Environmental Costs and Externalities
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This white paper provides an introduction to the concept of environmental “externalities”, in the specific context of prices for materials and waste disposal. It has been prepared for the Oregon Department of Environmental Quality as it works with stakeholders to consider options to restore and sustain funding for its work, including implementation of *Materials Management in Oregon: 2050 Vision and Framework for Action*.

An externality is a discrepancy between social costs and private costs. For example, the manufacture of a consumer good, such as a shirt or television, results in pollution. The costs of this pollution (such as health impacts or property damage) are not (typically) paid for by the producer, but rather are borne by other members of society. Thus, they are called “external” to the producer’s decision-making process.

This paper demonstrates that, in the presence of externalities, free markets may fail to result in the best allocation of resources. Economists refer to this situation as being “inefficient” or a “market failure.”

This paper is organized into three sections. A short background introduces several important concepts, including how free markets, in the presence of externalities, fail to maximize benefits to society as a whole, as well as some of the methods that economists use to estimate the cost of pollution externalities. These concepts are explored in greater detail in an appendix. The second section provides several examples of estimates of the cost of pollution externalities, specific to the production, recycling, and disposal of materials. This paper concludes with a short discussion of methods for internalizing externalized environmental costs.

Background

Economic theory asserts that a market economy with many producers and sellers for each good and service, as well as many buyers and consumers for each of those items, allocates limited resources efficiently. Efficiency here means that no alternative allocation of resources (involving different levels of production/consumption and different market prices) can make some better off without making others worse off.

Specifically, the market economy results in prices for goods and services that result in the most efficient allocation of resources. Forces of supply and demand result in these equilibrium prices. At these market prices, all participants are satisfied because they are each maximizing their production profits and/or consumption benefits.

However, this theoretical ideal rarely exists. One common reason is that market transactions between a producer and a consumer may cause uncompensated impacts, good or bad, to other producers or consumers. Economists refer to these uncompensated impacts as “externalities.” The impacts (and costs) are real, but “externalized” to other entities that are not party to the original market transaction. A common example of this is the pollution caused by production and/or disposal of materials. Pollution can result in a variety of costs to society, including but not limited to health impacts, disabilities, cognitive impairment, property damage, and reductions in the productivity of ecosystems. When these costs are not reflected in the market prices of goods, society as a whole is less well off. Production and consumption are higher than they would be if the market prices reflected these externalities. Scarce resources are not allocated in an optimal way, and the economy is not efficient. Economists sometimes refer to this situation as a “market failure.”

In this context, it is worth noting that in popular language the terms “price” and “cost” are often used interchangeably, but in fact they are not the same. “Price” refers to the amount that a consumer agrees to pay in order to obtain a good or service. In contrast, the “cost” of a good is higher than its “price”, if externalities are present.

Including externalities in the prices of products results in an allocation of resources that is more efficient – and thus optimal – for all of society. The last section of this paper introduces some of the methods proposed by economists for achieving that end. But first, it must be recognized that even quantifying these externalities involves some challenges. The basic approach involves two steps. First, pollutant emissions are quantified and expressed in terms of their environmental impacts. Second, these impacts are “monetized”, or expressed in terms of cost. More details on both of these steps, as well as the underlying economic theory of market efficiency and externalities, are provided in the appendix.

Examples of Externalized Environmental Costs and Market Prices

This section provides four examples in which the costs of emissions externalities are estimated and compared against market prices which exclude externalities. These examples provide some hints at what may be missed when decisions are made based on market prices that do not include full environmental costs.

In all four examples, seven different environmental impacts are considered. Each of these are defined and described in greater detail in the appendix. The cost estimates for the reference pollutants for the seven environmental impacts included in this analysis are, as follows:

- Climate Change: eCO_2 -- $50 per ton for future damages caused by release of an additional ton of CO_2 equivalents during the years 2010 through 2013. This is a round number estimate based on an interpolation from a recent (2013) US federal government analysis, assuming a discount rate of about 2.6%.
- Human Health Respiratory Impacts: $ePM_{2.5}$ -- $10,000 per ton.[1]
- Human Health Non-Cancers: eT (toluene) -- $118 per ton based on non-cancer health costs of mercury emissions from coal-fired power plants.[2]
- Human Health Cancers: eB (benzene) -- $3,030 per ton.[3]

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[1] Eastern Research Group, Draft Report: Cost Benefit Analysis for Six "Pure" Methods for Managing Leftover Latex Paint - Data, Assumptions and Methods, Prepared for the Paint Product Stewardship Initiative, 2006.

[2] Jeffrey Morris, Jennifer Bagby, Measuring Environmental Value for Natural Lawn and Garden Care Practices. *International Journal of Life Cycle Assessment*, 2008, 13(3), 226-234.

[3] Eastern Research Group, *op.cit*.

- Eutrophication: eN (nitrogen) -- $4 per ton based on EPA estimate of environmental benefit breakeven point for nitrogen removal in manure runoff from confined animal feeding operations.[4]
- Acidification: eSO_2 -- $290 per ton based on 10-year average of spot market clearing prices in EPA's annual acid rain program SO_2 emissions allowance auction.
- Ecotoxicity: e2,4-D -- $3,280 per ton.[5]

These costs tend to be in the moderate or mid-range of available estimates on the environmental costs of releases for the reference pollutants for these specific environmental impacts. As is the case for carbon dioxide, as detailed in the appendix, there are much higher estimates that could be used for the environmental impact of these reference substances. There are also much lower environmental cost estimates for some of these pollutants.

1. *The Environmental Cost of Bottled Water*

Franklin Associates recently conducted a study for OR DEQ on the environmental impacts of various systems for delivering drinking water to consumers.[6] One of the scenarios examined was 16.9 fluid ounces of bottled water marketed to consumers in a lightweight polyethylene terephthalate plastic bottle. Based on the environmental impacts estimated for that scenario the externalized environmental cost of that water delivery system is approximately $0.63.

Over 91% of this environmental cost is due to the potential human non-cancer impacts of this water delivery system. Ecotoxicity accounts for nearly 6%, human cancers for 2%, and climate change impacts for 0.5%. Acidification, eutrophication and human respiratory impacts are each 0.1% or less. The human non-cancer impacts are largely driven by dioxin emissions from fuel use throughout the life cycle of this water delivery system.

