

**Metrics for GHG and Energy
Science/Technology Committee
Oregon Global Warming Commission
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To assess the various legislative measures for reducing greenhouse gas emissions, it will be essential that we develop effective and transparent measurements and modeling approaches. For example, where do we place the “upstream” and “downstream” walls for assessing the GHG emissions of a specific activity? How do we infuse state-of-the-art observing systems yet maintain continuity with the historical record? Models are an essential component for more complex carbon release and uptake processes (e.g., growth and decay of forests). All of these techniques will need to be developed in cooperation with a broad constituency.

Evaluating climate change impacts, policies, and progress

The State of Oregon has initiated and committed itself to developing policy measures to reduce greenhouse gas (GHG) emissions by individuals, companies, and government agencies in Oregon. Lawmakers and the public will want policies to be effective at reducing GHG emissions while being consistent with other economic, social, and political objectives. Yet, precisely because efforts to manage GHG emissions are novel, the “best” policies cannot currently be identified. To be sure, careful preparatory analyses that take advantage of logic, modeling, and analogous policy experience can avoid the promulgation of foolish policies. Yet, at least three considerations -- the law of unintended consequences; shifts in economic, political, and social conditions when policies are kept in place long after they are designed; and the chance that risky “untried” policies may prove quite effective -- suggest that policies adopted today necessarily will and should involve some degree of trial and error. Thus, effective long term management of Oregon's GHG emissions will require effective and transparent monitoring, evaluation, and revision of existing GHG reduction policies. Effective policy will need to involve adaptive management that responds to new information about climate change and the policies undertaken to mitigate and adapt to it.

What should be monitored?

Oregon's research community can effectively support policymakers in developing regulatory, market-based, and other strategies for influencing the amount of GHGs large and small companies emit. This support should include a comprehensive, coordinated effort to monitor Oregon's concentrations of GHGs, emissions of GHGs, and GHG sequestration efforts while also keeping track of climate impacts, emission reduction strategies (both as written and as implemented), the behaviors targeted by those policies, and the various factors that influence both emissions and behaviors. Those measurements can facilitate a policy process that is responsive to new scientific information and promotes environmental sustainability while also providing both large and small businesses with the economic predictability essential to economic sustainability.

Monitoring GHG concentrations and net GHG emissions

An atmospheric measurement network provides one crucial element in assessing Oregon's efforts. Data from a network of several (~7) strategically-placed and well-instrumented towers, when combined with existing measurement systems and careful modeling techniques,

would allow relatively accurate estimation of net statewide GHG emissions (by comparing difference in GHG concentrations between ingoing and outgoing air masses). Adding more monitoring stations and systems to this “backbone” would allow identification of net emissions at regional scales, including urban areas (e.g., Portland, Bend, and the Willamette Valley), landfills, and important natural sources and sinks (e.g., forests, marshes, and agricultural areas). Monitoring systems could be designed to allow monitoring of smaller communities or commercial/industrial areas. Efforts in Oregon could take advantage of similar initiatives already underway nationally and in California.

Monitoring impacts of climate change

Although the policies and behaviors of Oregonians will have little influence on the impacts of climate change in Oregon, keeping track of those impacts will be a central concern of both policymakers and the public and may make a big difference in the importance and attention that we pay to climate change. Equally important, tracking sea level rise, snowpack levels, glacial melt, precipitation patterns, species migration and loss, and other indicators of climate change will be crucial to policymakers to ensure that policymakers have adequate, appropriate, and timely information to take action to adapt to and avert such impacts. Thus, monitoring current -- and accurately forecasting future -- trends in streamflow and temperature will be crucial to the future success of Oregon's agricultural sector. Likewise, monitoring annual snow melt patterns will be crucial to initiate adaptation strategies early enough to forestall the most costly impacts of climate change (e.g., building additional dams and/or developing water conservation and efficiency programs).

Tracking emission reduction policies

Keeping track of emission reduction policies is likely to be both more complicated and more crucial than it first appears. At present, emission reduction policies that have the potential to influence the behavior of Oregonians have already been adopted at the international, national, state, municipal, corporate, and individual levels. Within the state alone, GHG reduction measures have been adopted by the state legislature, by several municipalities, and by several major corporations [need to check the facts on this, but look into what actions Portland, Eugene, Bend, Intel, and Nike have taken]. Over the coming decades, many new GHG reduction policies will be adopted and current policies will be replaced or modified, at times in response to environmental concerns and at times in response to economic, political, or other non-environmental concerns. The ability to evaluate the track record of a particular policy requires comparing emissions by particular entities, sectors, or the state as a whole at a particular point in time to the policies that were in place for those actors, sectors, or the state at that same point in time. For example, domestic energy use in the future is likely to reflect the influence of state policies targeting a renewable energy portfolio, municipal construction standards regarding insulation, national appliance efficiency standards, and utility metering and energy conservation policies. It is easy to identify the current status of such policy influences on behavior but it would involve considerable effort (with only mixed results) to reconstruct accurately what those policy influences looked like five years ago, let alone twenty years ago. A systematic tracking of the status of such components over time will be necessary to accurately identify the reasons that different sectors have altered their behavior.

