

in table 2). Sources are mainly energy crops but also some forest residues. The resulting impact, although substantial, is still well below that from coal and lignite. As an indication, the resulting chronic mortality rates are less than 20% of those from the lignite reference technology reported above. The most important emissions are those of ozone precursors—such as nitrogen oxides and volatile organic compounds.

#### Nuclear

The sources of the effects and indeed the effects themselves for the nuclear fuel cycle are very different from those for the fossil fuel cycles. They can arise from occupational effects (especially from mining), routine radiation during generation, decommissioning, reprocessing, low-level waste disposal, high-level waste disposal, and accidents. The data in table 2 show occupational deaths of around 0.019 per TWh, largely at the mining, milling, and generation stages. These numbers are small in the context of normal operations. For example, a normal reactor of the kind in operation in France would produce 5.7 TWh a year. Hence, more than 10 years of operations would be needed before a single occupational death could be attributed to the plant. Likewise, numbers of deaths through cancer, severe hereditary effects, and non-fatal cancers caused by normal operations are extremely small.

The main sources of potential damage are accidents and non-routine radiation, and there is a lack of agreement between expert assessments from the industry and the public perception of these damages. The concerns about safety remain high, although the safety record has been improving steadily in most respects since 1990,<sup>34</sup> and the new generation of reactors are widely acknowledged to be much safer than earlier ones. After the events of Sept 11, 2001, designs have considered safety against the impact of a fuel-laden passenger aircraft.<sup>35</sup>

Safety procedures have also improved at the older reactors that are not considered as safe (especially the light water-cooled graphite-moderated reactor of the kind that was used in Chernobyl and of which 15 remain in operation in Lithuania and Russia). Not all indicators show steady improvement. The number of unplanned automatic shutdowns (scrams) declined in the 1990s but has remained stable since.<sup>34</sup>

There are also unresolved problems associated with the disposal of nuclear waste. The world's 441 operating reactors generate more than 10 000 tonnes of heavy-metal spent-fuel every year.<sup>34</sup> A cumulative 190 000 tonnes are in storage and, although increased reprocessing will reduce the rate of growth of the stockpile, much will remain and will need safe long-term storage. Finland, Sweden, and the USA have made the most progress in developing safe high-level waste repositories, although none is expected to be operating before 2020. To date there have been no serious incidents arising from the high-level waste.

Despite these mostly positive developments and several attempts to bridge the gap, there remains a firm divide between lay and expert estimates of the probability of nuclear accidents (webpanel 2).<sup>36–38</sup> There also remains the long lead time, in many cases of around 10 years, for approval and construction of nuclear power plants, though construction times can be cut to as little as 4 years for some modular designs.<sup>39</sup>

#### Costs of CO<sub>2</sub> and other greenhouse gases

The calculations reported in table 2 do not include any contribution from global warming. The different forms of power generation have very different contributions to CO<sub>2</sub> emissions (figure 2).

These contributions are the result of higher summer temperatures (increased costs), warmer winter temperatures (often decreased costs), flooding, increases in vector-borne diseases, and so on. The health costs of increased greenhouse-gas emissions are difficult to estimate and are controversial. A WHO study has estimated that the increase in greenhouse gases since 1990 has resulted in around 150 000 excess deaths in 2000. Almost all of these deaths took place in countries that are not members of the Organisation for Economic Cooperation and Development, where increased risk factors for malnutrition, diarrhoea, malaria, floods, and cardiovascular disease are attributed to climate change.<sup>41</sup>

The method for deriving these results involves taking linear approximations on increases in concentrations of greenhouse gases in 2025 and beyond: this approach does not lend itself to estimation of deaths per tonne of greenhouse gases and hence per TWh emitted between 1990 and 2000. A better way to estimate the health consequences of greenhouse gases in terms of emissions is to do a baseline run of a model with greenhouse-gas emissions, and then add a small amount of greenhouse gases and see the additional effect. This

See Online for webpanel 2

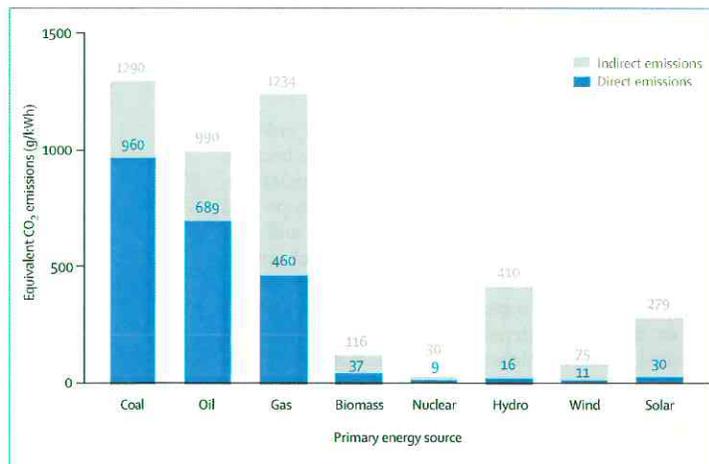


Figure 2: Full energy chain CO<sub>2</sub> equivalent emissions by primary energy source  
Data from IAEA, 2001.<sup>42</sup>

