Transforming Saskatchewan's Electrical Future

PART ONE

Sustainability is Achievable, But How Do We Get There?

By Mark Bigland-Pritchard and Peter Prebble

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This is the first in a series of CCPA Saskatchewan papers, written by Green Energy Project Saskatchewan researchers, on the options for sustainable electricity generation in the province. Future papers will consider each of the principal components outlined in the text below, explain the meaning and the relevance of some of the commonly-used technical terms (such as "baseload" and "smart grid"), and explore the policy options available to encourage the transition to sustanability.

About the Authors

Mark Bigland-Pritchard operates as a consultant in energy, environmental assessment, green building and architectural physics through his company, Low Energy Design Ltd. His background includes two engineering degrees, a PhD on energy performance and moisture risk in strawbale construction, several years of teaching energy studies at the Open University and the University of Sheffield (in Britain), and a diverse range of consultancy work in the public, private and voluntary sectors, spread over two decades and three continents. He is currently a director of the Saskatchewan chapter of the Canada Green Building Council.

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Transforming Saskatchewan's Electrical Future

Sustainability is Achievable, But How Do We Get There?

With the best solar and inland wind resources in Canada, extensive possibilities for sustainable biomass energy production, reasonable hydroelectric potential, and a very low population density, Saskatchewan should be well-placed to lead the world in the inevitable shift away from fossil fuels and nuclear power to renewable energy sources. Yet currently the province is heavily dependent on coal, and leads the world in greenhouse gas emissions per capita. How can we transform the way we source, convert and use energy so that we benefit from leadership of a green revolution?

A new collaborative study will be asking this question and producing an energy plan for Saskatchewan in the coming months. As well as the CCPA's Saskatchewan Office, this project's initial partners are the Coalition for a Clean Green Saskatchewan and the Saskatchewan Environmental Society. Taking as our aim the Brundtland Commission definition of sustainability[1] — meeting the needs of the present without compromising the ability of future generations to meet their own needs — we seek a pragmatic solution which offers economic, social and environmental benefits. Specifically, as a first step, how do we design an electricity system based on 100 per cent renewable energy, and how do we get there?

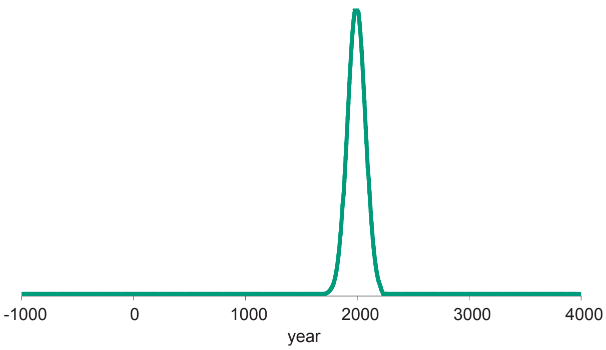
Saskatchewan's electricity generation system is at a crossroads. This situation is by no means unique to our province, but the combination of challenges and opportunities is unprecedented.

The province's nuclear debate in 2009 resulted in greater public awareness of some of the Saskatchewan realities. The most shocking of these is our enormous carbon footprint: 72 tonnes of carbon dioxide equivalent per person per year overall, and about 16 tonnes/person/year from electricity alone.[2] Northern European countries with a similar standard of living typically emit about 10 tonnes/person/year in total — itself an unsustainably high figure by a factor of about 10. We feel a moral responsibility to help change our province from world-class polluter to world-class pioneer of sustainability. This is a social justice issue, and not just an environmental concern. Page 5 describes the need for urgent action.

However, even if we fail to respond morally we will be forced to respond by economics. Despite the failure of the 2009 Copenhagen climate conference, some form of worldwide carbon pricing is inevitable, and the price of carbon will rise as time goes on. This will raise the price of fossil fuels — coal will in particular be strongly affected because of its high carbon dioxide emissions per unit of energy.

Non-renewable energy resources are being depleted. We may or may not have already passed "peak oil"; peak gas, peak uranium and peak coal will all follow in a matter of decades. So even if we do not make the transition away from non-renewable fuels today, we will eventually be forced by shortages to do so. Until a couple of centuries ago, humanity relied on energy derived ultimately from the sun. When fossil and nuclear fuels are exhausted, we will again be dependent on the sun — i.e. on the renewable options. We are currently somewhere near the top of a historic blip. In this context, why wait to develop renewable technologies?

Fossil Fuel Consumption



Like most North American jurisdictions, we have ageing generation stations, more than half (by output) coal-fired, and an ageing distribution infrastructure. Upgrading is necessary to maintain reliability, to connect new industrial facilities, and to introduce "smart grid" technologies which can enable more efficient and responsive service.

It is all too easy to focus on the problems — whether higher fuel bills at home, droughts and inundations abroad, or the misfortunes predicted to befall our grandchildren's generation if we do not change course now. However, we also see opportunities. A thoroughgoing improvement in energy efficiency will reduce costs throughout the province. Renewables — and even more so efficiency/conservation — have been consistently found to generate more jobs per dollar investment, and more jobs per kWh, than either fossil fuels or nuclear.[3,4,5,6,7,8,9]

The renewables available in Saskatchewan — wind, sun, hydro and biomass — are all ideally suited for community-scale development. As in Denmark in the 1990s, when their pioneering windpower industry began to expand,[10] we see massive scope for rural regeneration through cooperatives. A grid based more on distributed generation, and less on large power stations, can offer more jobs, stabilize more communities, help more families to stay together by creating an alternative to long-distance commuting, enable more family farms to stay solvent, and provide more interesting challenges for Saskatchewan's young engineers and technicians. As smart grid technology develops, it also offers better prospects of grid stability, fewer outages, and lower vulnerability to terrorist attack on the electrical network. And the opportunities for some First Nations communities — historically consigned to the windiest parts of the province — are potentially considerable.

Getting electricity right is also strategically important for other sectors of greenhouse gas production. Heating of buildings with ground source (so-called "geothermal") heat pumps only becomes sustainable if electricity is sustainable. The most promising technological means of seriously reducing transport-related emissions — plug-in hybrid and electric vehicles — require low-carbon electricity in order to contribute to sustainability, and also have the potential to help stabilize a grid dependent on variable sources. The hydrogen fuel cell vehicles which may become the new mainstream option around the middle of the century also depend on sustainable electricity for sustainable hydrogen production. While some biomass combustion possibilities would serve to threaten food supplies or eco-diversity, others potentially offer a synergy with sustainable agricultural methods. In the industrial sector, opportunities for greater energy efficiency often require an integrated approach encompassing electricity, process heat, water heating and space heating.