The price of bottled water can vary widely, with a recent review at one large Oregon retailer revealing prices ranging from $0.12 to $0.50 per bottle (for the size and type of bottle described above). For this product, then, externalized environmental costs may well exceed the market price for the product, perhaps by as much as a factor of five. This indicates that there likely is a significant overproduction and overconsumption of this product because it is priced substantially below total costs, taking into account externalized environmental costs. Another way of viewing this is the true cost of the product is significantly higher than its market price. Individuals purchasing this product incur only a portion of the costs in terms of market prices; the remaining costs are paid by members of society at large.

2. *The Environmental Cost of Installed Nylon Broadloom Carpet*

The National Institute of Standards and Technology (NIST) in the US Department of Commerce provides an online tool, BEES (Building for Environmental and Economic Sustainability), which estimates the environmental

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[4] Morris and Bagby, *op. cit.*

[5] *Ibid*.

[6] Land Quality Division, Department of Environmental Quality, State of Oregon, *Life Cycle Assessment of Drinking Water Systems: Bottle Water, Tap Water and Home/Office Delivery Water – Revised Final Peer-Reviewed Report*, Report 09-LQ-104, prepared by Franklin Associates, A Division of ERG, Portland, OR, October 22, 2009.

impacts of many types of building materials.[7] Based on BEES outputs for nylon broadloom, one square foot of installed carpet has an externalized environmental cost of $0.62. Human non-cancers again account for a substantial portion of this product's environmental impact, 30%. However, climate change is the dominant impact, accounting for 55%, or $0.34 of the $0.62 impact. Human respiratory disease potential accounts for 9.5%, ecotoxicity 3.4% and human cancers 1.9%. Acidification and eutrophication are again inconsequential.

The BEES model also provides an estimate for the average market price for this installed nylon broadloom carpet product. That market cost estimate is $2.13 per square foot. Hence this product's externalized environmental cost is estimated at 29% of its market price.

3. *The Environmental Cost of Household Consumption*

According to Oregon's consumption-based GHG emissions inventory, Oregon household purchases, use and end-of-life management of goods and services in 2010 caused emission of 61.2 million metric tons of carbon dioxide equivalents.[8] In that year households accounted for 82% of emissions calculated in Oregon's consumption-based GHG emissions inventory. The environmental cost of these household GHG emissions is $3.4 billion at a $50 per short ton external cost for CO_2 releases to the atmosphere.

A consumption-based inventory for Washington consumers estimated emissions of pollutants with the potential to cause human health respiratory, non-cancer and cancer impacts, as well as ecotoxicity impacts, in addition to GHG emissions.[9] Based on that inventory and the environmental costs indicated above for the reference pollutants for these other four impacts, total environmental cost for the five impacts is 4.9 times higher than the cost for just climate impacts.

Assuming Oregon household consumption-based human health and ecotoxicity impacting emissions are similarly related to their climate changing emissions, external costs for Oregon consumers caused environmental costs totaling $16.6 billion in 2010. This excludes any acidification and eutrophication costs. This may not represent much of an omission judging by the negligible portion of total costs these two impacts accounted for in the examples of bottled water and carpet discussed above, although bottled water and carpet are largely not produced from agricultural feedstocks, which can contribute more significantly to eutrophication impacts.

Household final demand (economic consumption) in 2010 in Oregon amounted to approximately $119 billion. Externalized environmental costs not included in market prices paid for household purchases of goods and services, thus, amounted to 14% of final demand in 2010. It is not surprising that excluded environmental costs as a percentage of market prices are higher for bottled water and carpet than overall consumption; total household consumption includes considerable expenditures on services (health care, education, professional services, etc.), which tend to have lower emissions per dollar spent than do materials.

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[7] The BEES estimates reported here were accessed from http://www.nist.gov/el/economics/beesonline.cfm on 7-30-13.

[8] Oregon Departments of Environmental Quality, Energy and Transportation, Oregon's Greenhouse Gas Emissions Through 2010: In-Boundary, Consumption-Based and Expanded Transportation Sector Inventories, July 18 2013, Table 3.5, page 43.

[9] Jeffrey Morris, H. Scott Matthews, Development of a Consumer Environmental Index and Results for Washington State Consumers, *Journal of Industrial Ecology*, 2010, 14(1), 399-421.

4. The Environmental Cost of Disposal & Environmental Opportunity Cost of Throwing Away Recyclables

LCA and impact assessment can also be used to estimate the opportunity costs when recyclable materials from Oregon are disposed rather than recycled. The monetization of environmental impacts via the reference pollutant environmental cost estimates listed above can provide a comparison of avoided disposal and upstream manufacturing environmental costs that are not incurred when recyclable materials are diverted to recycling rather than buried or burned in disposal facilities.

Landfills and incinerators are sources of emissions of carbon dioxide, methane and other greenhouse gases.[10] They also are sources of emissions that have the potential to harm public health and ecosystems. Given the mixture of facilities serving Oregon in 2010, the average ton of Oregon-generated MSW disposed in these facilities resulted in externalized environmental costs (gross, including collection and hauling) of $16 per ton. This gross cost per ton is based on estimated human health and ecosystem damage costs from pollutants emitted by collecting, hauling and disposing of one ton of garbage in Oregon in 2010. Discussion at the beginning of this section of the white paper and the appendix describe the human and ecosystem health impacts and estimated cost for each impact that were used to calculate this $16 per ton cost of disposal. Oregon disposed of 2.4 million tons of MSW in 2010[11], resulting in total externalized costs of $40.2 million.

That gross cost, however, doesn't tell the full story. Landfills, which handled 92% of MSW disposal in 2010, act as a sink for biogenic carbon. The anaerobic conditions of modern landfills inhibit biodegradation of biogenic carbon in disposed products. For wood and newspapers, more than 80% of the biogenic carbon does not biodegrade to carbon dioxide and methane due in part to the lignin in these materials which inhibits the anaerobic organisms causing biodegradation in a landfill. On the other hand, for food wastes over 85% of the biogenic carbon does biodegrade in the landfill. Given the composition of disposed MSW one needs to take the storage of biogenic carbon in a landfill into account to properly assess the climate impact of landfills.