method was used in a study by Bosello and colleagues.<sup>42</sup> Their results, although not directly comparable with those of the WHO study, paint a somewhat different picture. Instead of excess deaths worldwide, the net results were of savings of about 840 000 by 2050. However, both approaches do agree that developing countries face an increase in mortality. Moreover, later in the 21st century the number of deaths might increase everywhere.

Although these specific consequences remain controversial, figure 3 shows the correlation between the direct health effects of power generation (as quantified in table 2) and the estimated contribution of the relevant technology to greenhouse-gas emissions (equivalent CO<sub>2</sub> emissions per kWh of production). Figure 3 shows that the modes of generation that have the greatest immediate effects are also those that make the strongest contribution to climate change.

#### Putting the health costs of electricity generation in perspective

The ExternE results can be viewed from two comparative perspectives: in terms of the total health burdens caused by electricity generation, and relative to other sources of health burden, such as smoking. The total health burden of electricity generation will depend on which fuels are used and the total amount generated. In the UK, for example, total generation was around 386 TWh, of which 34% came from coal and lignite, 37% from gas, 23% from nuclear sources, 2% from oil, and the remaining 4% from hydro, wind, biomass, and other fuels.<sup>43</sup>

Taking the figures for health burdens by fuel type in table 2 we get the overall burden from electricity as given in table 3. The data indicate that about six accidental deaths and 13 occupational deaths can be attributed to the generation of electricity in the UK per year. Also, around 3800 deaths arise from the associated air pollution. There are around 35 000 cases of serious illness a year and 1.9 million cases of minor illnesses, as defined in table 2. These findings can be put in perspective by comparison with general mortality and morbidity data. There were roughly 260 000 deaths in England and Wales from respiratory and circulatory diseases in 2001, so, the estimates from electricity generation account for about 0.014% of the total. In terms of morbidity, there were around 667 000 episodes leading to hospital admission for respiratory and cerebrovascular diseases in England in 2001.<sup>44</sup> Over the same period the estimates of serious illnesses in these two categories arising from electricity generation in the UK amounted to about 840 (table 2). Although the electricity data are for the UK emissions all over Europe and hospital admissions are for England alone, one can see that electricity generation accounts for a very small part of the total admissions in these categories.

Another useful point of comparison is with the health effects of smoking. In terms of excess deaths per year, the process by which air pollution affects mortality is

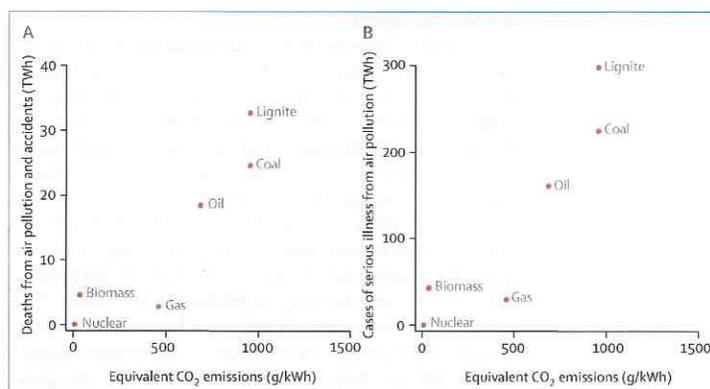


Figure 3: Health effects of electricity generation per TWh

(A) deaths from air pollution and accidents involving workers or the public; (B) cases of serious illness attributed to air pollution. Data for CO<sub>2</sub> equivalent emissions from IAEA, 2001.<sup>45</sup>

through accelerated ageing, and a shrinking of the probability of survival curve across the population. The consequence can be reported as an increase in the observed death rate, or as a change in life expectancy. Calculations made by the ExternE team indicate that the current concentrations of PM<sub>2.5</sub> in the EU and USA of around 20 µg/m<sup>3</sup> result in a loss of life expectancy of around 8 months. A UK review suggests a much smaller figure for the loss of life expectancy, or between 1 month and 1 year. This amount, however, includes only the acute effects of exposure to particulate matter and is certainly an underestimate of the total effect (chronic and acute).<sup>46</sup> We should also note that the gains in air quality from halving concentrations of particles will require reductions in emissions from not only power stations but also transport and other sources.<sup>46</sup>

A reasonable policy goal would be to reduce the life expectancy deficit of around 8 months by half, which would increase life expectancy by 4 months. By comparison, regular smoking is judged to cause a loss of life expectancy of 5–8 years, or about ten times the effects of PM<sub>2.5</sub> air pollution and 20 times the effects of a plausible reduction in air pollution. We should also note that the gains from reductions in air pollution apply to a much larger population than those from cessation of smoking.

