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We need to talk: The case for a multidisciplinary approach to designing green policy*

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Abstract: In order to sensibly design green policy, at least three separate disciplines need to be involved. Clearly, technology will be required to design new processes and redesign old ones. Government policy makers will need to ensure that new regulatory structures adapt and reflect societal goals of decreasing our impact on the planet. Lastly, we need to hear from the economists to make certain that our efforts to develop green processes actually have a net positive effect. This last point is not as obvious as it might appear. James Watt's invention of the external condenser for steam engines, which he patented in 1769, dramatically reduced coal requirements for a unit of output. Not surprisingly, demand for coal dropped as new steam engines incorporating that design became common after the patent expired in 1794. However, in the period 1830–1860 coal use in England actually increased by an order of magnitude. This is the efficiency paradox. As the effective cost of the product falls because more can be produced from the same raw materials, demand increases. The net result is higher overall consumption. While the focus of green chemistry is the effect emissions are having on the environment, to date we have tended to concentrate on inputs and processes, and not the emissions themselves. In designing policy and new processes, we need to keep phenomena such as the efficiency paradox in mind to ensure that our efforts to improve the environment actually have that effect in practice.

Keywords: efficiency paradox; emissions; energy; environment; policy.

INTRODUCTION

The years 1972 and 1973 were particularly turbulent ones for the petroleum industry. A combination of economic and political factors led to a number of significant increases in the price of oil and finally in October 1973 to the Arab oil embargo. Suddenly oil was scarce and much more expensive when it could be found. There was considerable doubt whether the standard of living we had become accustomed to in Europe and North America could be sustained. These shocks led to the first major energy conservation movement in the 20th century. In 1972, the United States consumed 16.37 million barrels of oil per day [1]. The average [2] U.S. domestic automobile got about 14 miles per U.S. gallon and the average U.S. import automobile got about 22.9 miles per U.S. gallon [3]. By 2004 (the last year for which the National Highway Traffic Safety Administration, NHTSA, has posted data), the average U.S. domestic automobile got 29.9 miles per U.S. gallon [4] while the average U.S. import automobile got 28.7 miles per U.S. gallon (p. 22 in [4]). The doubling in efficiency of U.S. domestic automobiles must therefore

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have resulted in a significant reduction in U.S. consumption of oil, which was the whole point of the legislatively mandated improvements in automotive fuel economy. Yet even without looking up the data, we all suspect that this is not the case. When we look up the data, it is worse than we might have imagined. By 2004, the United States was consuming 20.73 million barrels of oil per day (p. 325 in [1]), some 27 % more than in 1972. Why is this so? It is true that the number of vehicles has increased. In 1972, the number of registered vehicles in the United States was 118 796 671 [5]. By 2004, that number had grown to 237 949 800 [6]. In all the circumstances, a 27 % increase in oil consumption is not terrible, but the whole point of conservation was to reduce consumption, not increase it. This is why we (scientists, economists, and policy makers) need to talk.

In several past crises, the paradoxical impact improved efficiency has on total energy consumption has been independently described. One such study was *The Coal Question—An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines*, first published in 1865 [7] and republished with revisions in the following year. As can be inferred from the title, Jevons was concerned with the notion that coal stores in the United Kingdom were finite (which we might call "peak coal") and the impact that the exhaustion of Britain's coal mines would have on its economy. Then, as now, conservation was put forward as the solution to the problem at hand, and Jevons undertook his inquiry in the initial belief that this was so.

Following the oil crisis of the 1970s, the British economist Leonard Brookes and the U.S. economist Daniel Khazzoom independently rediscovered the efficiency paradox [8–10]. Rubin's book, which has a very accessible discussion of the efficiency paradox or rebound effect, was prompted by the concern over "peak oil". He notes that the observation that increased efficiency by itself does not reduce consumption is often unwelcome news, with Prof. Khazzoom having his life threatened following testimony at an environmental inquiry held before the construction of the James Bay hydroelectric project in northern Québec.

This paper investigates the approach of efficiency improvements "reduce, reuse, recycle" as a way to reduce our impact on the environment due to emissions of all kinds (including greenhouse gases) by examining in brief form some of Jevons' data and observations. In short, this paper serves to illustrate that efficiency improvement by itself will not save so much as an ice cube from global warming. We should also make it clear that we do not know the answer. However, as chemists now practicing in the legal field it has been a source of profound frustration to watch on the sidelines as society's efforts to improve the environment appear to have the opposite effect. While we do not know exactly how to get to our intended destination (although we have some ideas), we do know that as a species we have taken the wrong road and we need to get our bearings. If scientists, economists, and policy makers continue to independently devise solutions without talking to one another, we are in danger of becoming like Stephen Leacock's Lord Ronald, who "flung himself from the room, flung himself upon his horse, and rode madly off in all directions" [11].