That this type of path is viable is shown by a variety of studies worldwide.[11,12,13,14,15,16] We look forward to being able to demonstrate how Saskatchewan can expand its renewable energy resources and eventually eliminate fossil fuel fired electrical generation.

Climate Change (Man Made) and the Need for Urgent Action

Primarily as a result of anthropogenic emissions of the so-called "greenhouse gases" (principally carbon dioxide, but also methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride), heat losses into space from the earth's surface and lower atmosphere have declined. As the energy input from the sun varies only slightly, the result is that the mean temperature at the surface of the earth has increased. Mean global surface temperature rose by 0.74°C over the period 1906 to 2005, but further rises will occur for several decades even if greenhouse gas emissions stop today.[17,18]

A rise in greenhouse gas concentrations has been demonstrated by numerous computer models to result in a rise in mean global surface temperature. (These models are tested against past climate data stretching back thousands of years and obtained by analysis of tree rings, ice core samples etc. Modifications are made to give a better fit with the data, and then the model is applied to future climate.) Further climate modelling permits the consequences to be predicted. The negative impacts vary according to the temperature change reached, and are diverse in nature:

- ***a rise in sea level***, resulting partly from thermal expansion of water and partly from melting of land-based glaciers and ice shelves.[19] Because the latest research shows that polar ice-caps have been melting faster than had been predicted, the best estimates for sea level rise by the end of the century have risen to at least one metre, even if there is rapid progress in reducing greenhouse gas emissions. Together with land subsidence and more extreme weather, this poses a serious threat to (e.g.) Bangladesh, Burma, Vietnam, parts of coastal China, the Nile delta, the Netherlands, the Maldives, Pacific atolls, etc. The Pacific state of Tuvalu is already making arrangements for the complete evacuation of its citizens to New Zealand when water levels render it impossible to subsist in their homeland.
- ***changes in regional temperature and precipitation levels*** — and in the variation between winter and summer conditions. These changes will vary from region to region; not all regional mean temperatures will rise. Broadly speaking, higher temperature rises are expected in the northern hemisphere (especially the Arctic, which has already seen rises as much as 5°C[20]), and in central continental areas. In some African countries the result will be a sharp decline in crop production possibly by as early as 2020.[21] (The current long-term drought in parts of north-east Africa is consistent with this prediction.) At first, the Canadian prairies may benefit in terms of agricultural productivity, but, as global warming intensifies, prairie provinces face the prospect of prolonged droughts, with a partial desertification of the grasslands.
- ***changes in the frequencies, intensities and locations of climate extremes*** — droughts, floods, storms, etc, described by one commentator as "global weirding". In most locations, extremes will become more and more frequent — i.e. weather will be more unpredictable. While no one event can be attributed to global warming, the present increase in extreme weather events is fully consistent with global warming theory, and things are predicted to get worse still. There will be more summer heatwaves, like the one which resulted in 35000 deaths in Europe in the summer of 2003.[22] There will be more droughts, such as that experienced in north-eastern sub-Saharan Africa in 2005-6. There will be more flash floods, and

Climate Change (Man Made) and the Need for Urgent Action continued

more hurricanes and cyclones are predicted to become more intense.

- ***deleterious effects on local ecosystems.*** If plants and animals cannot adjust to the changes in time, they may also be unable to migrate fast enough to find a climate close to the one they are adapted for. In some cases (such as many high mountain habitats) there will be nowhere to go. The Intergovernmental Panel on Climate Change (IPCC) forecasts 20 to 30 per cent of plant and animal species assessed to date are at high risk of extinction if global average temperature rise exceeds 1.5 to 2.5°C.[23] Whatever threatens the survival of complex ecosystems also ultimately threatens human societies, starting with the people who most directly rely on natural resources for their livelihoods.

Exceeding the Tipping Points

The changes noted so far are mostly reversible: if greenhouse gas levels are reduced, the earth can eventually (over a period of several decades) return to equilibrium. But other possible changes would be fundamental and irreversible within human timescales once a "tipping point" is reached.

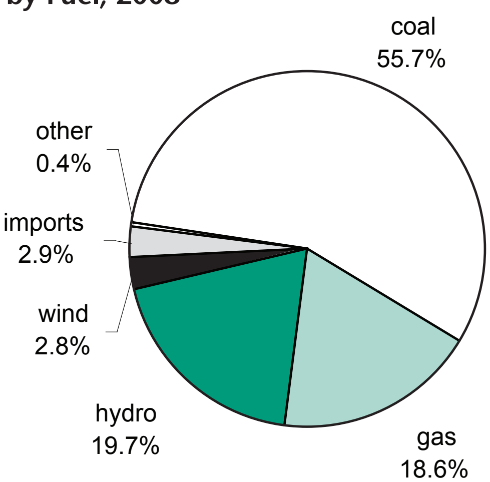
- Sea level rise of several metres from severe loss of the Greenland and Antarctic ice caps.
- Glacial melt in the Himalayas will increase flooding downstream. This will be followed by a significant decrease in river flows as the glaciers recede, negatively impacting millions of residents in China, India and Pakistan who rely on these rivers for water supplies.[24]
- Decline of the Amazon rainforest from forest fires, and ultimately the rapid breakdown of its soils, turning the rainforest from a valuable carbon sink into a net carbon source.
- Ocean acidification from increased carbon dioxide absorption, with potentially devastating effects on marine life and fisheries.
- Release of the potent greenhouse gas methane from the methane hydrates currently locked in under the ice; and also from bacterial action in marshland currently under permafrost. If these increases become large they will increase the pace of climate change.