	Cases	Percentage due to coal
<b>Accident-related deaths</b>		
Among the public	6	44%
Occupational	13	99%
<b>Air pollution</b>		
Deaths	3778	85%
Serious illness	35 186	84%
Minor illness	1 853 152	94%

Table 3: Health burdens from electricity generation in the UK, 2001

### Developing countries

As countries become more industrialised their use of electricity and petroleum products for transportation increases, which in turn creates new environmental health problems, largely in the form of respiratory diseases, cardiac diseases, and cancers. Although most estimates of such effects of commercial energy have been made for developed countries, some studies are available for countries such as China, India, and Brazil. The large effects are due in some cases to lack of adequate emission regulations but also in many countries to ineffective enforcement of existing regulations. In India, for example, concentrations of suspended particulate matter (roughly equivalent to total suspended particulate matter) and respirable suspended particulate matter (roughly equivalent to PM<sub>10</sub>) are frequently well in excess of national standards. In 2003, levels of suspended particulate matter exceeded national standards in 77 of the 91 residential monitoring stations more than 25 times and the standard respirable suspended particulate matter of 120 µg/m<sup>3</sup> (yearly average) was exceeded in most cities.<sup>47</sup> Such levels are associated with substantial health effects in other countries, and emerging research in India indicates that effects are similar there.<sup>48</sup> Thus, this failure of the environmental regulations to work effectively is having important consequences for human wellbeing. A study by the Institute of Economic Growth in New Delhi,<sup>49</sup> for example, has estimated yearly damage from urban air pollution in 15 major cities in India to be 111 billion rupees (US\$2.5 billion). Much of this cost, however, is attributable to sources such as transport and industry. In some states these costs are as high as 8% of the state domestic product.

Studies in China have also revealed important health effects from the operations of coal-fired power stations. A study of such plants in Shandong province estimated around 77 deaths per TWh from a normal coal-fired plant that met Chinese environmental standards.<sup>50</sup> This estimate is much higher than that for European plants, indicating both a lower population density in Europe as well as the use of cleaner technology. Estimates of effects on serious morbidity (respiratory and cerebrovascular hospital admissions, congestive heart failure, and cases of chronic bronchitis) are estimated at 975 per TWh compared with around 225 per TWh in Europe.<sup>50</sup>

Although the health consequences of commercial fuel in developing countries are beginning to be felt, and studies show that the benefits of adopting cleaner technologies to reduce emissions from power generation and transport are almost invariably justified, we should recognise that even the dirtiest commercial fuels are less damaging in health terms than the traditional fuels they could potentially replace. A comparison is provided in table 4 of replacement of traditional fuels in the home with electricity generated from coal. The estimates of the health costs of indoor air pollution are based on epidemiological studies as summarised in Desai and

	Indoor air pollution	Lignite-based electric energy
Mortality (cases per year)	1962 <sup>a</sup>	33 <sup>†</sup>
Morbidity (cases per year)	502 000 <sup>a</sup>	18 000 <sup>‡</sup>

Details of calculations available from the author. <sup>a</sup>Caused by acute respiratory infection in children and chronic obstructive pulmonary disease in women.  
<sup>†</sup>Caused by occupational and public accidents in the mining and transportation of fuel and in the generation of the electricity, and from respiratory and cardiovascular deaths associated with the emissions from the generation.  
<sup>‡</sup>Respiratory hospital admissions, cerebrovascular hospital admissions, restricted activity days, bronchodilator usage (in asthmatic adults and children), cough (in asthmatic adults and children), lower respiratory symptoms (in asthmatic adults and children), chronic bronchitis in adults and children and chronic cough in adults and children.

**Table 4: Health costs of indoor air pollution against that from electric power (per TWh of generation)**

colleagues,<sup>51</sup> whereas the health consequences of electricity generated from a state-of-the-art coal plant in India are taken from ExternE (table 2). The results refer to a plant producing 1 TWh (10<sup>9</sup> kW) of electricity in 1 year (a plant of about 150 MW would generate such an amount of electricity per year). This amount could provide enough electricity for basic lighting, cooking, and other needs for 333 000 households or about 1.6 million individuals, on the basis of a household size of five people.

Table 4 shows that the indoor fuels cause in the region of 1962 premature deaths and half a million cases of acute respiratory illness and chronic obstructive pulmonary disease in a year. If these fuels could be replaced by electricity then the health burden would be somewhere in the region of 33 premature deaths and 18 000 cases of illness, ranging from severe (hospital admissions for respiratory failure) to mild (a cough day). Even with allowance for the uncertainties that exist in these estimates, the difference between the two options, which is more than an order of magnitude, makes the case for a shift to cleaner commercial fuels unanswerable in health terms.