Furthermore some of Oregon's landfills capture some of the gas generated from the portion of biogenic carbon that does biodegrade in a landfill. The methane portion of that captured gas can be used to generate energy that displaces energy generated by combustion of fossil fuels elsewhere. The larger of the two MSW incinerators operating in Oregon in 2010 also generated energy that displaced fossil fuel generated energy.

When carbon storage and energy displacement credits are factored in, disposal of Oregon's 2010 MSW appears to shift from having environmental costs of $40.2 million to yielding a small net environmental benefit of $3.0 million.

But even that figure doesn't tell the full story, and it would be a mistake to conclude that sending MSW for disposal in landfills and incinerators is necessarily "good for the environment". These disposal methods have to be evaluated relative to other options, such as recycling and composting. Of the 2.4 million tons of Oregon MSW disposed in 2010 approximately 850 thousand, or 35%, consisted of readily recyclable or compostable materials,

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[10] Under the biogenic carbon accounting framework used for this analysis, emissions of carbon dioxide from biogenic materials landfilled or incinerated do not count as climate changing greenhouse gas emissions. Storage of biogenic carbon in landfills is a carbon sink and therefore counts as an offset to methane emissions from landfills.

[11] Oregon also disposed of another 1.6 million tons of MSW from other states in 2010.

including cardboard, newspaper, mixed paper, glass containers, PET plastic bottles, HDPE plastic bottles and tubs, plastic film, aluminum cans, tin-plated steel cans, yard debris and food scraps. The externalized environmental opportunity cost of throwing away these readily recyclable or compostable materials rather than recycling and composting them amounted to $86 million. The externalized environmental cost of collection and disposal for these materials ($6 million) plus externalized environmental costs of manufacturing products, packaging and fertilizers from virgin raw materials ($91 million), versus the externalized environmental cost of collecting, recycling/composting and shipping these materials to markets ($4 million) and manufacturing the recyclables into recycled-content products ($7 million), accounts for the $86 million opportunity cost of throwing away recyclables and compostables.

This $86 million is an opportunity cost because the opportunity to recycle and compost these materials has been lost, and as a result externalized environmental costs for managing Oregon's MSW are higher by this amount than they would be if these materials had been recycled and composted rather than thrown away.

It is important to remember that this $86 million represents the externalized environmental costs of disposing of readily recyclable and compostable materials in 2010. It does not include the financial costs of disposing of these recyclables and compostables. It is also important to remember that 65% of disposed MSW is not included in estimating the $86 million externalized cost, even though many of the materials included in this 65% are themselves recyclable and compostable (such as computers and carpet). The $86 million estimate is incomplete due in part to limitations in life cycle inventory data sets and the limited funding provided by DEQ to generate this estimate. As such, $86 million may be considered a low estimate of the opportunity cost of disposing of recyclable and compostable materials.

Possible Methods for Internalizing Externalized Environmental Costs

This section introduces several methods for mitigating externalized environmental costs.

Local zoning regulations can prevent industrial facilities from locating too close to residences or less polluting retail businesses. This won't necessarily reduce emissions from industrial facilities, but it will prevent localized externalized costs, such as local pollution from a waste incinerator.

Another regulatory approach is to impose emissions limits on businesses, households, industries and/or other economic entities whose activities result in pollutant emissions. The problems with such prescriptive approaches include lack of knowledge about emissions profiles for these economic entities and lack of information regarding the level of pollutant emissions for each entity that will yield an efficient allocation of scarce resources between production of goods and services and control of emissions. The advantages of the prescriptive approach include a higher level of certainty regarding the emissions reductions that will result.

Economists have a long history of favoring taxes and fees as a way to achieve reduced pollution and increased economic efficiency. Taxes tend to be a simpler approach to influencing pollution levels while still attaining supply-demand equilibrium in the affected markets. However, tax and other price based approaches to pollution control face the same issue of not having all the information needed to know exactly how much tax to impose to yield an efficient allocation of resources between production and pollution control. In an ideal political environment one could envision setting an initially low tax rate on production output and then gradually increasing the tax rate until pollution targets are attained and/or until supply-demand equilibrium effects get to production and pollution control levels that appear to be optimal. One problem with this approach is the difficulty of obtaining legislative approval to pursue a course that may involve increasing tax rates over time, or even fluctuations up and down in tax rates, until the desired output-pollution control equilibrium is attained, given the possibilities of overshoots as well as undershoots.

Taxes can be imposed either on products or on pollution emissions as a way to decrease the costs of externalized pollution. Products with high pollution intensities per dollar of price could be targeted first. Or pollutants that have especially high environmental costs could be targeted first if the preference is for pollution taxes rather than product taxes. Ideally, either course of action could reduce output of high pollution products and thereby lower environmental externalities. Taxes on pollutant emissions work indirectly to increase product costs and eventually result in higher product prices just as if the product had been taxed directly.

To take advantage of the opportunities for pollution reduction provided by diverting more MSW material from disposal to recycling, a tax could be added to disposal fees and gradually ramped up to attain a targeted MSW recycling rate. Or upfront taxes on products and packaging materials that end up in garbage could be used in a deposit-return system to reward product users who recycle rather than throwing those products in the garbage.

Arguably one of the most successful systems for reducing pollution has been EPA’s cap and trade program for sulfur dioxide emissions to reduce acid rain. What’s perhaps most interesting about cap and trade is that it involves both prescriptive and market price/tax approaches. The prescriptive part is the cap. EPA’s acid rain program involves a gradually lowered cap on sulfur dioxide emissions for the regulated industries such as coal-fired power plants. The market price approach part involves trading of sulfur dioxide emissions permits. For example, EPA conducts an annual auction at which sellers offer emissions permits and buyers offer to buy those permits at various prices. EPA works down the list of buy offers from highest bidder down until all the emission permits for sale are used up. The price at which this occurs is the clearing price at which all the permits offered are sold to all the buyers who bid at or above the market clearing price.