Monitoring emissions-producing behaviors

Calculating Oregon's net GHG emissions by monitoring ambient GHG concentrations and fluxes (cross-border transport) provides information about the aggregate effects of all emission reduction policies in place during the relevant period. But most emission reduction policies target one group of emitters more than others, for example, focusing on industry or households, manufacturing or agriculture, large or small emitters, or mobile or stationary sources. Assessing such policies accurately requires detailed measurements or accurate methods for estimating the emissions from different economic sectors and businesses. Most commercial and residential energy use is already tracked, and has been for years, at the level of individual and corporate users. With appropriate precautions taken to protect individual privacy, patterns of energy use across different sectors (including transport) and different categories of users could be identified and changes in those patterns could be assessed to determine whether their causes are due to self-conscious policy efforts or other factors.

Monitoring non-policy influences on climate-related behaviors

As the recent decline in miles driven in response to rising gasoline prices makes clear, emissions-producing behaviors may decline for reasons having nothing to do with self-conscious policy efforts. Accurately evaluating the effects of policies requires that such non-policy influences on behavior be accounted for before policy influence is inferred. A common method for evaluating policy influence involves statistical analyses designed to assess such influence on emissions behavior while “holding other factors constant.” Accomplishing the goal of “holding other factors constant” requires that such analyses include data on those other factors, i.e., the other influences on emissions behaviors. Thus, if it were 2015 and we wanted to assess the influence of efforts begun in 2005 to reduce transportation emissions, it would be helpful to have annual data on transportation emissions (from ambient monitors perhaps) as well as on gasoline consumed and miles driven, but also annual data on the average price of gasoline, characteristics of the car fleet, speed limits and enforcement policies, congestion levels, fog and ice events, and the many other influences on transportation emissions. Notably, it would be valuable to have data for all these variables beginning before 2005, to evaluate whether changes in emission levels occurred after the policy was adopted.

Monitoring other impacts of emissions reduction policies

Precisely because emissions reduction policies are likely to involve costs for those that must change their behavior as well as others, they are likely to be politically controversial. The public will want, and has a right to, information about the direct economic costs of policies as well as the more general and diffuse impacts policies have on the economy (whether serving as an economic drag or stimulus). The public will also want to know how policies designed to reduce emissions will influence non-monetizable things such as how long it takes to drive to work; the distribution of agricultural, industrial, and residential land uses; differential effects of income on different socio-economic classes, etc. Keeping track of these and other salient non-environmental “performance indicators” of emissions policies, perhaps by working with stakeholders to identify them from the outset, ensures that interested actors have accurate information on non-environmental as well as environmental aspects of policies so that tradeoffs between these different concerns can be made with the benefit of solid empirical information.

Pilot studies, experiments, comparative cases, and baselines

To truly know whether a government policy works -- i.e., to assess a policy's effectiveness -- requires initial pilot studies to evaluate approaches, or controlled experiments in which some group (of individuals, corporations, cities, counties) are subject to the policy while an otherwise-comparable group is not. A pilot study for a measurement and modeling approach to independent quantification of emissions might include a subset of measurement locations, evaluation of spatial model uncertainty, and model optimization to determine the number and locations of measurement systems that are used to inform models. An approach to evaluate policy effectiveness in terms of sociological response might involve assessment of how those subject to a policy behaved in comparison with a carefully developed and defensible baseline (or “counterfactual”) that represents how they would have behaved in the absence of the policy. We need to assess the effectiveness of state policies carefully in order to ensure the state maintains and expands the most effective ones and discontinues ineffective ones. To do that, in turn, requires designing policies at the outset to include mechanisms (whether experiments, baselines, or other strategies) that will allow careful and rigorous evaluation of their effectiveness later on. Appendix 1 is a description of a pilot observing/modeling system for Oregon.

Establishing Priorities

What steps should Oregon's scientific community take to position itself so it can provide the most useful guidance possible to Oregon's policy community in the short, medium, and long term future?

