical for the deployment of renewable electricity. In addition to enhanced technological capabilities, adequate manufacturing capacity, predictable policy conditions, acceptable financial risks, and access to capital are all needed to greatly accelerate the deployment of renewable electricity. Improvements in the relative position of renewable electricity will require consistent and long-term commitments from policy makers and the public. Investments and market-facing research that focuses on market needs as opposed
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Non-renewable technologies

- Coal-based generators that employ carbon capture and sequestration are also expected to play a role in providing electricity with lower specific carbon emissions than the current generating system.
- There are several options for separating carbon from coal. To capture carbon post-combustion, CO2 can be removed form the flue gas through a chemical absorption method.
- Post-combustion carbon capture is complicated by the low concentrations of CO2 in the flue gas, resulting from high ambient concentrations of nitrogen in the air feed (Herzog, 2001).
- An oxyfuel approach, which uses an air separation plant to produce oxygen that is fed to the power plant to be used in combustion, simplifies capture by yielding higher concentrations of CO2 in the flue gas (*ibid*.).
- Because combustion with oxygen yields unmanageably high temperatures given current technology, some of the flue gas would be recycled to moderate the temperature (*ibid.*).
- Another option is to partially oxidize coal to create a synthesis gas. The synthesis gas can be made to undergo a water-gas shift reaction to form CO2 and H2, with the former being captured and the latter being burned as a carbon-free fuel in a combustion turbine (Parson and Keith, 1998).

- Once the CO_2 has been separated using one of the separation methods described above, it can be sequestered in large reservoirs.
- Reservoirs capable of sequestering of order 10^2-10^4 GtC for thousands of years include the ocean, deep saline formations, depleted oil and gas reservoirs, and coal seams (Herzog, 2001; Parson and Keith, 1998).

- Carbon capture and sequestration is possible today and adds roughly 2 ¢/kWh to the cost of electricity if 90 percent of the carbon is captured and sequestered (Herzog, 2001), similar to the cost of other electric generation technologies with low carbon emissions (Johnson and Keith, 2004).
- The continued use of coal as a central generating technology in a low-carbon world also maintains energy security for many nations, as the global reserve/production ratio for coal is over 200 years globally (BP, 2003).

- Another alternative to reduce carbon emissions in the electric power sector is nuclear.
- Over the next 20 years, nuclear power capacity is expected to grow by a modest 9 GW, with plant construction in the developing world offsetting plant retirements in the developed world (EIA, 2002, 91).
- On a life-cycle basis, the greenhouse gases emitted per kWh from nuclear is two orders of magnitude less than for fossil-based electricity generation and comparable to renewables (Metz et al., 2001, 240).
- Despite the maturity of nuclear technology, capital costs remain high: currently 1700-3100 $/kW, rendering it uncompetitive with combined-cycle gas turbines in places where natural gas infrastructure already exists.
- However, under a strong constraint on carbon emissions and higher natural gas prices, nuclear could play a key role in climate change mitigation.
- In order for nuclear power to emerge as important player in the electric power sector, four basic challenges must be met: cost, safety, proliferation, and waste (Ansolabehere, 2003, 3).
- The saliency of Chernobyl and Three Mile Island as well as new security concerns that have emerged post 9/11 also present a significant ongoing public relations challenge to the nuclear industry, which stagnates potential growth.

Nuclear

- A major advantage to nuclear power is that none of the traditional pollutants are released in producing electricity.
- However, there are major concerns about the treatment and risks associated with the generation and storage of radioactive wastes.
- Nuclear power was reviewed extensively in the 1970's where most fuel cycle analysis revealed that nuclear power posed less risk to humans and the environment than traditional fuels (coal and oil), although disposal of radioactive waste was not treated.
- This, however, excludes the fact that the risks associated with nuclear power, although rare, can be devastating.
- Since the 1970's, very little assessment of nuclear fuel cycles has been conducted .
- However, recent discussion in the U.S. of the disposal of spent fuels and policies designed to encourage investment in nuclear facilities should increase the study of possible nuclear futures in the next several years.
- However, throughout the rest of the world, many studies have been published and the environmental consequences of nuclear power continue to be investigated due to its continued use (Rashad, 2000; Wu, 1995; Gulden, 2000; Fisk, 1999; Al-Rashden, 1999; Aumonier, 1998; Ion, 1997). In countries like Korea there is no domestic fossil fueled energy supply, making nuclear attractive (Lee, et al., 2000).
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- The life cycle stages of the nuclear fuel cycle include uranium mining and milling, conversion of uranium to uranium hexafluoride, enrichment, fabrication into fuel elements, use of the fuel to generate electric power, power plant decommissioning and reprocessing or disposal of spent fuel.