The efficiency aspect of this arrangement is that regulated facilities can determine what their costs of installing sulfur dioxide emissions controls might be and then attempt to buy permits for additional emissions from other regulated facilities. Other facilities whose pollution controls are such that they are emitting sulfur dioxide at levels below their regulated limit can sell unneeded permits to facilities wishing to buy their way to attainment of the regulatory cap. This results in overall emissions targets being achieved at the (theoretically) lowest overall cost.

The downside to cap and trade is that households and others in the neighborhood of the permit purchasers will be subject to higher levels of sulfur dioxide emissions than they would if the facility attained their mandated emissions limit. Hence there is an inevitable tradeoff between aggregate efficiency of the cap and trade system in terms of minimizing compliance costs, and the local distributional impacts that result from the attainment of aggregate minimum cost. If these distributional impacts are large enough and the pollutant has serious enough health and ecosystem impacts, then the decrease in aggregate cost for generators of the pollutant may come at the expense of overall human and ecosystem health. In other words cap and trade may not even achieve a lower level of externalized pollution costs compared with a system that simply required each regulated entity to meet its mandated emissions limit.

A non-regulatory approach specific to government purchasing would have purchasing policies that direct cost decisions to be based on full social costs, as opposed to simple market prices. This is easier to justify in the realm of public purchasing. Although it may in some cases lead to the purchase of products with higher market prices, the overall social costs of these purchases would be lower than if government simply purchased the lowest-priced goods. This approach is easier to justify in public procurement, where the purchasing entity (government) presumably has a fundamental interest in advancing overall social welfare. In contrast, if private firms engage in this approach on a voluntary basis, the higher expenses incurred may put the firm at a competitive disadvantage relative to other firms.

Conclusion

The State of Oregon is considering options to fund implementation of *Materials Management in Oregon: 2050 Vision and Framework for Action*. Several options may serve the dual purpose of not only funding this work, but also correcting (in part if not in full) existing market failures. These market failures result from the prices of goods and services not reflecting the costs of pollution paid by society. The costs of pollution associated with production and disposal of materials is significant. Current failure to account for these “externalities” results in levels of production and consumption that are not economically efficient (optimized) when viewed from the perspective of society. Internalizing these externalities holds the potential of reducing overall system costs and leading to a more optimal allocation of scarce resources.

APPENDIX

This appendix provides additional detail on several of the concepts introduced above. It is organized into three sections. First, we see how, in the absence of externalities, free markets result in prices and levels of production and consumption that maximize benefits to society as a whole. Second, it is demonstrated that in the presence of externalities, when prices fail to reflect full costs, market forces result in society as a whole being made worse off. Last, some of the methods that economists use to estimate the cost of pollution externalities are introduced.

The Assertion that Market Economies Maximize Efficiency

Economic theory asserts that a market economy with many producers and sellers for each good and service, as well as many buyers and consumers for each of those items, allocates limited resources efficiently. Efficiency here means that no alternative allocation of resources (involving different levels of production/consumption and different market prices) can make some better off without making others worse off.

The proof of this assertion about efficiency is complicated.[12] There are two important ideas that need to be proved:

1. That there exists a set of prices, one price for each and every good and service, such that every market is in equilibrium, i.e., supply is equal to demand in each market.
2. That this set of prices yields an efficient allocation of limited resources.

Assumptions regarding markets, buyers and sellers that are used to prove these two assertions are many, including that all producer/sellers and all consumer/buyers are price takers. This means that producers determine their supply decisions assuming that the amount of a good or service that they decide to sell on a market will not change the price at which they can sell that quantity. Similarly consumers assume that the amount of a good or service they decide to purchase will not change the purchase price they pay.

Another assumption regarding buyers and sellers used for proving the market efficiency assertion is that producers/sellers are profit maximizers and have technical constraints on their production that causes their costs per unit to rise as they increase the amount of the good or service they decide to produce and sell. Decreasing costs per unit can result in monopolization which contravenes the price taker assumption that is used to prove efficiency for a market economy. Similarly, consumers/buyers aim to maximize consumption benefits and have preferences for goods and services that cause their benefits per unit of a particular good or service consumed to decline as consumption goes up. In addition, the fact that producers face increasing costs as they expand output means that the value they obtain from using any particular resource declines as more of that resource is used.

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[12] Two expositions of this proof are: G. Debreu, *Theory of Value: An Axiomatic Analysis of Economic Equilibrium*, Cowles Foundation for Research in Economics at Yale University, Monograph 17, New York: John Wiley & Sons, Inc. 1959; and J. Quirk, R. Saposnik, *Introduction to General Equilibrium Theory and Welfare Economics*, Economics Handbook Series, New York: McGraw-Hill Book Company, 1968.

These decreasing returns to increased production and consumption, combined with buyers and sellers taking market prices as given, mean that producer/sellers will produce any given good up to the point at which their additional cost from producing/selling an additional unit just equals the market price. That is, producers/sellers increase output and sales up to the point at which profit on the last unit sold is zero. Producing and selling additional units will result in losses, while producing and selling fewer units will leave profits on the table.

Similarly, consumer/buyers will purchase and consume each good or service up to the point at which the value of the additional benefit from consuming an additional unit is just equal to the market price. Consuming additional units of that good or service yields a benefit value that is less than the purchase price, while purchasing and consuming fewer units means that positive consumption benefits remain to be enjoyed if additional units are purchased and consumed.

Finally, the owners of resources, such as land, labor, minerals and fuels, sell these resources to producers. These market transactions are guided toward equilibrium, where supply equals demand, by the fact that that producers will purchase resources only up to the point at which the value of the output generated from the last resource unit purchased is no less than the price they have to pay to resource owners. The resource owner/ sellers themselves are guided to this equilibrium because they also are price takers.

Producers, consumers and resource owners being price takers and facing decreasing returns means that there will be a price in each market at which all producer/sellers in that market are maximizing profits, all consumer/buyers are maximizing consumption benefits, producers are paying no more for their resource inputs than is profitable, and resource sellers are also achieving maximization of their returns to resource ownership. The competitive market system works so that all market prices move around until that sweet point set of prices is reached at which supply equals demand and all participants are satisfied because they are each maximizing their production profits, returns to resource ownership, and/or consumption benefits.