It is not known with precision at what level of greenhouse gas concentrations any of these phenomena would reach a tipping point. But current climatological theory, tested against empirical data, predicts that most of these irreversible changes will become unstoppable if greenhouse gas concentrations hit the sort of levels that are projected for later this century. **They can only be avoided by moving quickly to implement a major reduction in worldwide greenhouse gas emissions.** The vast majority of the international scientific community has emphasized that atmospheric carbon dioxide levels should not be permitted to rise above 450 parts per million. (They are currently at 389ppm, compared to a pre-industrial level of about 280ppm, and are rising at a rate of about 2ppm per year.[25]) As a result of research published after the IPCC assessment had been substantially completed, many climate scientists would now say that atmospheric carbon dioxide levels need to be reduced to below 350 parts per million if irreversible change is to be avoided.[26] According to the best models, this would limit the rise in mean global surface temperature to between 1.5 and 2°C above its pre-industrial value. For comparison, current emission trends would see an increase of between 2.5 and 6°C within this century.[27] ***If the world's leading climatologists are correct — and the reasons so far put forward for doubting them are flimsy at best — the situation is urgent.***

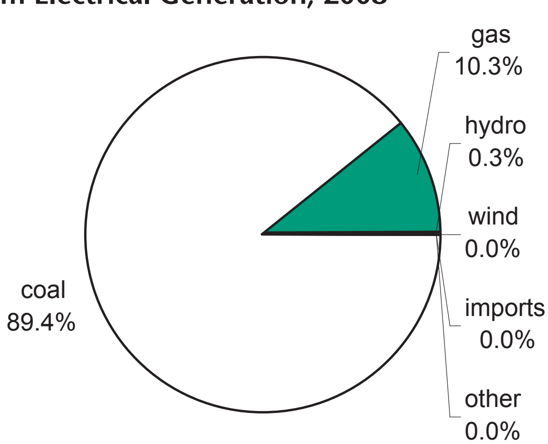
How Can We Begin Greening Saskatchewan's Grid?

Of the 20480 gigawatt-hours (GWh) of electricity generated to meet Saskatchewan's needs in 2008, 56 per cent was from coal and 19 per cent was from natural gas.[28] Both these sources of electricity are responsible for significant greenhouse gas emissions, but of the two, coal is by far the largest source of greenhouse gas emissions both in total amount and on a per-GWh basis.

Proportions of Power Generated, by Fuel, 2008



Proportions of GHGs Emitted from Electrical Generation, 2008



In Saskatchewan renewable energy sources account for slightly less than a quarter of electricity supply. In 2008, hydro makes up nearly 20 per cent of gross electricity supply, and wind nearly 3 per cent. Power imports account for the remaining 3 per cent of electricity supplied.[29]

Not all the power that is generated from the above-mentioned sources actually reaches the customer — nearly 10 per cent (1,879 GWh) is lost in the course of electricity transmission (line losses).[30] While significant losses are inevitable in a geographical area as large as Saskatchewan, they are exacerbated by the siting of the three largest power stations in the far south of the province, remote from major consumption centres.

As we begin to take the first steps toward creating a renewable electricity grid in Saskatchewan, there are a few guiding principles worth considering:

1. **We should try to use electricity more efficiently.** Construction of new electrical capacity is always much more expensive than investing in the efficient use of electricity. Thus we should use SaskPower, our publicly owned crown corporation, as a vehicle for advancing major investment in electricity efficiency.
2. **We should try to reduce transmission line losses whenever possible.** In Saskatchewan renewable energy sources will often offer advantages in this regard, as in nearly every case they can be located closer to consumers than our coal fired generating stations, which are all near the U.S. border.
3. Because of its high greenhouse gas emissions, **we should try to phase out coal fired**

electricity generation as quickly as possible, unless the coal fired power plant is fully equipped with a mechanism to remove and bury the carbon dioxide. Natural gas power plants have lower emissions, so are less of a priority for phase out, but we should look for opportunities to use natural gas more efficiently, such as in combination with the production of industrial steam heat. Natural gas generating stations can ramp up and down quickly and can thus also be used to complement wind power.

4. **We should develop a mix of renewable energy sources that will complement each other** and that when used together will provide us with a secure electricity supply that has the lowest possible greenhouse gas impact.

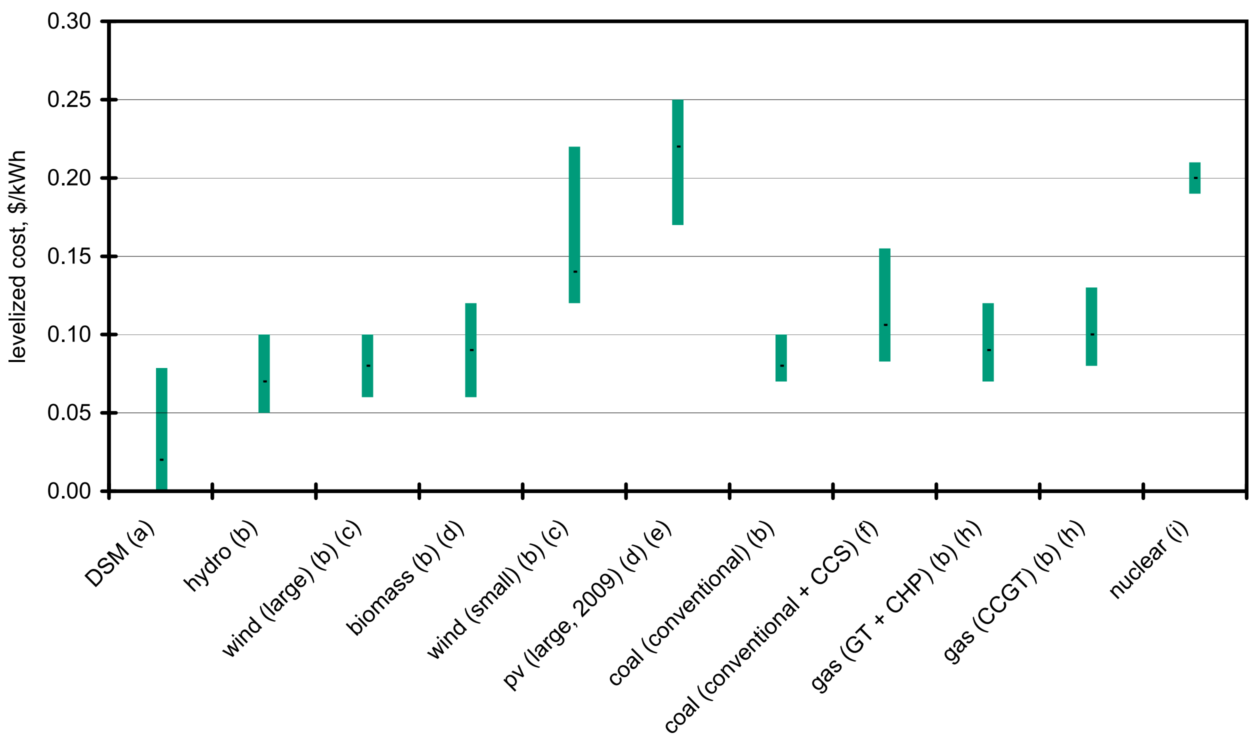
Some options (such as high-efficiency combined-cycle natural gas power stations, and coal with carbon capture and storage) should be considered as temporary, transitional measures on the way to a fully sustainable system.