JEVONS' DEVELOPMENT OF THE EFFICIENCY PARADOX

As discussed earlier, in 1865, the British economist William Stanley Jevons (1835–1882) analyzed England's consumption of coal in an attempt to understand the impact exhaustion of Britain's coal supplies would have on its economy and what might be done to ameliorate that impact. His study focused on the application of coal power to steam engines used to pump coal out of the coal mines because Jevons observed that after the introduction of James Watt's steam engine, there was an increase in coal consumption in Britain. He realized that Watt's improvements resulting in energy efficiency reduced the unit cost of the work performed. With lower cost, applications that were previously uneconomical could now be performed by steam, which resulted in increased coal use. Jevons' analysis of the link between improvements in energy efficiency and increased demand led to his description of the phenomenon that has come to be recognized as Jevons' paradox.

The progress of improvements in steam engine technology and its influence on coal consumption was an important element in Jevons' study. Jevons described the historical development of engine technology and argued that the great increase in the United Kingdom's consumption of coal was due to the successive increases in energy efficiency brought about by successive technological improvements to the steam engine, with particular credit going to Watt's improvements to the steam engine. Jevons wrote, "Whatever, therefore, conduces to increase the efficiency of coal, and to diminish the cost of its use, directly tends to augment the value of the steam-engine, and to enlarge the field of its operations" (pp. 127–128 in [7]), quoting from C. W. Williams' *The Combustion of Coal*, 1841.

The first steam engine was built in 1698 by the English military engineer Captain Thomas Savery (c. 1650–1715) to remove water that had leaked into coal mines, however, the Savery steam engine was too expensive to use because its rate of consumption of coal was too high. This was followed in 1712 by improvements introduced by Thomas Newcomen (1663–1729) that increased the efficiency of the steam engine, making it more powerful and economical than its predecessor. However, Newcomen's improvements did not sufficiently improve the economic equation to bring such engines into common use. The Newcomen engine still had a higher cost of operation than the cost of using the power of horses, wind, or air in the same application (p. 126 in [7]). J. Smeaton's (1724–1792) improvements further improved the efficiency of the steam engine. This improvement was sufficient (when combined with earlier improvements) to finally make the steam engine commercially viable.

The most significant improvements made to steam engine design were brought about by the Scottish engineer James Watt (1736–1819). His modifications increased the efficiency of the engine by doubling the capacity of the Newcomen–Smeaton engine. Jevons wrote: "Watt's two chief inventions of the condenser and the expansive mode of working are simply two modes of economizing heat…And with the exception of contrivances, such as the crank, the governor, and the minor mechanism of an engine, necessary for regulating, transmitting, or modifying its power, it may be said that the whole history of the steam-engine is one of economy" (p. 127 in [7]). The Watt steam engine soon proved to have the greater significance of becoming the motive force of the Industrial Revolution, and indeed played a considerable role in the development of English patent law [12].

To support his thesis, Jevons calculated the fuel efficiency of an engine as measured by its work or duty (expressed as pounds of water raised one foot) generated by burning a bushel (84 pounds) of coal at different periods as efficiency was improved with each successive technological improvement to the steam engine (p. 128 in [7]) (Table 1).

Table 1

Year	Improvement	Duty in lbs
1769	Average of old atmospheric engines	5 590 000
1772	Smeaton's atmospheric engine	9 450 000
1776	Watt's improved engine	21 600 000
1779–1788	Watt's engine working expansively	26 600 000
1820	Engine improved by Cornish engineers	28 000 000
1830	Average duty of Cornish engines	43 350 000
1859	Average duty of Cornish engines (per 112 lbs.?)	54 000 000
1859	Extreme duty of best engine (per 112 lbs.?)	80 000 000

What he observed was that in less than 100 years, the efficiency of the engine was increased more than 10-fold by successive improvements. "But no one must suppose that coal thus saved is spared—it is only saved from one use to be employed in others, and the profits gained soon lead to extended employment in many new forms. The several branches of industry are closely interdependent, and the progress of any one leads to the progress of nearly all" (p. 136 in [7]). Consider that the duty went from 5.59 million lb in 1769 with the original engine, through 9.45 million lb with Smeaton's enhancement in 1772, to 26.6 million lb with Watt's improved engine by 1788, reaching 43.3 million lb in 1830 with the Cornish engine. With each step in the progression, more engines were sold, and the market grew. And as the market grew, the machines became cheaper, and then more widely adopted. Soon the steam engine was adapted for transportation, railroads displaced horse carts, and steamships displaced sail. The steam engine transformed society.