The main priority at this point should be to establish an institutional framework that initiates a dialogue through which the scientific community can better understand what information the policy community is likely to demand regarding climate change and the policy community can better understand the information that the scientific community will be able to provide regarding climate change. A working group of legislators, stakeholders, natural scientists, and social scientists could be established to develop a detailed strategy for engaging Oregon's scientific community effectively in future climate policy making. That group could explore the questions and constraints of most concern to policy makers and the extent to which a “science advising strategy” can be developed that is responsive, both substantively and temporally, to the needs of the policy community. A specific example of this approach is described in the companion piece, “Knowledge to Action Networks: A Summary.”

The Climate Impacts Group (CIG) at the University of Washington is a good example of a boundary organization that promotes and facilitates links between climate research and stakeholders. With multi-year funding from NOAA through the Regional Integrated Sciences and Assessment (RISA) program, CIG works directly with stakeholders to identify needs for seasonal climate forecast and predictions of climate impacts which are addressed through scientific research in several sectors: water resources, forest ecosystems, aquatic ecosystems, and coastal zones. They have recently added two new sectors: human health and agriculture as part of a statewide assessment of climate impacts for Washington. Partnering with CIG on the development of essential data products for monitoring would leverage Oregon's investments.

Other first steps might involve cataloguing existing resources available for the tasks delineated above. Efforts have already been made as part of Oregon's existing climate policies, as part of national efforts, and by research centers and individual scholars to measure and/or estimate Oregon's GHG concentrations and emissions as well as climate impacts in Oregon. Future efforts should build on that sound research base and involve scientists who have expertise on these questions. Efforts should also be made to identify informational resources from which

historical trends have not yet, but could be, generated. Thus, a dataset of historical energy use patterns and relative prices of different energy sources could shed light on likely impacts of different policy options while also providing the analytic foundation for evaluating the impacts of such policies as are adopted.

Identifying existing historical resources would also provide a foundation for developing a baseline suite of key environmental parameters that could be used in advising future and evaluating past policies. To the extent that new “state of the art” data collection efforts are initiated, they should be developed in such a way that the new data remains comparable with existing historical records. [The New York Times recently reported on insights into climate change made possible only because data collection of temperature and precipitation over the last 112 years (and including 41,000 daily measurements) had been made using “exactly the same” but “old-fashioned” methods (<http://www.nytimes.com/2008/09/16/science/earth/16moho.html>).]

Appendix 1

Measuring, modeling and monitoring to evaluate the effectiveness of actions taken to reduce greenhouse gases

To reduce consequences of climate change, Oregon has set targets to reduce its emissions of greenhouse gases (GHGs). By 2020, the goal is to achieve greenhouse gas levels 10% less than 1990 levels and by 2050 to achieve greenhouse gas levels 75% below 1990 levels. As actions are implemented at the individual, local community, watershed and state levels, there is a need to evaluate the effectiveness of those actions. Thus, a recommendation of the CCIG was to develop and implement a measurement and monitoring system for the Oregon Strategy for Greenhouse Gas Reductions.

State Level Plan for Atmospheric Carbon Monitoring in Oregon

There is a need to evaluate effectiveness of GHG emissions reductions, to track emissions for years to decades, and to identify areas for improvement. An atmospheric measurement network provides an ideal, independent tool for this purpose, since it monitors the levels of GHG concentrations in the atmosphere and, via transport modeling, allows linking these to the “causes” (i.e. surface GHG emissions at various spatial scales). A well-designed network will provide data at sufficient accuracy and precision for evaluating effectiveness of GHG control strategies.

Long-term atmospheric monitoring downstream of a GHG emission source will provide temporal trends of GHG concentrations and, consequently, changes in the strength of the targeted source. Since the “field of view” (or footprint) of atmospheric observations changes with the wind conditions, atmospheric transport modeling needs to be involved to identify the exact contribution of each source within the downstream area. Based on climate records, sensor positions can be optimized to provide the best amount of information on a targeted source, with a target area changing from local to regional when increasing the measurement height. Other factors influencing the observed atmospheric concentration signal, such as the varying “background” concentration of advected air masses, or the diurnal and seasonal changes in biospheric sources or sinks, will be considered as components in the comprehensive modeling framework.