It should be noted that carbon capture and storage is not yet a fully proven technology: there are currently only four functioning CCS projects in the world, none of them associated with electrical generation, and costs are high and uncertain. Only 80 to 90 per cent of the carbon dioxide can be captured, and the process may be expected to consume between 10 and 20 per cent of the plant's power output. Hence this technology is far from carbon-neutral — and even less so if, as in the Weyburn-Midale project, it is used to facilitate enhanced oil recovery. However, CCS could at some point in the future enable some carbon-negative electricity generation in biomass power stations.

Given the limitations of the transitional options, wherever possible we should give preference to the renewables — the sources which will last for as long as the sun shines, and the rivers flow, and the wind blows and the plants grow.

One of the purposes of the Saskatchewan Green Energy Project will be to precisely define the mix

Rough Comparison of per-kWh Generation Costs: Renewable and Non-renewable Options in Saskatchewan



A further explanation of this data is provided on page 17.

of renewable energy systems needed to create a low carbon grid. In very broad terms however, what low carbon systems could be introduced to get us started? Our current Saskatchewan electricity grid had total generating capacity of 3641 megawatts (MW) at the end of 2008.[31] In the next 7-10 years, we are likely to invest in at least 1200MW of new electricity generation. If those were "green megawatts", what might they look like?

We suggest our first priority should be to invest in at least 300MW of electricity efficiency. In 2007 SaskPower set this goal, to be achieved by 2017,[32] but then reversed it in 2008-09 after the change of government, reducing it to 100MW.[33] An investment of 300MW in energy savings by 2017 would create jobs and economic benefits in every Saskatchewan community. While Saskatchewan has traditionally spent less than $1 million per year on electricity efficiency, next door the province of Manitoba's electricity efficiency budget has been over $35 million per year for years.[34] Even greater commitment has been shown in the state of California, which prioritized electricity efficiency ever since the 1970s. The remarkable result is that on a per capita basis, electricity demand in California has not risen since that time.[35] More recently, eastern U.S. states like Vermont and Massachusetts have initiated programmes along similar lines, with similar results. Vermont has found that electricity efficiency programs save the residents of that state $1.70 for every dollar invested.[36] In these jurisdictions, attractive financial incentives are implemented to encourage the mass replacement of dozens of inefficient technologies with super energy efficient ones. If we applied this thinking in Saskatchewan, a wide array of investments could be planned for, including incentive programs for occupancy sensors and timers, LED lighting, T-8 and T-5 fluorescent lighting, the most energy-efficient motors, pumps, compressed air equipment and irrigation systems, high-efficiency retrofits to refrigeration facilities, and advanced controls for ventilation and air conditioning systems.

Electricity efficiency is an excellent way of reducing greenhouse gas emissions on the grid. We believe electricity savings far beyond 300MW are possible in Saskatchewan. An important purpose of the Green Energy Project will be to identify those deeper savings and how they are best achieved.

A second set of "green megawatts" could be created in northern Saskatchewan through the development of low impact hydroelectricity. Small scale, run of the river hydro projects should be developed with the informed approval of, and in close partnership with, First Nations and Métis communities, and should bring jobs and tangible economic benefits to those communities. 125MW could readily be constructed by 2020. A more ambitious target will be the subject of analysis by the Green Energy Project.

A third option is a combination of expanded wind power complemented by hydro — including imported hydro from Manitoba. Already, to the credit of the Saskatchewan government, a 200MW expansion of wind power by 2013 has been announced, slightly more than doubling current capacity.[37] However, we believe this wind power expansion initiative can be greatly enhanced by 2020. Saskatchewan has vast wind power resources. The only limitation is their variability. However, intermittency problems can be overcome in a number of ways,[38] of which at least two should be immediately implemented in current planning. First, new wind turbines should be spread out all across southern Saskatchewan, taking advantage of the fact that although the wind may not be blowing in a particular location, it will be in many others.[39] Second, wind power should be coordinated with dammed hydro: water can be stored in its high-level reservoir when the wind is blowing and released when the wind is not blowing. A combination of wind and hydro is very attractive because these two renewable energy sources can be coordinated at very low cost and with low greenhouse gas emissions.[40]

In contrast to only 3 per cent of Saskatchewan's electricity coming from wind, Spain produces 13 per cent of its electricity from wind power,[41] while in Denmark wind power delivers 15 per cent on its eastern grid and 23 per cent on its western grid, averaging 20 per cent overall.[42] If this level of wind power was adopted in Saskatchewan over the coming decade, we would add between 600 and 1300 MW of additional wind power capacity, when compared to current levels. The Green Energy Project will examine how this would best be accomplished, where the turbines are best located, how community ownership of wind power can be effectively promoted and how our transmission connections with Manitoba can be strengthened. Higher penetration of wind power will require upgrades to Saskatchewan's transmission grid and the cost and nature of these upgrades will be studied.

A fourth component in a renewable electricity mix for Saskatchewan is biomass. This can take the form of burning surplus straw or the residue from timber milling for electricity generation, generation from landfill gas, and many other interesting options. One promising possibility, still at the research stage, is a pyrolysis process which would yield a combustible gas for power production and biochar (a solid product akin to activated charcoal) for use as a soil improver superior to the original straw or woodchips. If a fully sustainable biochar technology can be successfully developed on an appropriate scale, it offers the possibility of net negative greenhouse gas emissions through agriculturally-useful carbon sequestration. But even without resort to such as-yet-unproven technology, we believe that biomass has the potential to meet approximately 20 per cent of Saskatchewan's electricity needs by 2030. For now, we assume a very modest 2017 goal of constructing 125 megawatts of biomass, much of which would utilize forestry residues along the forest fringe, either for stand-alone electrical generation or (better) in combined heat and power stations.[43,44,45] A major focus of the Green Energy Project will be to map out a comprehensive, greenhouse gas neutral plan for utilizing Saskatchewan's biomass.