Jevons ascertained the amount of coal that had been raised from the UK coal mines using Mining Records data and accounting for the variability of coal consumption "upon the fluctuating activity of trade" (p. 236 in [7]), and calculated that in the period 1781–1863 coal consumption had grown at a rate of 3.5 % per year, or 41 % per decade. Using this estimated rate of growth, he was able to estimate the probable future consumption of coal and estimated the total consumption for the 100-year period 1861–1961, taking into account as far as he was able the various uncertainties, at approximately 100 billion tons. He concluded that since resources were not sufficient for even 100 years, long before the 100 years was reached, the growth rate, which was the measure of prosperity, would have to decline (pp. 241–242 in [7]).

In examining the prices of coal prior to and after the invention of the Watt steam engine, Jevons considered two other factors that raised the price of large coal in the early years and "thus disguise the real rise of price due to the growing demand and the depth of mines" (p. 81 in [7]). Taking these other factors into account, Jevons concluded that the cost of the best quality of Newcastle coal had doubled within a century due to the greater depth of the collieries necessitated by earlier consumption of shallower coal. So it is with petroleum today, as we are forced to consider ever harsher environments and lower grades of crude in our search for new supplies.

The efficiency paradox can also be observed in the impact of the Bessemer process, which drastically reduced the cost of making steel.

BESSEMER PROCESS

The Bessemer process for making steel reduced the cost of steel production by at least 80 % [13], thereby allowing for the mass production of steel from molten pig iron with increased quality. Its inventor, Sir Henry Bessemer (1813–1898), took out a patent on the process in 1855. The process was also independently invented in 1851 by William Kelly in the United States. Bessemer first described the process to a meeting of the British Association in Cheltenham that he titled "The Manufacture of Iron Without Fuel". Given the remarkable improvement in efficiency the process brought about, he can be excused for the hyperbole.

Prior to the Bessemer process, steel was difficult and expensive to make due to the amount of fuel consumed in making it. Consequently, steel was used only to make small, specialized items such as cutlery and cutting tools. For this reason, cast iron and wrought iron had been used in the early stages of the Industrial Revolution to make bridges and the framework for buildings.

The Bessemer process operated on the principle of refining molten pig iron in a converter by injecting air continuously through the molten steel. As the air was injected into the molten iron, the oxygen in the air removed the impurities contained in pig iron (i.e., manganese, silicon, and excess carbon) as slag or gas in a series of exothermic reactions, thereby converting the iron to molten steel [14,15]. The practice of removing waste as a gas will be touched upon later in this paper. The Bessemer process was a cheaper way to produce steel than other methods of that era because the exothermic oxidation of impurities made a significant contribution to the heat needed to maintain the steel in a molten state. Prior to the Bessemer process, England produced 50 000 tons of steel annually at a price of 50–60 £/ton. In 1877, England produced 750 000 tons at 10 £/ton [16].

At the time of Jevons' work, Bessemer was still perfecting his process (pp. 114, 317, 325 in [7]). However, Jevons was able to consider a similar advance in iron making, the Nielson "hot blast" process, which significantly reduced the amount of coal needed to produce a ton of pig iron from 7 tons to 2. What was the effect? In 1830, Scottish production of pig iron was some 37 000 tons. By 1863, Scotland was producing 1 160 000 tons of pig iron. The net result was a 10-fold increase in coal consumed in the making of pig iron (pp. 316–317 in [7]).

MODERN-DAY EFFICIENCY PARADOX

As outlined in the introduction, the efficiency paradox is not just a Victorian curiosity. The oil shock of the early 1970s did lead to a significant improvement in the efficiency of the average automobile—nearly double by 2004. The problem is that there are now more than twice as many cars on the road. While some policy makers are learning to appreciate that efficiency alone is not the answer to environmental impacts such as climate change, we still do not seem to be making real progress in curtailing these impacts [17].