### Role of CO<sub>2</sub> capture and storage

Because of the major contribution of fossil-fuel use in electricity generation to global emissions of CO<sub>2</sub>, there has been interest in the potential of CO<sub>2</sub> capture and storage to mitigate climate change. In this process, CO<sub>2</sub> from large point sources such as power plants is captured and stored in isolation from the atmosphere. The technology of capture is already commercially available for large CO<sub>2</sub> emitters, such as power plants, but the long-term storage of CO<sub>2</sub> is mostly untested.<sup>52</sup> In theory, however, the capture and storage of a high proportion of CO<sub>2</sub> emissions from large point sources of fossil-fuel combustion, such as power stations, is possible.

There are three main methods of capture. Post-combustion capture, suitable for a modern

pulverised coal power plant or a natural gas combined cycle plant, entails separation of CO<sub>2</sub> from the flue gases derived from the combustion of the primary fuel in air. Typically, an organic solvent such as monoethanolamine is used to capture the CO<sub>2</sub>, which is present at concentrations of 3–15% in flue gases. In pre-combustion capture, the primary fuel is mixed with steam and air or oxygen to generate a synthesis gas high in carbon monoxide and hydrogen, which is further treated with steam to yield more hydrogen and CO, at concentrations of around 15–60% by dry volume. This method is suitable for power plants based on integrated gasification combined cycle technology. The third system (oxyfuel) uses oxygen at 90–95% purity instead of air for combustion to yield a flue gas high in CO<sub>2</sub> and water. The resulting high concentration stream of CO<sub>2</sub> is compressed and dried for transportation by pipeline or tanker for storage in geological formations, in deep ocean waters, or by mineral carbonation (figure 3).

#### Environment and health risks and benefits

Because CO<sub>2</sub> capture and storage is still a fairly new technology, our understanding of its health implications is incomplete. An assessment needs to be based on a life-cycle approach that takes into account the extraction and processing of the primary fuel, the generation and distribution of electricity, and the handling and storage of waste products. The benefits include the reduction of CO<sub>2</sub> emissions, which are estimated to be around 85–95% lower than with similar technology and no CO<sub>2</sub> capture and storage. The concentrations in the flue gas of other substances harmful to human health are likely to be similar to, or lower than, those of plants without capture and storage technology. This is because the capture process entails the removal of some emissions or the upstream removal of impurities, such as sulphur compounds, and is required for the efficient operation of the technology. However, plants with such technology operate at lower efficiency (have higher energy requirements) than similar plants without it. The increase in fuel consumption per kWh associated is in the range 10–40%.<sup>52</sup> As a result, there is a need to process more of the primary fuel. Thus, even where the concentration of an impurity in the flue gases is reduced, the overall emissions per kWh could still be higher.

A study by Rubin and colleagues,<sup>53</sup> reported also in the 2005 IPCC Special Report on Carbon Dioxide Capture and Storage, is one of the few published assessments of the resource and emission consequences of common fossil-fuel power plants (pulverised coal, integrated gasification combine cycle, and natural gas combined cycle technology) using CO<sub>2</sub> capture (table 5). With all three plant types, the increase in primary fuel use and the need for capture and storage reagents is clear. With pulverised coal, additional amounts of limestone (for control of sulphur dioxide) and ammonia (for control of nitrogen oxides) is required. All three also have increases

	Pulverised coal		Integrated gasification combined cycle system		Natural gas combined cycle plant	
	Rate	Increase	Rate	Increase	Rate	Increase
<b>Resource consumption</b>						
Fuel	390	93	361	49	156	23
Limestone	27.5	6.8	..	..	..	..
Ammonia	0.80	0.19	..	..	..	..
CO <sub>2</sub> capture and storage reagents	2.76	2.76	0.005	0.005	0.80	0.80
<b>Solid wastes or by-products</b>						
Ash or slag	28.1	6.7	34.2	4.7	..	..
FGD residues	49.6	12.2	..	..	..	..
Sulphur	..	..	7.53	1.04	..	..
Spent CO <sub>2</sub> capture and storage sorbent	4.05	4.05	0.005	0.005	0.94	0.94
<b>Atmospheric emissions</b>						
Carbon dioxide	0.07	-704	97	-720	43	-342
Sulphur oxides	0.001	-0.29	0.33	0.05	..	..
Nitrogen oxides	0.77	0.18	0.10	0.01	0.11	0.02
Ammonia	0.23	0.22	..	..	0.002	0.002

Values shown are rates in kg per megawatt hour for the capture plant, plus increases over the reference plant rates for the same plant type. FGD=flue gas desulphurisation. Data from IPCC.<sup>54</sup>

**Table 5: Illustrative consequences of CO<sub>2</sub> capture and storage energy requirements on plant-level resource consumption and non-CO<sub>2</sub> emission rates for three current power plant systems**

in solid waste products. Sulphur dioxide emissions are lower for pulverised coal, but higher for integrated gasification combined cycle technology, whereas emissions of nitrogen oxides are higher for all three, and emissions of ammonia are increased in pulverised coal and natural gas combined cycle plants. The effect of these emission changes on human health has not been systematically estimated, but it would be reasonable to assume proportionate increases in occupational and other risks associated with the increased consumption of the primary fuel and other resources, net adverse effects relating to solid wastes, and mixed effects relating to the changes in atmospheric emissions.