For example, if the price is too low, consumers will try to buy more than producers want to sell at that low price. This will drive up prices, until consumers are no longer willing to buy more. When the price is too high, producers will want to sell more than consumers are willing to buy. This will drive prices down. The market price will tend to move to a price where demand is equal to supply, because at that price producers are selling all they want to produce and consumers are buying all they want to consume.

Furthermore, at that equilibrium price no producer or consumer can become better off without another producer or consumer becoming worse off. For example, for producer profits to go up, their market prices would have to go up. This would make consumers worse off because their benefits from the last units of purchases would be less than the new, higher market prices. In other words, at a higher market price producers would be better off, but consumers would be worse off. Competitive markets prevent this disequilibrium scenario from persisting.

This discussion indicates that if there is an equilibrium price for every good and service, and if all these prices can all exist simultaneously, then the market economy will be efficient. (Again, “efficient” in economics means that no alternative allocation of resources can make some better off without making others worse off.) Proving that such a set of prices is possible is the difficult part of showing that a market economy can be efficient. This report will not delve into this part of the market economy efficiency proof. The interested reader is advised to refer to the extensive literature in economics on competitive equilibrium and efficiency, such as those noted in footnote 12.

The next section discusses situations in which the real world may prevent attainment of an efficient allocation of resources in a market economy.

Real World Situations That Inhibit Efficiency in a Market Economy

The real world can inhibit efficient resource allocation in many ways. For example, a single seller (monopolist) or single buyer (monopsonist) of a particular good or service will have market power that may distort prices to be too high or too low, respectively. This can cause underproduction or overproduction, respectively, of that good or service. The result is inefficient resource allocation.

One particularly troublesome situation that inhibits efficiency and optimality is when a market transaction between a producer and a consumer of an item causes uncompensated impacts, good or bad, to other producers or consumers. An often cited hypothetical example from a previous economic era is if an open hearth blast furnace for making steel locates next to a laundry that air-dries clothes (i.e., before the advent of indoor clothes driers). The soot from the coal and coke used for steel making will sully the clothes the laundry hangs out to dry. The blast furnace will not have to pay the laundry for the extra costs the laundry incurs to, for example, construct a pollution proof enclosure and method for drying clothes.

Economists describe this situation by saying that the steel mill is imposing an external cost on the laundry. The word “external” is used to indicate that the steel maker has to buy coal, coke and other steelmaking supplies from a variety of markets to produce steel, and it has to sell that steel in the steel marketplace. But, the steel maker does not have to buy soot emissions control equipment that would prevent release of the soot which sullies the laundry’s clothes drying. Rather, the laundry has to pay higher costs for clothes drying than it would if the steel maker did not emit soot pollutants.

This is called an external effect of steel making because the steel maker has externalized the costs of its air pollution onto the neighboring laundry. That is, the steel maker does not pay the costs of its pollution emissions, so somewhat like a monopsonist choosing how much pollution control equipment to buy, the steel maker chooses to buy less pollution controls than it would purchase if it did have to buy pollution controls in order to produce steel. Here the steel maker chooses to not buy any pollution controls because there is no need to have those controls in order to make steel. The result is that the steel mill’s output is higher than it would be under a competitive market economy that did somehow require that the steel maker buy pollution controls in order to make steel, or alternatively, that required the steel maker to pay for the costs of its pollution. The costs of pollution are paid for by the owner and customers of the nearby laundry, not the steel maker, and the prices that the steel maker charges for its steel do not reflect these prices. The word “externalities” has come to characterize such situations of externalizing costs onto other entities that are not compensated for costs they have to pay even though they are not parties to any of the transactions causing these costs.

There may be ways to mitigate such situations. A governmental entity that oversees steelmaking could impose a regulation requiring the steel producer to reduce its soot emissions to a level that does not cause problems for drying clothes. Or, as mentioned above, the laundry could develop methods to prevent the incursion of soot into its clothes drying operation. Another possibility is that the laundry could find that a cheaper alternative is to buy soot emissions controls for the steel maker, provided the steel maker agrees to install the controls.

The issue with having the laundry pay to control the soot pollution is that other laundries that aren't located next to steel furnaces will not have to pay soot control costs. Their profit margins will be higher. As a result, the price for laundry services may be such that the laundry next to the steel maker can't cover all its costs at the market price it receives for laundering and will be forced to close its doors.

On the other hand, if the steel maker voluntarily pays for soot pollution controls, its profits will fall relative to steel makers not controlling their emissions. This may eventually force the steel maker to go out of business due to the competitive market price it receives for steel not being high enough to cover the costs all steel makers are paying and also cover the costs of pollution controls.

A potential issue with governmental regulation to solve this problem is that the governmental entity does not know what level of soot pollution is optimal. Another way of stating this is that it is difficult to know how much less resources would be used for steel making if steel prices had to rise to compensate steel producers for the costs of controlling soot pollution. Furthermore, it is difficult for the governmental regulator to know how much resource use and output in laundering should rise to attain the optimal equilibrium in which the value at the margin of resources used in steelmaking would become equal to their value in laundering and all other productive uses for those resources. All that is known is that the level of steel production is too high, because the steel price is too low due to the steel maker not paying for soot emissions. Further, it is understood that the "price" of this steel does not reflect its true and full costs.

An example of externalities that is more realistic and also pertinent to modern times is that, in general, the health of humans and ecosystems is impacted by release of pollutants from production, use and end-of-life disposal of virtually all the goods and services people consume. In many, if not most cases, producers/sellers do not pay for costs to public health and ecosystems caused by their pollution releases. Furthermore, some goods or services are more polluting than others. Hence, externalization of pollution costs onto the general public and ecosystems means that prices for more polluting goods and services are too low and their consumption too high, compared with prices for less polluting goods and services. This means that too many limited resources are being purchased for production of highly polluting goods and services. The welfare of society as a whole is not maximized because the increased costs of pollution (health impacts, reduced resource productivity, etc.) exceed the added benefits that producers and consumers realize from the higher level of production/consumption of highly-polluting goods.