Again, as noted in the introduction the oil shock led to both Brookes and Khazzoom re-examining the actual impact that efficiency improvements had on fuel consumption and their rediscovery of the paradoxical result that Jevons had described.

In 1992, Harry Saunders reviewed the work of Brookes and Khazzoom [18] using neoclassical growth theory. He noted that "Common sense says that energy efficiency gains will reduce energy demand below where it would otherwise be. So evident is that that most countries' energy policies—not to mention oil industry forecasts and many academic writings—take it as a cornerstone fact." He concluded that the work of Brookes and Khazzoom suggested otherwise and could not be dismissed lightly.

FUTURE CONSIDERATIONS

In an effort to reduce our environmental impact (including our carbon footprint), government has been focused on the indirect approach of attempting to reduce carbon emissions by reducing energy use through energy efficiency. That is, the focus has been on inputs, rather than outputs, i.e., waste and chemical substance emissions. When policy has been directed to the emissions themselves, legislation has taken the "bad dog" approach by forbidding it instead of trying to provide an economic incentive to reduce emissions.

The fundamental problem is that we have long considered the disposal of waste as cost free. In considering the Bessemer furnace, while fuel use in the form of added coke was reduced, the point of the process was to save fuel by utilizing the exothermic conversion of impurities. Excess carbon was converted to carbon dioxide, which was then emitted to the atmosphere. However, the obvious point is that the greenhouse potential of carbon dioxide does not depend upon its source. The whole concern was the input and the savings of coke, not the output.

If we are to have any hope of reducing emissions we have to focus on them directly, and appreciate that waste disposal is not cost free. In the current system it can be argued that at least a portion of the cost of the atmospheric disposal of carbon emissions from fossil fuel use must be borne by those who received no benefit from the activity in question.

The legal system permits those who suffer loss due to the conduct of others to recover compensation, but they must be able to show who caused the loss and quantify it. Moreover, the party suffering the loss must invest a considerable sum to bring the case to court.

The loss is generally measured by its impact on the victim. If the waste disposed on the victim's land reduces its value, the landowner can recover the difference, or in some cases the cost to restore the land to its previous value. However, this approach does not and cannot account for other real costs such as species loss, the wild fires currently raging in British Columbia and Russia, or the loss of land as ocean levels rise. Moreover, the cost of cleaning up a mess after the fact is usually much greater than the cost associated with preventing the loss in the first place. In Superfund litigation in the United States, bankruptcy is often a complicating factor [19].

The problem is a mind set that we have had probably from the beginning of civilization. The Ten Commandments and Hammurabi's Code both prohibit theft, but are silent on the question of waste disposal. Part of the problem relates to the failure to fully appreciate the costs associated with indiscriminate disposal of waste. Metal oxides may be regarded as inert, and their disposal as dust as innocuous as disposing of sand or clean top-soil on someone else's land. As we are now learning, such assumptions are not always safe [20]. It is well known that the processing of nickel sulfide ores can result in significant sulfur emissions. Yet, for many years nickel was considered so vital to the economy that the impact of these emissions was considered something that society had to tolerate. Indeed, in Ontario from 1921 to 1970 the only remedy for damage from such fumes was to seek compensation from an arbitration system. The right to bring an action or to seek an injunction to stop the emissions was taken away [21]. Once the legislative tide turned, and significant fines were imposed for such emissions, work to reduce such emissions was undertaken [22].

The only incentive to recycling industrial waste, such as in the mining sector, has been the opportunity cost of throwing away valuable material in such waste that could be recovered for less than the value it would receive in the market. An example is the recycling of slime wastes from electrolytic processes to recover additional base metal and precious metals [23]. Another example is the interest caused by triple-digit oil prices in quarrying and recycling off-specification nylon buried years earlier in a landfill near Kingston, Ontario [24,25].

By examining energy and material (or mass) balances for our current energy processes as well as future alternative clean/green energy sources, we can ensure that we are optimizing our current energy sources, i.e., using energy efficiently and minimizing emissions/pollutants.