These four illustrations alone flag immediate opportunities for producing at least 850 megawatts of renewable, low carbon electricity in Saskatchewan by 2020 and "creating" another 300 megawatts of electricity through efficiency measures that can be done with absolute confidence. This alone would enable the phasing out of Saskatchewan's oldest and least efficient coal-fired generating stations.

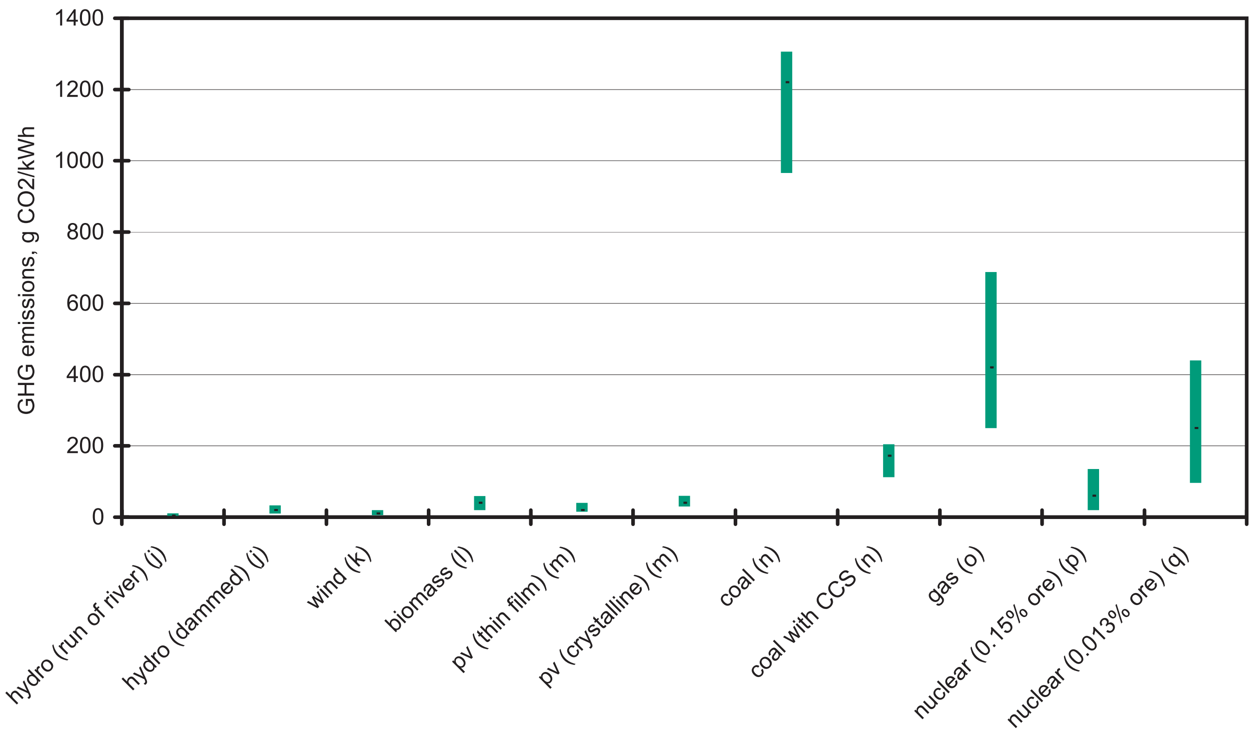
The full opportunities for renewable electricity and conservation development in Saskatchewan are much greater than identified here, but detailed planning work is necessary to properly flush them out. This work should have been done by SaskPower, but has not been. We hope significant amounts of it can be accomplished through the Green Energy Project. The exciting thing about all the options identified so far is that they are cost effective. Large scale wind (in the best locations) and hydro are competitive with natural gas. Energy efficiency would be so cost effective that much of it can be done by SaskPower at only half the current retail price per kWh of electricity. Only small scale hydro and biomass are likely to be slightly more expensive than today's electricity prices.

A fifth future opportunity to meet electricity needs from renewable energy is solar photovoltaic systems. The cost of these systems is still much higher than current electricity prices, but the price of solar photovoltaic systems is falling very quickly, and widely predicted to be in the same range as other newly-installed generation options ("grid parity") in less than a decade.[46] When this happens, we predict that they will be popular in Saskatchewan since they produce electricity very well at cold temperatures. There will, however, be logistical obstacles to their use, some of which are best addressed immediately. As a matter of standard practice, new buildings under construction in Saskatchewan should be wired to readily accommodate the installation of solar photovoltaic systems. The Saskatchewan Institute of Applied Science and Technology should ensure that all electricians graduating from its journeyperson programs are trained in the installation and maintenance of rooftop and wall-mounted photovoltaic panels. In the coming decades, there is much potential not only for building-integrated systems, but for (more cost-effective) solar electric power plants. Other installations (as is also the case with wind power) can provide a stable additional income for farmers while leaving the land on which they are built substantially available for grazing. Such plants are increasingly common in Europe, and are already being constructed in Ontario, where the provincial government has adopted feed-in tariffs to promote their use.[47]

Some options — such as concentrating solar thermal power (CSP) and deep-well geothermal (taking advantage of hot rocks several kilometres underground) — remain speculative.

It is clear, however, that a transition to a sustainable electricity system is a real possibility in Saskatchewan. None of the technical and economic barriers is insuperable: the questions to be resolved concern the best technical, legislative and logistical routes to take — and whether the province can find the political will to do so.

Rough Comparison of per-kWh Greenhouse Gas Emissions: Renewable and Non-renewable Options in Saskatchewan



A further explanation of this data is provided on page 17.

Endnotes

1 World Commission on Environment and Development (chair: Gro Harlem Brundtland) (1987): *Our Common Future.* Oxford University Press.