- The nuclear life cycle air emissions are generally orders of magnitude lower than the emissions from fossil-fueled electricity generation technologies.
- The different upstream assumptions made in these studies as well as those presented in the subsequent section on renewable sources, are generally within the same range but vary greatly from study to study.
- If these emission levels were the only basis of a decision between nuclear or renewable technologies, there would not be a clear winner.

- The cost and environmental impacts from transport in this fuel cycle can be large since the few areas where uranium is enriched can be very far from where it is consumed.
- This would lead to long distance shipments.

- ***Future Technologies***
- Several new designs promise greater safety and lower costs. Several projects build on current technologies, such as the “inherently safe” light water reactor designs.
- The most recent CANDU technology which adopts light water cooling and a more compact core that reduces capital cost.
- It also runs on low-enriched uranium, with high burn-up, which extends the fuel life by about three times and reduces high level waste volumes. Units will be assembled from prefabricated modules, eventually cutting construction time to 3 years (this trend applies to all nuclear technologies).
- Based on recent Asian implementations, manufacturers of the technology project costs of $1255/kW with later units under $1100/kWe.
- Breeder reactors have been under development for more than 30 years, but significant technical challenges remain.
- Pebble-bed reactors promise to be cost-competitive and meltdown-proof by using gas instead of water and operating at high temperatures which increases efficiency.
- However, they are still technical issues that need to be resolved and the development is still at laboratory scale.
- Finally, enrichment processes including laser enrichment procedures are aimed at decreased costs and energy requirements. The increased deployment of enrichment by centrifuge or laser will reduce the life cycle Greenhouse House Gases (GHG) emissions.

Waste Streams

- Developing an acceptable method for dealing with spent fuel from the nuclear fuel cycle is one of the most important determinants of whether there is a future for nuclear power .
- The major element of uncertainty is the possibility of exposure to radioactive waste hundreds or even thousands of years from now.
- Several LCA studies have considered the long term storage of high-level spent fuel.
- However, in order to calculate the risk associated with this storage, the probability of a major accident per year is multiplied by the predicted exposure from such an incident.
- One study calculates that the probability of large-scale exposure is so low that expected exposure is much lower than that from current during normal operation of the plant, which is very low (Dreicer, 1995).
- The issue of how to safely store spent nuclear waste has yet to be resolved and remains an obstacle for building new nuclear power plants.

Natural Gas

- The low capital cost of the generators, rapid construction, and low emissions made these plants less expensive and more attractive than coal units.
- DOE predicted in 2003 that by 2025, 29% of the electricity will be generated from natural gas (EIA, 2003a).
- This has been adjusted in the 2005 forecast to 15% by 2025 (EIA, 2005a). Natural gas prices have doubled from the start of 2002 to start of 2005 making the operation of existing plants generally unattractive; future shortages of gas could curtail delivery to electricity generation plants.
- The life cycle stages of natural gas include construction and decommissioning of the power plant, natural gas exploration and extraction, construction of the natural gas pipeline, natural gas production and distribution, ammonia production and distribution, NOx removal, and power plant operation. Emissions from this fuel cycle include CO2, CH4, Non-Methane Hydrocarbons (NMHCs), NOx, SOx, CO, PM, and benzene.
- The high efficiency possible with today's technology and lower carbon content per BTU give the gas fuel cycle lower net emissions of CO2 than other fossil fuel cycles (as little as half that of coal).
- However, quantities of methane (CH4), a powerful greenhouse gas, leak throughout the fuel cycle. Other important environmental consequences of this fuel cycle are the consumption of water, land impacts from drilling and exploration, the potential for pipeline fires and explosions as well as discharged drilling mud.