Additionally, there are health and safety issues relating to the transport of concentrated CO<sub>2</sub> by pipeline or tanker (eg, a small risk of asphyxia with local build up of CO<sub>2</sub>, toxicity from hydrogen sulphide; figure 4), although such risks probably differ little from those associated with hydrocarbon pipelines already in operation. Leaks of CO<sub>2</sub> after its storage in geological formations probably carries a low risk to human health comparable to that associated with current activities such as natural gas storage and enhanced oil recovery. The effects of the injection of CO<sub>2</sub> into deep ocean waters on ecosystems remain uncertain.

Thus, whatever the potential contribution of CO<sub>2</sub> capture and storage to mitigation of climate change, and whatever the economic case (which is closely tied to the price of the primary fuels), the effects of this technology on health seem mixed. Its use does not fundamentally

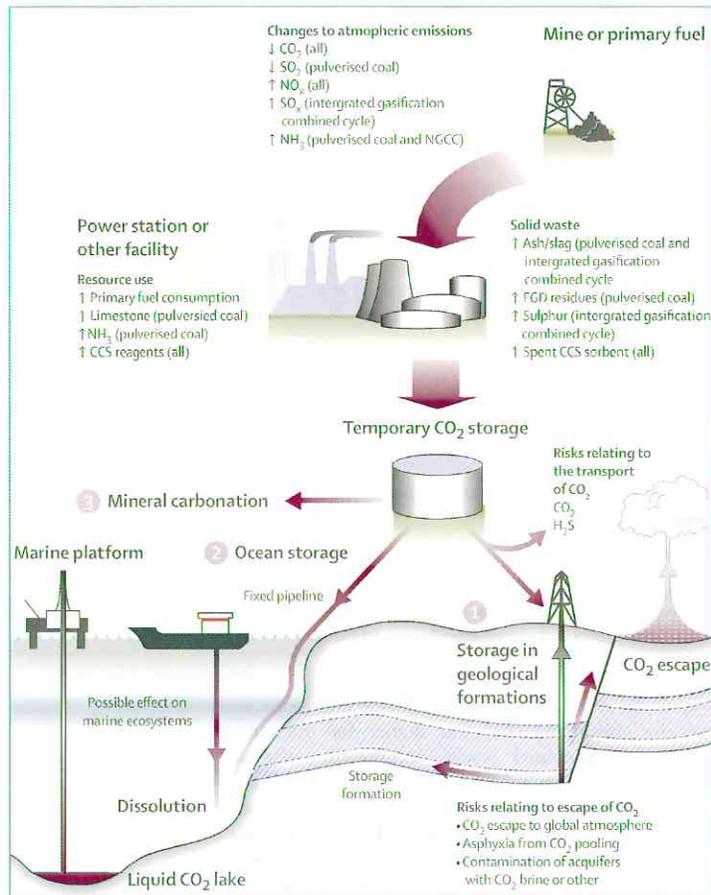


Figure 4: Summary of the principal CO<sub>2</sub> capture and storage processes and associated sources of environment and health risks  
 NGCC=natural gas combined cycle. FGD=flue gas desulphurisation. CCS=CO<sub>2</sub> capture and storage. Adapted from figures in the IPCC special report on Carbon Dioxide Capture and Storage.<sup>57</sup>

See Online for webpanel 3 alter the sources of adverse health effects associated with fossil fuels, and it could in some cases increase immediate and near-term consequences because of efficiency losses and need for additional resource use. From an environment and health perspective, therefore, CO<sub>2</sub> capture and storage is at best only a partial solution.

#### Health effects of renewable energy

In view of the evident health and environmental costs of conventional fossil-fuel combustion, the modern debate has appropriately turned towards other energy sources: the so-called renewables, derived directly or indirectly from the energy of sunlight (direct solar, hydroelectricity, wind, wave, biofuel production, and surface heat), the gravitational pull of the moon (tidal), or the radioactivity of the Earth's interior (geothermal). In varying degrees these sources share four main drawbacks: low energy

density—ie, the power production per square metre of land area is low, which places constraints on large-scale production; intermittency, which means that methods have to be found to store their energy or to supplement it by more controllable forms of power generation to manage variations in production and demand; constraints on their location, which is generally governed by geological, hydrological, meteorological, and other factors, and which might therefore require long-distance transmission from the site of generation to the place of use; and environmental effects, aesthetic effects, or both, that might in part offset the broader environmental and health gains derived from lower air pollution and greenhouse-gas emissions.