2 Environment Canada (2008:May): *National Inventory Report 1990-2006: Greenhouse Gas Sources and Sinks in Canada — the Canadian government's submission to the UN framework convention on climate change.* Available online at *www.ec.gc.ca/ghg* (last accessed 2010:Mar:11). This is the highest per capita figure in Canada, exceeded by at most 4 US states (Wyoming, Alaska, West Virginia and probably North Dakota) and by no major jurisdiction elsewhere in the world. It should be noted that the largest proportion of the high energy consumption which drives the massive Saskatchewan figure is by a few large facilities serving extractive and fossil fuel industries.

3 Kammen DM, Kapadia K & Fripp M (2004:Apr amended 2006:Jan): *Putting Renewables to Work — how many jobs can the clean energy industry generate?* Renewable and Appropriate Energy Laboratory, University of California, Berkeley, CA, USA. Available online at *http://rael.berkeley.edu/sites/default/files/very-old-site/renewables.jobs.2006.pdf* (last accessed 2010:Mar:18)

4 Thompson, David (2008): *Green Jobs — it's time to build Alberta's future*, Sierra Club Prairie / Greenpeace / Alberta Federation of Labour. Available online at *http://www.afl.org/upload/GreenJobsReport2009.pdf* (last accessed 2010:Mar:18)

5 Ragwitz M; Schade W; Breitschpf B; Walz R; Helfrich N; Rathman M; Resch G; Faber T; Panzer C; Haas R; Nathani C; Holzhey M; Zagame P; Fougeyrollas A & Konstantinaviciute I (2009:Apr): *The impact of renewable energy policy on economic growth and employment in the European Union*, European Commission DG Energy and Transport. Available online at *http://ec.europa.eu/energy/renewables/studies/doc/renewables/2009_employ_res_summary.pdf* (last accessed 2010:Mar:18)

6 Goldberg M; Sinclair K & Milligan M (2004): *Job and economic development impact (JEDI) model: a user-friendly tool to calculate economic impacts from wind projects.* Prepared for Global WINDPOWER 2004, 2004:Mar:28-31. National Renewable Energy Laboratory, Golden, CO, USA: NREL/CP-500-35953. Available online at *http://www.nrel.gov/docs/fy04osti/35953.pdf* (last accessed 2010:Mar:18)

7 Welsh Galluzzo, Teresa (updated 2005:Jul): *Small Packages, Big Benefits: economic advantages of local wind projects.* Policy brief, the Iowa Policy Project, Mount Vernon, IA, USA. Available online at *http://www.iowapolicyproject.org/2005docs/050405-wind.pdf* (last accessed 2010:Mar:18)

8 Lanz, Eric & Tegen, Suzanne (2009:Aug), NREL *Response to the Report* "Study of the Effects on Employment of Public Aid to Renewable Energy Sources" *from King Juan Carlos University (Spain)*. National Renewable Energy Laboratory, Golden CO, USA: NREL/TP-500-37720. Available online at *http://www.nrel.gov/docs/fy09osti/46261.pdf* (last accessed 2010:Mar:18)

9 Tegen, Suzanne (2006:May): *Comparing Statewide Economic Impacts of New Generation from Wind, Coal, and Natural Gas in Arizona, Colorado, and Michigan.* National Renewable Energy Laboratory , Golden CO,

USA: NREL/TP-500-37720. Available online at *http://www.nrel.gov/docs/fy06osti/37720.pdf* (last accessed 2010:Mar:18)

10 See, for example, Maegaard, Preben (2008:Feb): *Denmark: Wind Leader in Standby*, p2. Available online at *http://www.maegaard.net/pdf_files/Article%20for%20European%20Sustainable%20Energy%20_2_5.pdf* (last accessed 2010:Mar:10)

11 Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2009:Jan): *Neues Denken, Neue Energie*, pp12-13. The targets are 25 per cent renewables by 2020, 50 per cent by 2030, with an aspiration of 100 per cent by 2050. Formerly available online at *http://www.bmu.de/energieeffizienz*; available in pdf in English or German on request from the communicating author of this paper. Official policy on energy efficiency and renewables has not changed since the present CDU/CSU-FDP coalition government took power in September of 2009 (though the timescale for nuclear phase-out, also set out in the document, is now subject to review). For a detailed German "progress report" for the period 1990-2008, see Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2009:Jan): *Renewable Energy Sources in Figures.* Available online at *http://www.erneuerbare-energien.de/files/english/renewable_energy/downloads/application/pdf/broschuere_ee_zahlen_en_bf.pdf* (last accessed 2010:Mar:11)

12 Helwig-Larsen, Tim; Bull, Jamie; et al for Centre for Alternative Technology (2007): *Zero Carbon Britain*, CAT Publications, Machynlleth, Wales. Report and other resources available online at *http://www.zerocarbonbritain.org/* (last accessed 2010:Mar:11)

13 Barrett, Mark (2006:Apr): *A Renewable Energy System for the UK*, Complex Built Environment Systems Group, Bartlett School of Graduate Studies, University College London. Available online at *http://www.cbes.ucl.ac.uk/projects/EnergyReview.htm* (last accessed 2010:Mar:11)

14 Straub, Noelle & Behr, Peter in New York Times (2009:Apr:22): *Energy regulatory chief says new coal, nuclear plants may be unnecessary*: Available at *http://www.nytimes.com/gwire/2009/04/22/22greenwire-no-need-to-build-new-us-coal-or-nuclear-plants-10630.html* (last accessed 2010:Mar:11)

15 Burda, Cherise; The Pembina Institute & Peters, Roger (2008:Nov): *Plugging Ontario into a Green Future: a Renewable Is Doable action plan*. Pembina Institute, Toronto, ON. Available at *http://ontario.pembina.org* (last accessed 2010:Mar:11)

16 Bell, Jeff & Weis, Tim (2009:Jan): *Greening the Grid: powering Alberta's future with renewable energy*. The Pembina Institute, Drayton Valley, AB. Available at *http://alberta.pembina.org* (last accessed 2010:Mar:11)

17 IPCC (2007): Solomon, S; Qin, D; Manning, M; Chen, Z; Marquis, M; Avery, K B; Tignor, M & Miller, H L (eds): *Summary for Policy Makers. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, England & New York, NY, USA, p.5.