A market system which internalized the costs of pollution onto the producers of pollution would result in an efficient allocation of limited resources. I.e., a polluters-pay-for-pollution market system would be more efficient than a market system where pollution costs are externalized onto the health of the general public and ecosystems. The public has to pay increased health care costs as a result of the externalized costs of pollution. And ecosystems and the services they provide, such as cleaning air and water through natural filtration, are degraded. Internalizing the cost of pollution into market prices would increase efficiency because the prices for the more pollution intense goods and services would go up relative to the prices for the less polluting items. Demand and supply equilibrium for the former would fall, and market quantities for the latter would rise. At the same time the externalized costs to public health and ecosystems would fall to zero, as those costs would now be internalized and paid by the producers/sellers of each good and service to the extent that each item caused public health and ecosystem costs. The result would be an efficient allocation of resources.

However, we cannot say for certain that no one would be worse off if all pollution costs were internalized. It may seem obvious that most, if not all, would be better off, but it is the narrow and non-dynamic nature of the market equilibrium and efficiency results for competitive economies that makes that conclusion not readily applicable when considering changes from one set of market prices and characteristics for an economy to another set of prices and characteristics, even when the former are obviously inefficient.

For example, internalizing pollution costs will likely decrease the incomes of workers and owners in the more polluting industries as costs go up and production goes down in those industries. Prices in those industries may go up or down depending on shifts in each industry's supply and demand curves. Incomes of workers and owners in the less polluting industries likely will go in the opposite direction as output in those industries rises. With these shifts in both quantities and prices it is difficult to determine whether everyone is better off and no one worse off after internalization of pollution costs into prices of goods and services.

What can be said is that the market system with externalized pollution costs is inefficient because there is overproduction of the pollution intense goods and services and underproduction of the less polluting goods and services. The pollution intense goods and services would have internalized plus externalized costs for the last units produced and sold that are higher than their market prices by a greater amount relative to the less polluting goods and services. This is because profit maximizing producers/sellers would have produced until internalized costs of the last units equaled market price. Hence internalized plus externalized costs of those last units would be higher than market prices, and the margin by which they are higher would be larger the greater the pollution intensity of the good or service.

Taking this discussion on efficiency and externalities a bit further, it should be apparent that an efficient allocation of scarce resources is not necessarily a sustainable allocation. The efficiency principle of no one being able to be better off without someone else being worse off says nothing about the distribution of income or the distribution of those scarce resources. It says nothing about whether an economy that internalizes some or all externalized environmental costs has made everyone better off and no one worse off, nor does it necessarily provide that a given level of production and consumption can be maintained in perpetuity. In other words, efficiency may be a necessary condition for sustainability, but it is clearly not sufficient. Of the three aspects of a society that need to be considered when evaluating the society's sustainability – economy, environment and social equity, efficiency addresses mainly the first and basically ignores the third. Furthermore, given the absence of future generations in the money voting processes that determine market prices and quantities in the present, one cannot even say whether what appears to be a currently efficient allocation of scarce resources is efficient in the long run. For example, the present generation's judgment about the degree to which they are willing to pay to internalize environmental externalities may be wide of the mark in terms of the level of internalization needed to make scarce resource allocation efficient across the present and many future generations. Thus one should regard economic efficiency as an important aspect in the evaluation of a society's sustainability. But it is only one of many societal aspects that need to be considered in sustainability analyses.

The next section discusses some of the challenges in estimating the costs of pollution externalities, let alone determining what eventual impacts on economy wide employment and income would result from internalizing those externalities.

Estimating the Costs of Pollution Externalities

There are numerous challenges in estimating the cost of pollution externalities. Typically two major steps are taken. First, pollutant emissions are quantified and expressed in terms of their environmental impacts. Second, these impacts are "monetized", or expressed in terms of cost.

When it comes to quantifying the environmental impacts of different pollutants, one challenge is that any particular pollutant may have more than one environmental impact. For example, sulfur dioxide (SO_2) emissions to the atmosphere can cause human respiratory impacts because SO_2 can react with other compounds in the atmosphere to form small particles which when inhaled cause respiratory illnesses. SO_2 also is a precursor (i.e., chemical forerunner) to acid rain because it combines with water, oxygen and other chemicals in the atmosphere to form sulfuric acid. This compound then deposits on buildings, cars, and trees, as well as in waterways, causing harm to plant and animal life and buildings, among other impacts from deposition of sulfuric acid. Each of these impacts likely has a different cost per pound or ton of SO_2 emitted from a fossil fuel-fired power plant or other emissions source.

Life cycle analysis (LCA) and its impact assessments provide a methodology for converting emissions of numerous pollutants into a manageable number of mutually exclusive environmental impacts. Mutually exclusive impact categories mitigate the double counting problems that could occur with pollutants such as sulfur dioxide that can cause more than one type of environmental impact. EPA's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) model is a life cycle impact assessment tool with mutually exclusive impact categories. Although there is more than one way of expressing pollutant loads as environmental and health impacts, an exposition of the different methods is not fully relevant to this white paper. For the purpose of simplicity, we limit our discussion here to the EPA TRACI model.

TRACI provides indexing weights known as characterization factors for each pollutant that is a potential cause of each particular environmental impact. These characterization factors allow emissions of disparate pollutants that cause a particular impact to be aggregated/summed into an equivalent quantity of emissions for a single reference pollutant that also causes the particular impact.[13] This greatly simplifies reporting and analysis of

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[13] Jane C. Bare, *Developing a Consistent Decision-Making Framework by Using the U.S. EPA's TRACI,* U.S. Environmental Protection Agency, Cincinnati, OH, 2002; Jane C. Bare, Gregory A. Norris, David W. Pennington and Thomas McKone, TRACI:

different levels of pollution. By grouping pollution impacts into a handful of categories, environmental costs and benefits modeling is able to reduce the complexity of tracking hundreds of pollutants. This makes environmental impact data far more accessible to policy makers.

As an example of this aggregation technique, releases of various greenhouse gases (GHGs) -- carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and others -- cause global warming which leads to climate change. In its periodic climate change assessments the United Nations Intergovernmental Panel on Climate Change (IPCC) thoroughly reviews available scientific data to determine the strength of each pollutant relative to carbon dioxide in causing global warming. The IPCC assessment codified in TRACI estimates that over a hundred year time frame methane is 25 times and nitrous oxide 298 times more harmful than CO_2. Based on the global warming potential for each GHG pollutant, the emissions of all GHGs can be aggregated into the single reference substance CO_2. The aggregated quantity is termed carbon dioxide equivalents, denoted herein as eCO_2. This eCO_2 indicator serves as a measure for the climate change potential from releases of all GHGs.