With the exception of biomass, most renewable power systems do not rely on combustion and thus do not produce notable amounts of air pollution directly. However, some emissions of air pollutants can arise during manufacture and transport, such as in the production of steel for wind turbines and concrete for dams, but these are low compared with any but the cleanest system relying on combustion for electricity generation.

#### Hydroelectric

There are some 48 000 large dams in operation worldwide, contributing to provision of drinking water, irrigation, flood control, and 20% of the world's electricity. Although apparently a clean form of electric power, hydroelectricity is controversial because of its social, health, and environmental costs (webpanel 3).<sup>54–59</sup>

Concerns about these issues have caused a re-appraisal of role of hydroelectricity, and a much more cautious policy towards its further development<sup>64</sup>—notwithstanding the current ambitious programmes in China, India, and elsewhere.

Despite these concerns, hydropower from large dams has several important advantages. Among the non-fossil-fuel forms of power generation, it provides a comparatively constant source and store of energy, which, with large reservoir heads, can be very rapidly mobilised to meet surges in demand. Also relevant is that the untapped potential for hydroelectric development is greatest in regions (Asia, sub-Saharan Africa, South America) where many of the 2 billion people currently without access to electricity live. In these regions, hydroelectricity could have an important role in future energy provision, provided projects follow good practice guidance.<sup>34</sup> However, the unexploited capacity is limited and they are associated with appreciable emission of CO<sub>2</sub> and methane from anaerobic fermentation in the static water (webpanel 3).

Among the range of social and health effects are the occupational risks during construction, and the low but finite chance of dam failure. The probability of such events is extremely difficult to establish, since they can be triggered by earthquakes, wars, terrorist activity, or engineering failures.

### Solar

The theoretical potential of the direct capture of solar energy either through photovoltaic systems or by heat generation is enormous. After allowance for energy reflected by the atmosphere, around  $3.9 \times 10^{24}$  J are incident on the Earth's surface per year—almost 10 000 times more than current global energy consumption. Thus, the capture of less than 1% of photonic energy would serve all human energy needs. The limited assessment available by a full cycle analysis<sup>58</sup> indicates few drawbacks, though possible concerns might arise in relation to the production, handling, and disposal of the photovoltaic materials, and if battery or other technology is needed for energy storage.

The constraint on much wider use is primarily technical. With photovoltaic systems (which depend on quantum excitation of electrons in layered semiconductors), the efficiency of solar capture—the ratio of power output to the power of the incident radiation—is limited by, among other factors, the fact photovoltaic cells capture energy from across only a limited range of the solar electromagnetic spectrum. The best overall efficiency with current technology is around 10–15%. Given the time-averaged rate of incident solar energy of 100–300 W, this means little more than 10–45  $\text{Wm}^{-2}$  as a global average. Although thermal systems might be more cost-effective than photovoltaic systems, they too capture only a fraction of the incident energy. Thus, solar systems suffer problems of cost, large requirements for land area, and intermittency. Nonetheless, from a health perspective, the potential benefits of direct solar capture seem very desirable.

### Biomass

Fresh (as opposed to fossilised) biomass is a potentially large store of renewable energy, which can be transformed into useful power by combustion or by thermochemical or biochemical conversion to liquid (ethanol, methanol) or gaseous fuels (methane, hydrogen).<sup>60</sup> However, its usefulness as a major energy source is limited by the inherent inefficiency of photosynthesis, which captures no more than a small percentage of solar energy reaching the Earth's surface.<sup>61</sup> The energy yield of even the most productive cultivated crops is therefore little higher than  $1 \text{ Wm}^{-2}$ ; the imperfect efficiency of the energy conversion means that the power density is less than  $1 \text{ Wm}^{-2}$ —an order of magnitude lower than direct solar capture through photovoltaic or thermal systems, and up to four orders of magnitude lower than fossil-fuel combustion. To substitute for even a modest fraction of current or future coal use, for example, would require substantial land area to be given over to fuel crops—often in competition with food production. However, some high-yielding crops, for example South American sugar cane, are already being used successfully as fuel sources, though mainly for transport. And bioelectricity could have an important function in supporting electricity needs particularly of

rural populations in lower-income countries. Furthermore if fuel crops are used in state of the art power-generating plants that meet the latest EU environmental standards the health consequences of bioelectricity production, although substantial, are still well below those from coal and lignite.