18 For an introductory treatment of the science of climate change and its likely impacts, the following are recommended:

Houghton, John (3rd ed, 2004): *Global Warming — the complete briefing*, CUP, Cambridge, England

Lynas, Mark (2007, updated 2008): *Six Degrees — our future on a hotter planet*, Harper Perennial, London

Weaver, Andrew (2008): *Keeping Our Cool — Canada in a warming world*, Viking Canada, Toronto

Roach, Rachel et al (2008): *Two Degrees, One Chance*, Tearfund / Christian Aid / Practical Action / Oxfam, London, England. Available at: *http://www.tearfund.org/webdocs/website/Campaigning/Policy%20and%20research/Two_degrees_One_chance_final.pdf* (last accessed 2010:Mar:11)

New Economics Foundation: the *"Up in Smoke"* series of reports: see *http://www.neweconomics.org/gen/z_sys_publications.aspx* to consult the nef publications list

Unfortunately, it is also necessary to counter specious arguments presented by so-called "sceptics". For responses and explanations, see *http://www.skepticalscience.com/argument.php*, *http://www.realclimate.org/*, and *http://climateprogress.org*. See also the series of videos at *http://www.youtube.com/view_play_list?p=029130BFDC78FA33*

19 Allison, I; Bindoff, NL; Bindschadler, RA; Cox, PM; de Noblet, N; England, MH; Francis, JE; Gruber, N; Haywood, AM; Karoly, DJ; Kaser, G; Le Quéré, C; Lenton, TM; Mann, ME; McNeil, BI; Pitman, AJ; Rahmstort, S; Rignot, E; Schellnhuber, H; Schneider, SH; Sherwood, SC; Somerville, RCJ; Steffen, K; Steig, EJ; Visbeck, M; Weaver, AJ (2009): *The Copenhagen Diagnosis 2009 — Updating the World on the Latest Climate Science*. Climate Change Research Centre (CCRC), University of New South Wales, Sydney, Australia, p 37. Available online at *http://www.ccrc.unsw.edu.au/Copenhagen/Copenhagen_Diagnosis_HIGH.pdf* (last accessed 2010:Mar:21). During the period 1961-2003 thermal expansion accounted for 40 per cent of the rise in sea level, and declining mountain glaciers and ice sheets accounted for 60 per cent. Satellite data indicate sea level rose 3.4 mm per year since 1993.

20 IPCC (2007): Parry ML; Canziani OF; Palutikof, JP; van der Linden J & Hanson CE, eds: *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group 2 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, England & New York, NY, USA, p. 656

21 IPCC (2007): *Summary for Policymakers*. In: IPCC (2007), Parry et al, op cit, p.13. The IPCC states that in some African countries "yields from rain-fed agriculture could be reduced by up to 50 per cent by 2020."

22 IPCC (2007): Parry et al, *op cit*, p. 397

23 IPCC (2007): *Summary for Policymakers*. In: IPCC (2007), Parry et al, op cit, p 11

24 *ibid*, p13

25 Earth System Research Laboratory (Global Monitoring Division) (ongoing): *Trends in Atmospheric Carbon Dioxide (Recent Mauna Loa* CO_2*)*, National Oceanic & Atmospheric Administration, US Department of Commerce. Available at *http://www.esrl.noaa.gov/gmd/ccgg/trends/* (last accessed 2010:Mar:21). 389ppm represents the average seasonal cycle value.

26 Hansen, James et al (2008:Apr:07): *Target Atmospheric* CO_2*: Where Should Humanity Aim?*, Open Atmos. Sci. J. (2008), vol. 2, pp. 217-231. Available at *http://arxiv.org/pdf/0804.1126v3*. For further explanation, see Hansen, James et al: *Target Atmospheric CO2: Supporting Material*, Open Atmos.Sci. J. (2008), vol. 2. Available at *http://arxiv.org/pdf/0804.1135v3*. Both last accessed on 2010:Mar:11

27 IPCC (2007): Solomon et al, *op cit*, p14. To put this in context, the difference in average global temperature between the last ice age and today was 5 degrees C.

28 Saskatchewan Power Corporation (2009): *2008 Environment Report*. Available at *http://www.saskpower.com/environment/report/2008/pdf/2009complete.pdf* (last accessed 2010:Mar:11)

29 *ibid*

30 *ibid*

31 *ibid*

32 Saskatchewan Power Corporation (2007:Sep:17): *"SaskPower Eneraction will help customers save money and the environment"*, Government of Saskatchewan news release

33 Saskatchewan Power Corporation (2009): *op cit*, p17

34 Presentations made in summer 2006 to Peter Prebble MLA by Lloyd Kuczek (Division Manager, Consumer Marketing and Sales, Power Smart, Manitoba Hydro), Lois Morrison (Manager of Marketing Programs, Manitoba Hydro), Rhonda Orr (Manager of Government Relations and Current Issues Coordination, Manitoba Hydro), Gerry Rose (Vice-President of Customer Service and Marketing, Power Smart, Manitoba Hydro), Rick Patrick (Vice-President of Environment and Regulatory Affairs, SaskPower) and Demand Side Management Unit staff, SaskPower

35 California Public Utilities Commission & California Energy Commission (2006:Aug): *Energy Efficiency — California's Highest Priority Resource: lowering energy costs, promoting economic growth and protecting the environment*, pp 3-4

36 Meeting in July of 2007 between Peter Prebble MLA and Blair Hamilton (President, Efficiency Vermont), Scudder Parker (Senior Project Manager, Efficiency Vermont) and Robert Ide (Director, Energy Efficiency, Department of Public Services, State of Vermont)

37 Saskatchewan Power Corporation (2009:Oct:28): *"SaskPower leading the way in wind generation"*, Government of Saskatchewan news release

38 For an outline discussion of the major options, see Canadian Renewable Energy Alliance (2009:Feb): *Six Ways of Providing Base Load Power from Wind*. Available online at *http://www.canrea.ca/site/wp-content/uploads/2009/03/canrea-six-ways-of-providing-base-load-power-from-wind-feb09.pdf* (last accessed 2010:Mar:21)

39 For a detailed study of the effect of wind turbine dispersal on output reliability in a 72250 km^2 area of the inland southwest United States, see: Archer, Cristina L & Jacobson, Mark Z (2007:Nov): *Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms*, J Appl Meteorology & Climatology, vol 46, pp 1701-1717. Available at *http://www.stanford.edu/group/efmh/winds/aj07_jam.pdf* (last accessed 2010:Mar:11)

40 For a description of the system in place in Denmark, see: energinet.dk (2009): *Wind Power to Combat Climate Change*, available online at *http://www.e-pages.dk/energinet/126/* (last accessed 2010:Mar:11)