Another example illustrates how the TRACI model avoids double counting. Substances that are scored by TRACI 2.0 for human respiratory health impacts include filterable and condensable particulate matter, SO_2, nitrogen oxides (NO_x), and total suspended particulates. These substances all have zero characterization factor scores for human health carcinogenic and toxicity impacts. What might seem like another possibility for double counting is thus avoided using the TRACI methodology.

Several examples in the next section of this paper estimate the externalized costs associated with seven different types of environmental impacts drawn from TRACI. The seven TRACI environmental impacts and the reference substance for each are:

- Climate change – the potential increase in greenhouse effects due to anthropogenic emissions. CO_2 from burning fossil fuels is the most common source of greenhouse gases (GHGs). Methane from anaerobic decomposition of organic material is another large source of greenhouse gases. The reference substance for climate change potential is carbon dioxide and the pollutants that have climate impacts are characterized and converted by the TRACI model into carbon dioxide equivalents, denoted herein by eCO_2.
- Human respiratory disease and death from particulates – potential human health impacts from anthropogenic releases of coarse particles known to aggravate respiratory conditions such as asthma, releases of fine particles that can lead to more serious respiratory symptoms and disease, and releases of particulate precursors such as nitrogen oxides and sulfur oxides. The reference substance for human respiratory disease potential is particulate matter no larger than

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The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. *Journal of Industrial Ecology* 2003, 6(3-4): 49-78; and Jane C. Bare, TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental Impacts 2.0. *Clean Technologies and Environmental Policy*, 2011, 13(5) 687-696, provide expositions on the original and latest versions of the TRACI model.

2.5 microns. Pollutants that have respiratory health impacts are converted into this reference pollutant equivalences, denoted herein by $ePM_{2.5}$.

- Human disease and death from toxics -- potential human health impacts from releases of chemicals that are toxic to humans (other than respiratory and carcinogenic effects). There are a large number of chemical and heavy metal pollutants that are toxic to humans, including 2,4-D, benzene, DDT, formaldehyde, permethrin, toluene, chromium, copper, lead, mercury, silver, and zinc. The reference substance for human toxicity potential used herein is toluene and pollutants that have human toxicity impacts are characterized and converted by the TRACI model into toluene equivalents, denoted by eT.
- Human disease and death from carcinogens -- potential human health impacts from releases of chemicals that are carcinogenic to humans. There are a large number of chemical and heavy metal pollutants that are carcinogenic to humans, including 2,4-D, benzene, DDT, formaldehyde, kepone, permethrin, chromium, and lead. The reference substance for human carcinogenic potential used herein is benzene and the pollutants that have human carcinogenic impacts are aggregated into benzene equivalents, denoted by eB.
- Eutrophication -- potential environmental impacts from addition of mineral nutrients to the soil or water resulting from emissions of eutrophying pollutants to air, soil or water. The addition to soil or water of mineral nutrients, such as nitrogen and phosphorous, can yield generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, nutrient additions tend to increase algae growth, which can lead to reductions in oxygen and death of fish and other species. The reference substance for eutrophication potential is nitrogen and pollutants that have eutrophying impacts are characterized by nitrogen equivalents, eN.
- Acidification -- potential environmental impacts from anthropogenic releases of acidifying compounds, principally from fossil fuel and biomass combustion, which affect trees, soil, buildings, animals and humans. The main pollutants involved in acidification are sulfur, nitrogen and hydrogen compounds – e.g., sulfur oxides, sulfuric acid, nitrogen oxides, hydrochloric acid, and ammonia. The reference substance for acidification potential used herein is sulfur dioxide and the pollutants that have acidifying impacts are characterized by sulfur dioxide equivalents, eSO_2.
- Ecosystems toxicity -- the relative potential for chemicals released into the environment to harm terrestrial and aquatic ecosystems, including wildlife. There are a large number of chemical and heavy metal pollutants that are toxic to ecosystems, including 2,4-D, benzene, DDT, ethyl benzene, formaldehyde, kepone, permethrin, toluene, chromium, copper, lead, silver, and zinc. The reference substance for ecotoxicity potential used herein is 2,4-D and pollutants that have toxicity impacts to ecosystems are characterized by 2,4-D equivalents, denoted by e2,4-D.

For each of these seven environmental impacts the reference substance score refers only to the appropriate specific aspect of the reference substance's impact. For example, the TRACI score for human carcinogens is measured in benzene equivalents that are based on the relative strength of each pollutant's carcinogenic effects compared to benzene's carcinogenic effects. Other effects associated with the same pollutants are expressed relative to the reference substances for other impacts for pollutants such as SO_2 that have the potential to cause more than one type of environmental impact.

Developing these reference substance scores for pollution is the first step in estimating the environmental costs of externalized pollution. The next step involves developing dollar costs for emissions of the reference substances. Available estimates for these costs for a particular reference substance vary widely. The cost of climate impacts for CO_2 emissions provides a good example of the lack of consensus on environmental costs.

The low end cost that might be used for CO_2 as the reference substance for climate change is its trading price for voluntary greenhouse gas emission reductions. Operating much as the markets in sulfur dioxide emissions permits do, markets are available for trading voluntary greenhouse gas emissions reduction pledges. Over recent years prices on voluntary markets have ranged around $5 per short ton.[14] Values on the European Union Emissions Trading System for emissions permits based on mandatory caps are higher, ranging around $20 per short ton, but fluctuating down to nearly zero and up to $35.[15] Fluctuations in the EU's carbon prices have been due to a variety of factors specific to the EU's carbon cap and trade system. In addition, the financial chaos of 2007-08 and the following recession that continues to today likely contributed to that market's instabilities. When demand for goods and services falls mandatory caps may no longer provide binding constraints that require firms to buy carbon credits in order to meet their emissions caps.[16] Hence demand to purchase credits from carbon markets falls.