### Wind, wave, and geothermal

Wind energy, mainly produced by horizontal-axis turbines of varying sizes, is one of the more cost-effective forms of renewable energy with today's technology. As with solar power, the obvious variability of its generation raises questions about solutions for energy storage and so-called despatchable capacity in other parts of the electricity grid. With connections across a wide network, the natural geographical variation in wind speed could help to smooth out fluctuations, but this might not entirely avoid the need for additional generation capacity elsewhere. Similar considerations obtain in relation to wave power. However, the balance of health risks and benefits, though imprecisely defined, would seem strongly favourable, as it does for geothermal energy. The latter is an option only in selected locations worldwide, though ground-source heat pumps using surface pipes or bore holes are local options for space heating and offer good energy return (around 3 W back for every 1 W of energy expenditure). Although geothermal generation has some local air pollution associated with it, the effects are much smaller than for fossil-fuel sources and it can be considered a much cleaner source.<sup>62</sup>

### Nuclear fusion

A nuclear technology that offers some hope for future electricity generation is fusion.<sup>63</sup> However, its commercial development is still some way off because of major technical challenges (webpanel 4). If these issues can be overcome, nuclear power offers comparatively clean electricity production with little contribution to greenhouse-gas emissions. It shares the range of environmental and health risks of fission technology but at generally lower levels. The main product of normal operation is helium-4 (webpanel 4), which is an inert gas, but the fusion reaction also requires a radioactive isotope of hydrogen, tritium, which is difficult to capture completely, so some leakage is inevitable. The short half-life of just 12 years will help limit the build-up in the environment, but there could be important effects on health in an economy with a substantial number of fusion plants. The high-energy neutrons produced in a reactor make the structural materials surrounding the fusion chamber radioactive, with a similar inventory of radioactive materials to a fission reactor. The half-lives of the radioisotopes produced by fusion are substantially less than those for fission, they tend to be less biologically active, and there is potential to use low activation materials that do not easily become radioactive with neutron bombardment. Most materials of the core would

See Online for webpanel 4

be radioactive for around 50 years, and other low-level waste for another 100 years or so. Thus the difficulties of handling and storing radioactive waste would be smaller than for fission.

The risk of major accident is also substantially less. Fusion is not a chain reaction and requires very demanding control conditions (extremes of temperature and pressure, and magnetic containment), which, if disrupted, would rapidly halt the reaction. Moreover, unlike a fission reactor, the fusion chamber contains very little fuel—enough only to perpetuate the reaction for a minute or so—and stopping the supply would result in rapid shut-down. Fusion also has much less overlap with weapons technology. Plutonium (needed for atomic bombs) can be bred by use of the neutrons from a fusion reactor, but only with extensive redesign of the reactor—which would therefore be easy to monitor.

Although nuclear power has promise as a future energy technology, more than half a century of research with several experimental reactors has failed to produce net energy output in controlled production. The best estimates are that perhaps another 50 years will pass before the technology is developed to the point of commercial viability, which will be too late to make a significant contribution to mitigation of climate change over this century. Nuclear energy is not therefore a solution to climate change, but it remains an attractive hope for electricity production for future generations.

### Conclusion

The generation of electricity has both health benefits and costs. The health benefits of a shift away from non-commercial fuels to commercial ones, particularly when they are used for electricity generation, are evident from the evidence in developed countries in the past century and which is still taking place in developing countries. Moreover, the substitution of dirty energy for clean is not the only change that increases wellbeing. Efficient lighting, refrigeration, clothes washers, radios and TVs, computers, and numerous appliances that use electricity make possible those activities that otherwise would not be possible.

Although there are health costs associated with the generation of electricity, especially from fossil fuels, they are much smaller than those associated with indoor air pollution from burning fuels directly in homes. The drawbacks lie mainly with their contribution to outdoor air pollution, occupational risks, and greenhouse gas emissions.

Assessment of the health effects of electricity generation should include all stages of the fuel cycle, such as mining, transportation, and disposal of waste. Studies in Europe, based on the ExternE methods, have provided estimates of the effect, in terms of excess deaths and various categories of morbidity.<sup>10–12</sup> The effects are not unimportant, especially from the use of coal and lignite.

The study also reports estimates of the effect of nuclear generation. The role nuclear power should have in future energy production depends on a balance of (perceived) risks. It currently accounts for around 17% of global electricity production and makes a small contribution to reducing greenhouse gases; thus, a decision not to replace current nuclear capacity would correspondingly increase the challenge of limiting greenhouse-gas emissions. Such a decision would be welcome in health terms if the nuclear plants were replaced by capacity in renewable production additional to the level of renewable production that would otherwise occur.

Forms of renewable energy generation are still in the early phases of their technological development, but most seem to be associated with few adverse effects on health and to contribute little to the longer-term environmental threat of climate change. Their rapid expansion is partly constrained by the intermittency and low density of energy production.