Tower GHG Measurements. A nested design is envisioned for installation of instruments to quantify inputs and outputs from/to the state, and quantify the contributions of major urban areas. As the backbone of the network (state level), a “ring” of tall towers (>50m measurement height) would be installed to determine inputs and outputs from Oregon (e.g. N, S, E, W boundaries). Provided a sufficient number of towers (at least 7 for Oregon) are placed in representative locations, this setup alone would allow treating the state of Oregon as a “black box”, i.e. statewide GHG emissions could be estimated from the concentration difference of ingoing and outgoing air masses, without addressing emission patterns on smaller scales in detail. Based on this backbone, the network could be refined to provide further information on regional to local scale emission sources such as urban areas (e.g. Portland, Bend, and the Willamette Valley), landfills, or the most important biospheric sources or sinks. Statewide, we envision 5-10 additional monitoring systems customized to the targeted emission source, set up at strategic locations to complement the outer ring of towers. Depending on available funds, the network can be further refined to the local level, equipping individual smaller communities or

commercial/industrial areas with their own monitoring systems. Each site of the network outlined above would be equipped for continuous measurements of GHG (CO₂, CH₄, N₂O), and carbon monoxide (CO) as a tracer of emissions. In Oregon, methane (CH₄) may be the largest source of non-CO₂ greenhouse gas; it is mostly emitted by microbial processes associated with livestock and landfills. N₂O emissions from agricultural crops may be an issue in the Willamette Valley. California found that this source is currently estimated to be a stronger CO₂ equivalent emission than CH₄.

This approach is being currently being pursued by other states. In California, the Lawrence Berkeley National Laboratory (LBNL) initiated the California Greenhouse Gas Emissions Project (CALGEM) under contract to the State of California. Through subcontract and in collaboration with the NOAA Earth System Research Laboratory (NOAA-ESRL), the LBNL-ESRL team is now making periodic flask measurements of a broad suite of GHGs (CO₂, CO, CH₄, SF₆, H₂, and halo carbons) at two towers in the San Francisco Bay and Sacramento Valley areas, and continuous measurements of CO₂, CH₄, CO, and ²²²Rn at the Sacramento Valley tower (with CO and ²²²Rn providing information on the source of emissions and atmospheric mixing respectively). ¹⁴C isotope measurements are also made to isolate the fossil fuel component of observed CO₂ anomalies. Other chemical tracers can be correlated with the ¹⁴C depletion of CO₂. In Oregon, NOAA plans similar measurements on Mount Bachelor, which is an excellent site for measuring gases flowing over Oregon in the free troposphere. Measurements in the boundary layer can then be compared to a local reference. NOAA envisions a national program where individual states and perhaps counties start making high accuracy measurements and NOAA would provide advice, reference gases, and guidance for data quality (i.e. regular comparisons of air samples). Then the data could be used in national and global data assimilation systems.

Meteorological measurements would also be necessary at all towers for modeling (e.g. temperature, precipitation, diffuse/direct PAR, relative humidity, wind velocity, net radiation in a manner consistent with CALGEM. The measurement and modeling program should be developed as a community product, with consistency across state boundaries.

Terrestrial ecosystem sources and sinks. Terrestrial ecosystems also contribute to variation in atmospheric CO₂. To determine this component, tower flux sites that measure net exchange of CO₂ and water vapor between vegetation and the atmosphere can be used to inform models. There are three AmeriFlux sites currently operating in Oregon: Douglas-fir near the Coast Range and ponderosa pine near Sisters (funded by the US Dept of Energy). More flux sites could be added to better represent terrestrial ecosystem contributions to atmospheric CO₂ in Oregon and to understand climate effects on the ecosystems (vulnerability, sensitivity to interannual variation in climate such as prolonged drought and warmer spring weather). These data are needed to evaluate performance of models and for model-data integration in some regional to continental approaches to mapping terrestrial ecosystem carbon dioxide and water vapor exchange with the atmosphere.

Remote sensing observations. NASA plans to launch the Orbiting Carbon Observatory (OCO) satellite in late 2008, measuring atmospheric column CO₂ concentrations with 10% global coverage. This can be incorporated into the atmospheric transport modeling scheme.

Data management. There is an existing data management strategy that is very flexible and could accommodate multiple contributors and users (CarbonTracker). We have also had professional assistance in database design and management for similar datasets that is transferable.

Communication. A process needs to be developed for posing important questions to policy-makers and land managers, reframing the questions for scientists who would conduct the appropriate analysis, and communicate the results back to policy-makers and managers.

To examine distribution of emissions and determine effectiveness of actions taken to reduce GHG emissions, results from the monitoring network and modeling can be posted on a state web site (e.g. ODOE) indicating spatial distribution of seasonal to annual emissions of CO₂, and net exchange of carbon dioxide by terrestrial ecosystems.