Prices on both voluntary and mandatory markets for GHG emissions tend to be lower than prices derived from direct attempts to estimate the costs of climate change and relate those costs to today's emissions of GHGs. This may be a reflection of the social and political difficulties of imposing costs on today's economic activity that are based on potential future scenarios that are not well understood or universally accepted.

One example of a well-respected study is the relatively recent review of the economic costs of climate change conducted by Nicholas Stern (former Chief Economist at the World Bank). It determined that a reasonable estimate for the cost of current greenhouse gas emissions was $85 per metric ton of eCO_2. This estimate is based on the risk of catastrophic environmental impacts in the future if substantial reductions in greenhouse gas emissions are not implemented today. [17] A recent working paper that has not yet been published in the peer-

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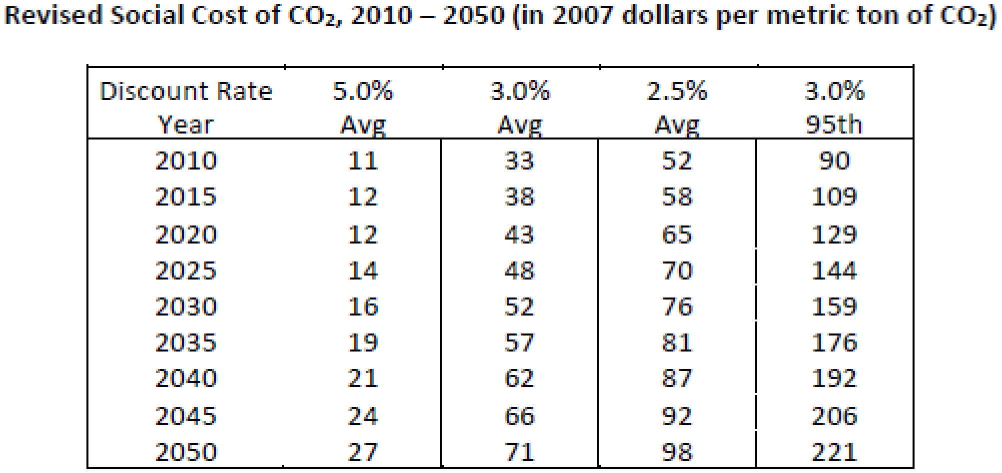
[14] Richard G. Newell, William A. Pizer, Daniel Raimi, Carbon Markets 15 Years after Kyoto: Lessons Learned, New Challenges. *Journal of Economic Perspectives*, 2013, 27(1), 123-146.

[15] Ibid.

[16] EPA's annual auction of sulfur dioxide emissions permits under its acid rain program illustrates the price volatility that can be induced in a cap and trade system as a result of economic cycles. The spot market auction clearing price was in a steady upward trajectory from $126 in 2000 to $860 in 2006. The financial crisis of 2007-08 reversed that trend with the 2007 and 2008 clearing prices falling to $433 and $380, respectively. The following Great Recession coincided with a steepening decline to $62 and $36 in 2009 and 2010, respectively. Clearing prices in the 2011-2013 auctions have been $2, $1 and $0.17, respectively.

[17] Nicholas Stern, *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge, England and New York, NY, 2007.

reviewed literature provides a very high estimate near $1,000 per metric ton of carbon dioxide equivalents.[18] On the other hand, there is a recent study that estimated GHG emissions costs to be lower than prices for emissions permits under mandatory cap and trade. That estimate is $8 per metric ton, published in an article in a prestigious economics journal.[19]



Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per metric ton of CO_2)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

Note: CO_2 costs are emissions-year specific.

Finally, The US Government's Interagency Working Group on Social Cost of Carbon recently issued its latest revision of the social cost of carbon emissions. The table above shows these latest estimates as a function of the year in which an additional metric ton of CO_2 is emitted and the social discount rate.[20,21] Because climate impact costs are projected to ramp up as time passes and the amount of CO_2 in the atmosphere increases, the discounted value of future impacts from a current year's emissions rises as years go by and those future events come ever closer. Also, the lower the discount rate the larger the present discounted value of those future costs.[22]

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[18] Frank Ackerman, Elizabeth A. Stanton, Climate Risks and Carbon Prices: Revising the Social Cost of Carbon. Stockholm Environment Institute – U.S. Center working paper, Somerville, MA, 2011.

[19] Nicholas Z. Muller, Robert Mendelsohn, William Nordhaus, Environmental Accounting for Pollution in the United States Economy. *American Economic Review*, 2011, 101 (August), 1649-1675.

[20] Interagency Working Group on Social Cost of Carbon, US Government (with participation by Council of Economic Advisers, Council on Environmental Quality, Dept. of Agriculture, Dept. of Commerce, Dept. of Energy, Dept. of Transportation, EPA, National Economic Council, OMB, Office of Science and Technology Policy, and Dept. of Treasury), Technical Support Document – Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866, May 2013.

[21] Avg in the table refers to the average future damage costs estimated by three different integrated climate impact assessment models for an increase in one metric ton of CO_2 emissions in the year indicated by the table rows. 95th refers to the damage cost for the three models at the 95% probability level, meaning that one would expect based on the models that estimated costs have only a 5% chance of being higher than this level for emissions in the year indicated by table rows.

[22] There is much debate among economists as to what the social discount rate should be, with some suggesting that the discount rate in future years should follow the declining exponential function tending toward zero for more distant years. See, for example, Paul R. Portney and John P. Weyant (eds.), *Discounting and Intergenerational Equity*, Resources for the Future, Washington, DC, 1999.

A further issue that one encounters when developing economic cost estimates for environmental impacts is that some impacts are more global and others more local. CO_2 emissions have global impacts whereas emissions of other pollutants, say chromium or cadmium or lead, likely have effects that are more severe close to the place where they are emitted, or more severe given the type of media to which they are emitted. TRACI 2.0 has begun to deal with this issue by providing separate cancer, non-cancer and ecotoxicity characterization factors for emissions to urban versus non-urban air, emissions to fresh versus salt water, and emissions to agricultural land versus non-agricultural land. Such distinctions are very useful if one knows the point source of the emissions to be characterized. They also can provide an indication of the effect that uncertainty about location of emissions can have on the estimates of environmental impact potentials.