Much work is under way to improve the technologies used in electricity generation, and policymakers have been raising standards at all stages of the fuel cycle. The case for raising environmental standards is made on grounds of cost benefit, which requires the health impact to be valued in monetary terms. Although such values are not reported in this paper, regulatory impact studies have almost always confirmed that the benefits (which are predominantly health related) of the higher standards exceed the costs, in both the quickly industrialising and the more industrialised countries.

Although these are complex and rapidly evolving issues, the key messages from a health perspective are clear. Population health will substantially benefit from improved access to electricity and from modal switch away from fossil fuels towards renewable sources of electricity generation where possible. The case for such switching cannot be judged purely on traditional cost-effectiveness comparisons of current technology, since investment in renewable sources and increases in volume of production should bring cost efficiencies to newer (often the renewable) technologies; moreover, the cost-benefit equation is more favourable to renewable technologies where proper account can be taken of environmental and health effects. In addition to increasing access to electricity (see the first paper in this Series), our progress towards those strategic goals can be measured (webpanel 5).

### Acknowledgments

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### Conflict of interest statement

We declare that we have no conflict of interest.

See Online for webpanel 5

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# Welcome!

NextEra Energy Canada welcomes you to the Community Update Meeting regarding the Adelaide, Bornish and Jericho Wind Energy Centres.

## We are here to:

- ✦ Describe the projects
- ✦ Provide you with information on the Renewable Energy Approvals process
- ✦ Answer your questions
- ✦ Consider your comments



# Wind Energy Centres - Open House

## A Leader in Clean Energy

NextEra Energy Canada is an indirect, wholly-owned subsidiary of NextEra Energy Resources. NextEra Energy Resources, LLC is the largest generator of wind energy in North America.

## NextEra Energy Canada

NextEra Energy Canada is a leading renewable energy developer in Canada. NextEra Energy Canada is focused on developing electricity derived from clean, renewable sources throughout the provinces. Our Canadian operations are headquartered in Burlington, Ontario. We are the owner and operator of wind energy projects in the following provinces:

- ✦ Quebec: Mount Copper and Mount Miller Wind Energy Centres
- ✦ Nova Scotia: Pubnico Point Wind Energy Centre
- ✦ Alberta: Ghost Pine Wind Energy Centre

NextEra Energy Canada is currently working to permit eight wind energy centres in Ontario.

## NextEra Energy Resources

We are:

- ✦ A leading global generator of renewable energy
- ✦ The largest generator of both wind and solar power in North America operating wind energy facilities for 21 years
- ✦ The operator of approximately 85 wind projects in 17 states and 3 provinces with more than 9,500 wind turbines providing over 8,500 megawatts of generation

## Did you know that NextEra Energy Resources...

- ✦ Began developing renewable projects in 1989?
- ✦ Has approximately 4,500 employees in North America?
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### **NextEra Energy Canada's Local Partner**

Canadian Green Power Investment & Management Services Inc. is dedicated to enabling Ontario to become self-sufficient in the development and production of clean, green energy. Canadian Green Power:

- ✦ Is an independently owned wind power development company headquartered in Ontario
- ✦ Works closely with local landowners to determine potential locations for wind turbines and negotiate the safe and respectful access to landowner property
- ✦ Has been active in the project area since 2005

**Over 200 local landowners are currently participating in the NextEra Energy Canada/Canadian Green Power wind project collaboration.**



# Wind Energy Centres - Open House

## Why is Southwestern Ontario a great choice for wind energy?

### **Wind developers favour Southwestern Ontario for two main reasons:**

1. Strong and consistent wind levels, particularly around the Great Lakes
2. Available and adjacent electricity transmission
  - ✦ Wind data has been collected in the Project Study Area since 2007 measuring wind speeds at heights of 40 metres (131 feet), 50 metres (164 feet) and 60 metres (197 feet)
  - ✦ Wind speeds are viable for wind energy generation
  - ✦ The region is well served by existing and planned transmission lines (such as Hydro One's Bruce to Milton line) that have available capacity to receive the electricity generated by the project



# Wind Energy Centres - Open House

## Benefits of Wind Power

### Environmental Compatibility

- ✦ Creates no air or water pollution
- ✦ Minimal greenhouse gas emissions
- ✦ Efficient and reliable
- ✦ Allows land to remain in agricultural use
- ✦ Does not use water in power generation
- ✦ Low environmental impact
- ✦ Free, renewable energy source

### Local Economic Benefits

- ✦ Provides employment opportunities
- ✦ Adds tax base to the county
- ✦ Supports the economy through purchases of regional goods and services
- ✦ 6-10 full time jobs per project
- ✦ 200-300 construction jobs
- ✦ Delivers landowner lease payments

### Price Stability

- ✦ Helps stabilize the cost of power
- ✦ Decentralizes power production
- ✦ No fuel cost
- ✦ Electricity produced domestically