Energy balance calculations offer a way to evaluate energy efficiency because these calculations describe the relationship between the energy consumed in a process (i.e., input energy) and the energy produced/stored from a process (i.e., energy output). The general equation for calculating energy balances is based on the fundamental law of energy conservation:

$$E_{\text{input}} = E_{\text{output}} + E_{\text{stored}}$$

where

E_{input} = total energy entering the system

E_{output} = total energy leaving with products + total energy leaving with waste materials + total energy lost to surroundings

E_{stored} = total energy stored, not otherwise accounted for

Setting out formulae for energy and mass balances in a paper directed primarily to chemists could be considered superfluous. However, the paper may be read by others, including people who make business decisions, and clearly they are not doing such calculations. The Spanish lettuce sold in the United Kingdom takes 127 calories worth of aviation fuel to fly it to market for every calorie of energy in the lettuce (p. 218 in [8]). Older farms required about 1 calorie of energy to be expended for each 3 calories of food energy produced. Today that ratio is 10:1 (p. 223 in [8]). Neither of these "advancements" makes any sense at all. If proponents of ethanol from corn as an automobile biofuel had been required to show an energy balance, it is doubtful that so much would have been invested in that endeavor [26]. Even Middle Eastern crude suffers somewhat if we fully account for the energy used in supporting infrastructure such as electricity generation and water desalination.

Material balances offer a way to monitor inputs and outputs of a system such as an industrial facility or process. This information allows us to determine what is being released as a result of a process by determining the differences between input, output, accumulation, and depletion of a substance. The general equation for calculating material balance is based on the fundamental law of mass conservation and can be summarized with the following general equation:

$$M_{input} = M_{output} + M_{stored}$$

where

M_{input} = mass of compound in the raw material fed into the process

M_{output} = mass of compound in the finished product and waste disposed of as waste (i.e., landfill) and that is released to air, land, and water

$(M_{output} = M_{product} + M_{disposed} + M_{emitted})$

M_{stored} = mass of compound accumulated or depleted in the system not otherwise accounted for

It must be appreciated that these equations are very much simplified. For instance, there are likely to be multiple inputs, which could be represented as $M_{input\ 1}$, $M_{input\ 2}$, and so on. There is also the issue of the environmental impact of the materials disposed of or emitted, which is discussed below.

APPROACHES

We propose two approaches to minimizing emissions:

1) Considering the by-products generated by an industrial facility/process to evaluate whether the by-product (s) can be reused in another part of the process rather than disposing of it as waste or emitting it.
2) Government establishing a royalty system to charge for the cost associated with waste, similar to the royalty charged for the extraction of valuable materials from the ground. There have been two types of system that have been pursed as options to reducing greenhouse gas emissions, i.e., an environmental tax, and cap-and-trade.

An environmental tax, such as a carbon tax, is levied on the input assuming that all the carbon in the fuel is eventually emitted. The intent is to force companies to pay an amount that is applied only for every unit of pollution that they produce; thereby giving companies a financial incentive to reduce emissions. However, such an input tax can be reduced in one of three ways: reduced production, increased efficiency, or alternate use. As already discussed, increased efficiency only reduces the unit cost impact, not the total cost.

What we propose for study is a royalty system on outputs of waste. It might be argued that such a system would be too complex, yet Canada has a system in place that has been tracking some 300 substances since the 1990s, the National Pollutant Release Inventory [27]. Data for greenhouse gas emissions have been collected since 2004 [28]. In setting an emissions royalty for each of these compounds, some estimate of their relative environmental impacts will have to be made. For greenhouse gases, global warming potential is one measure that has been proposed to estimate the impact of each such gas on a molar basis. While the potential of a compound to contribute to climate change is important, so are other factors such as toxicity and eutrophication potential. Arriving at a scale of charges that properly accounts for all potential environmental impacts will not be easy, involving as it does multiple value judgments. However, we suggest that an iterative process in which the royalty rates are adjusted when distortions are observed is likely to be the most productive approach.

Those companies that are thus induced to reduce emissions and their environmental impact will benefit by minimizing the royalty they pay. Those companies that do not attempt to reduce emissions and perhaps have greater emissions than others in the same sector or industry will have to incur the expense of the royalty, thereby cutting into their profits. There are many advantages to such a system. Firstly, it institutes a comprehensive "use pay" system that will not permit those who profit from industrial activity to off-load their costs on others as Ontario legislation permitted certain smelters to do. It is also a "pay as you go" system, which would prevent clean-up costs being avoided through bankruptcy. Secondly, it will make green technologies/noncombustive energy sources (i.e., wind, solar, hydropower, geothermal, and nuclear) more desirable to pursue because there will be fewer harmful emissions from these processes, and thus a reduced waste royalty expense associated with their use.