Transport

- The increasing demand for natural gas has resulted in an elaborate network of gas pipelines transporting natural gas long distances. While some infrastructure no longer links vital supply and demand, other pipelines are operated at full capacity and are the bottleneck of the natural gas fired electricity system.
- Shipping energy by pipeline is a relatively efficient method. Average loss (including leakage and fuel use in transport of natural gas) is approximately 3% in the U.S. (EIA, 2000a).
- The emissions of methane are the largest release of GHG gases in this phase.

- Recycling the flue gas to increase the CO2 concentration of the flue stream (still using amine scrubbers), adding H2 to the turbine in order to decrease the amount of methane required and therefore the CO2 released, and using a steam reformer, can help to improve the cost and efficiency of the CCS system. This latter technology involves precombustion removal of CO2 (Aasen et al., 2004).
- Steam reforming has a larger energy penalty, 9%, than the amine scrubbed, 14%. The amine technology was first developed for removal of CO2 from natural gas fired electricity generation and there are several functioning plants with this technology in operation today.
- The cost and efficiency of a steam reformer system is uncertain at this point.

Waste Streams

- Discharges of water pollutants are small as is the solid waste (mostly from pipeline transport and natural gas extraction).

Conclusions

- Electricity is essential to our lifestyles and the economy. The share of electricity in the total amount of energy that we consume is likely to rise.
- Past technologies for generating electricity were inefficient, polluting, and unsustainable. Technological change has increased efficiency and lowered cost.
- Ever more stringent environmental regulations have lowered environmental discharges, although they also increased costs.
- Sustainability of electricity has not been addressed directly, although recent legislation (specifically the Renewable Portfolio Standards) requiring that a proportion of electricity come from renewable sources does begin to address the issue. Profit incentives and the market place encourage generators to work hard to lower costs and provide the kinds of services that consumers are willing to pay for. Government regulation or the use of market incentives are needed to address environmental and sustainability concerns.

- In setting environmental and sustainability goals and in choosing fuels and technologies for generation, life cycle analysis is needed to compare the extraction to end of life implications of the alternatives.
- Generation itself is responsible for only a portion of the materials and fuels used and the environmental discharges during the whole life cycle of electricity.
- This viewpoint makes clear that even a seemingly benign generation technology like hydrogen powered fuel cells that emit nothing except water vapor pose problems through the materials, energy, and environmental discharges during their life cycle.
- Current technology does not offer an entirely sustainable generation technology or one without adverse environmental consequences.

- However, current technology offers more sustainable and environmental technologies than those currently in use.
- Combined cycle natural gas turbines are another important innovation.
- Using the combustion gases to drive a turbine directly, rather than heating steam to drive the turbine, increases efficiency. Adding a second cycle increases efficiency still more.
- This fuel is naturally clean, although not sustainable. Emissions of NOx and GHG would have to be curtailed to make the fuel-technology less environmentally harmful.
- Distributed generation, offering combined heat and power offers still greater efficiencies.
- Renewable resources, such as hydro and wind are no longer perceived to be entirely benign. Photovoltaic power has less environmental consequences, although its high costs and ability to generate energy only when the sun shines pose problems.
- Biomass offers a renewable fuel that can be burned to produce low pollutant emissions and no net CO_2 emissions. Cost is an issue, as is the large amount of land that would be required to generate a major proportion of electricity.

- Electricity generation will be less polluting and more renewable than it has been in the past; it is also likely to be more expensive.
- If we were willing to pay more for electricity, it could be made still less polluting and more sustainable.
- No current or near-term technology will be entirely benign, but environmental emissions and sustainability can be improved to levels undreamed of a few years ago.
- To achieve progress most cost effectively, we need to provide incentives or regulations to attain these goals.
- Each of the fuels and technologies has promise, but no one is dominant.
- Society should provide incentives rather than pick a winner among the alternatives.
- We must back up our desires for clean technologies and sustainable fuels by being willing to pay somewhat more for electricity.