41 Backwell, Ben (2009:Dec:23) in Recharge News: *Spanish wind power capacity reaches 18GW in 2009*. Available online at *http://www.rechargenews.com/energy/wind/article202124.ece* (last accessed 2010:Mar:11)

42 energinet.dk (2010): *Environmental Report 2009*, p9. Available online (together with the equivalent reports from 2006 on) at *http://www.energinet.dk/NR/rdonlyres/E46D998A-7477-4D6B-B2E0-D5F2071A466B/0/Environmentalreport2009.pdf* (last accessed 2010:Mar:11)

43 McKenzie, John (SaskPower Manager, Strategic Corporate Development) (2008): *Saskatchewan's electricity environment*, IPAC Energy Conference, 2008:Feb:26-28. McKenzie identifies opportunities for 120MW electrical generation from biomass using forestry residue, plus the potential for several small biomass projects (each under 10MW) using a variety of technologies.

44 SaskPower website entry on biomass: *What is its potential as a supply option in SaskPower's system?* Available at *http://www.saskpower.com/future_power/supply_options/biomass.shtml* (last accessed 2010:Mar:11)

45 More options for biomass sources (presented mostly in the context of motor fuels, but in our current view more appropriate for electricity and space heating) are given in some detail in: Saskatchewan Environmental Society (ed. Coxworth, Ann) (2007:Jan): *Towards a Sustainable Energy Strategy in Saskatchewan*, SES, Saskatoon, pp 14-16. Available at *http://www.environmentalsociety.ca/energy_report.pdf* (last accessed 2010:Mar:11)

46 Lazard (2009:Feb): *Levelized Cost of Energy Analysis, Version 3.0*, p8. Available at *http://blog.cleanenergy.org/files/2009/04/lazard2009_levelizedcostofenergy.pdf* (last accessed 2010:Mar:11)

47 Gipe, Paul (2009:Sep:24): *Ontario launches comprehensive system of feed-in tariffs: first system of advanced renewable tariffs in North America*. Available at *http://wind-works.org/FeedLaws/Canada/OntarioLaunchesSystemofFeed-inTariffs.html* (last accessed 2010:Mar:11) For full public presentation notes on the Ontario FIT, see: Ontario Power Authority (2009:Aug:21): presentation on the Green Energy and Green Economy Act to the Métis Provincial Youth Forum in Sudbury, ON. Available at *http://wind-works.org/FeedLaws/Canada/OPA%20GEA%20Summary%20AGA%20Metis%20Youth%20Forum%20presentation.pdf* (last accessed 2010:Mar:11)

Endnotes to Graphs

(a) Demand-side management: facilitation and active encouragement of efficiency and conservation measures by the electrical utility. This will be treated in more detail in the second paper in this series.

(b) SaskPower (2009:Oct:06), Powering a sustainable energy future. Submission to the Saskatchewan Legislative Assembly's Standing Committee on Crowns and Central Agencies.

(c) SaskPower define [3]large[2] wind as windfarms larger than 150MW capacity. It is more common practice worldwide to delineate [3]large[2] from [3]small[2] by turbine size rather than windfarm size: we will therefore be seeking to ascertain and assess the assumptions behind the SaskPower data.

(d) Lazard (2009:Feb), Levelized Cost of Energy Analysis, version 3.0

(e) Figures for photovoltaic panels have been adjusted to better represent mid-Saskatchewan climate. These are for large units only (10MW capacity) building-integrated and other small arrays will typically be significantly more costly per kWh

(f) Derived by taking the figures for conventional coal and adding carbon capture and storage at $15 to $50 per tonne. Assumes that 88% of the CO_2 is captured and stored, and that 15% of plant output is lost in powering the CCS process (in line with SaskPower figures for the proposed refit of Boundary Dam 3 with CCS in 2013)

(g) Integrated Gasification Combined Cycle coal combustion coal and steam are reacted to produce syngas (mostly carbon monoxide and hydrogen), which is then burnt to produce power.

(h) Of the several options available for gas-fired power stations, only two of the most energy-efficient (depending on circumstances) are listed here. A gas turbine power station with combined heat and power produces electricity at low efficiencies, but also generates moderately high temperature steam or water, typically for industrial process heat. A combined cycle gas turbine power station achieves high efficiencies in electrical production (55% is a typical figure, compared to about 35% in most existing thermal power stations)

(i) Figures derived from press reports of the failed bid in 2009 by AECL to build new ACR reactors in Ontario. [An even higher per-kWh cost emerged from a proposal in 2009:Jan by a Russian-led consortium for a reactor in Turkey.] Spreadsheet available from the authors.

(j) Based on Hydro Quebec figures cited at: http://www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/pop_01_06.pdf

(k) From LCA studies carried out by NEEDS, CASES, Ecoinvent and Vestas see www.wind-energy-the-facts.org/en/environment/chapter-1-environmental-benefits/lca-in-wind-energy.html

(l) Elsayed, Matthews and Mortimer, (2003). Carbon and energy balances for a range of biofuels options. ETSU B/B6/000784/00/00. URN 03/836 for the Sustainable Energy Programmes of the Department of Trade and Industry, Resources Research Unit, Sheffield Hallam University, England, March 2003

(m) Based on V M Fthenakis, H C Kim & E S Alsema (2008), Emissions from Photovoltaic Life Cycles, Environ. Sci. Technol, 2008, 42, 2168-2174

(n) Calculated from publicly available data for Saskatchewan coal, and SaskPower assumptions re carbon capture efficiency and CCS power requirements

(o) Options within the range shown vary from new CCGT with CHP to older gas turbines without CHP

(p) Average of a number of studies, from Benjamin K Sovacool (2008:Jun), Valuing the greenhouse gas emissions from nuclear power a critical survey, Energy Policy 36 (2008): 2940-2953. Sovacool lists 103 lifecycle studies, which he reduces to 19 by eliminating those which do not meet his criteria of recent data, accessibility and transparent methodology. These are further reduced here to 6 on grounds of comprehensiveness and absence of industry bias.

(q) Figures used for 0.15% ore adjusted to take account of the increased use of fossil fuels in the front end and back end of the nuclear process, using the methodology of Storm van Leeuwen as presented in documents at www.stormsmith.nl