CONCLUSION

We recognize that an emission royalty is not without obstacles that will need to be overcome. Firstly, setting a royalty rate that maximizes economic efficiency and fairly balances the cost associated with the emission of a gram of mercury compared to a gram of methane will not be trivial. However, the most productive approach would be to make a best estimate and then adjust the royalty for different substances should distortions caused by the initial rates chosen appear. Secondly, just as there are unscrupulous operators who bypass electricity or gas meters, there will undoubtedly be those who will be tempted to under-report emissions. Also, as Jeff Rubin points out, such an approach will inevitably require a system of tariffs on imports from jurisdictions that do not share it (p. 169 in [8]).

If the object is to reduce *the total amount of emissions*, which we need to do if we are to blunt the effect of climate change, we must focus on emissions. Indirect methods, particularly those that seek to reduce outputs by improving the efficiency with which we use inputs, are frequently counterproductive. Had we cared to listen, the fact that our present approach is unsustainable was explained nearly 150 years ago. It was explained again after the oil shocks of the early 1970s. Perhaps Calvin in the Calvin and Hobbs cartoon series has the correct diagnosis: "It's not denial. I'm just very particular about the reality I choose to accept."

There are a number of competing interests that also complicate the discussion. Should we run the risk of future climate change if measures to prevent it mean jobs will be lost today? Are we prepared to pay the full cost of our way of life? The significant use of credit to facilitate consumption in Western society suggests that we may not be prepared to do so, and that is with credit card companies charging interest at rates far higher than other borrowing rates. The issue is not the quality of our information; the issue is our willingness to act upon it. We may be better informed, but it is unclear that we are any wiser [29].

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21. *The Damage by Fumes Arbitration Act*, 1921 S.O., c. 85 (1921). The Act was amended from time to time until its repeal in 1970 – S.O., c.103 (1970). The statute provided that where damage had been occasioned by sulfur fumes to crops, trees, or other vegetation directly or indirectly, such damage may be determined by the arbitrator so appointed, who shall have exclusive jurisdiction to determine the amount of such damage and to make an award. The statute further provided that the remedies provided for in the Act were in lieu of all other remedies, and actions, including actions for an injunction, were prohibited. Actions pending at the time the statute came into force were stayed. There was no appeal provided and judicial review of the arbitrator's decisions was prohibited. Thus, any landowner adversely affected by sulfur fumes from industrial activity was required to suffer the result, and was limited to whatever award the arbitrator might make for damage to vegetation on the property.
22. G. D. Senior, W. J. Trahar, L. K. Smith, P. J. Guy. CA Patent 2116322, Filed 25 August 1992, Issued 18 March 1993.
23. B. H. Morrison. CA Patent 1091035, Filed 03 May 1977, Issued 09 December 1980. "Slimes from electrolytic copper refinery are first treated by leaching them with dilute sulphuric acid under an oxygen partial pressure of up to 50 psi and an elevated temperature, until copper and tellurium present in the slimes are substantially dissolved, and effecting a liquid-solid separation of the leached slurry so produced to separate the leach liquor from the leach slimes. The leach liquor is then treated with metallic copper to cement the tellurium as copper telluride. The latter is separated from the remaining solution which is suitable for the production of copper sulphate. The leach slimes containing mainly selenium, lead, silver, gold and other impurities are dried, mixed with a binder and pelletized and the pellets are then roasted to remove selenium as selenium dioxide. (The patent notes that an adequate flue system for removing about 300 pounds of $Se0_2$ per hour was employed in the example described—see page 8, lines 23–27.) Finally, the roasted pellets are smelted to remove the remaining impurities (the patent does not say what became of them) leaving a doré metal containing essentially silver and gold."
24. K. Laudrum. *Canadian Plant* (September 2008).
25. City of Kingston, Ontario, Report to Council, Report No. 07-025 at 19 (2007), available at <http://www.cityofkingston.ca/pdf/council/agenda/2007/A06_Rpt14.pdf>.
26. K. Sanderson. *Nature* **444**, 673 (2006).
27. A description of the system, and access to the collected data available at <http://www.ec.gc.ca/inrp-npri/default.asp?lang=en>.
28. Environment Canada web site: <http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=EEA9E6B0-1#ghg>.
29. The early 20th century English barrister F. E. Smith had a quick but often cruel wit. He was arguing a complex case when the judge interrupted: "I have listened to you for an hour, and I'm none the wiser." He responded: "None the wiser, perhaps, my lord. But certainly better informed." E. C. Gerhart. *Quote it Completely*, p. 224, William S. Hein, Buffalo, NY (1998).

