EcoSecurities Consulting Limited
529 SE Grand Avenue
Suite 300
Portland, Oregon 97214
USA

Tel +1 503 231 2727
Fax +1 503 231 2728
www.ecosecurities.com

A Report for NWPCC

Forecasting the Future Value of Carbon

A Literature Review of Mid- to Long-Term Carbon Price Forecasts

January 30, 2009

Table of contents

1 Introduction

The Northwest Power and Conservation Council (NWPCC) is currently developing its next Northwest Power Plan. As part of this process, NWPCC is considering the impacts of climate change policy on its resource planning. This report is designed to deliver insight into how CO_2 liability costs may evolve in a carbon-constrained world, so as to assist NWPCC in incorporating potential future CO_2 liabilities into its planning process for the power system in the Pacific Northwest.

Climate change mitigation policy is evolving relatively rapidly both internationally and domestically, and the cost of complying with future greenhouse gas (GHG) emissions constraints is becoming an increasingly important consideration in evaluating the financial performance of companies, projects and investments that have significant exposure to potential GHG mandates.

As pollutants, GHGs are notable for several reasons. First, they mix effectively in the atmosphere and, indeed, any given molecule of CO_2 emitted through human activities can be shifted anywhere in the atmosphere within a matter of days. Second, GHGs tend to have long atmospheric residence times and do not quickly precipitate out of the atmosphere as do pollutants like sulfur dioxide (SO_2). Moreover, GHG emissions do not pose local health risks as do criteria pollutants (i.e. there is no risk of GHG “hot spots.”)

This combination of characteristics means that GHGs are uniquely suited to market-based approaches that achieve least-cost compliance with emission reduction mandates. This is precisely the reason emissions trading has received so much attention during the development of both domestic and international climate change policy. Properly structured, emissions trading can significantly cut the costs of achieving any given reduction target.

Emissions trading can in principle occur at multiple levels, and it is possible to envision simultaneous domestic, regional, and international trading programs. Each of these programs could, in theory, have different market clearing prices owing to different operating rules and differing access to cost-effective emissions reduction opportunities. From the standpoint of projecting carbon prices in a carbon-constrained world, however, trying to anticipate the range of potential geography- or sector-specific trading markets simply adds too much complexity to an analysis of future carbon prices, and the uncertainty bands around such projections would render the projections themselves of questionable value.

For these reasons, a relatively high-level look at GHG markets is likely to generate the most useful insight into the economic implications of future carbon constraints. An international GHG market-clearing price, for example, reflecting a market that is able to take advantage of the broadest array of emission reduction options, will reflect a conservative estimate of the economic impacts associated with any given level of carbon emissions constraint. This makes political sense since political pressures, given enough time, will likely shrink any major differential between the market-clearing prices in domestic and international GHG trading systems

There remains a good deal of uncertainty regarding the manner through which GHGs will be regulated and how the markets will respond as a result. Policy options such as cap-and-trade programs and carbon taxes offer regulatory options with distinct costs and benefits.

Debating the use of carbon taxes versus cap-and-trade programs is popular among policymakers wishing to address the issue of climate change. On the one hand, a carbon tax sets a price that regulated emitters must pay for every ton of GHG they release into the atmosphere above a given level. A cap-and-trade program, in contrast, sets a limit on GHG emissions themselves. Under a cap-and-trade, the regulating body issues “allowances” to capped entities, representing the right to emit a certain amount of GHGs. Allowance holders that reduce their emissions below this amount may sell their allowances to those who exceed their cap. Thus, a carbon tax fixes the *price* of carbon while leaving the environmental results uncertain, while a cap-and-trade program fixes the *quantity* of emissions while letting price be determined by the market.

Those who support a carbon tax consider price reliability to be of key importance. If the costs of regulation are certain, decision-makers can make investments based on predictable, long-term energy prices. They also argue that taxes are more easily implemented and more transparent than cap-and-trade systems. Cap-and-trade advocates, on the other hand, point to the political challenges associated with imposing a carbon tax significant enough to materially influence GHG emissions. Given the short window of time we have to address the climate change problem, they argue, it is better to be certain of the environmental result than of the cost.

Politicians historically favor cap-and-trade systems; the current regulatory climate—both in the United States and abroad—generally favors the development of such programs. Established systems include emissions trading under the Kyoto Protocol, the European Union Emission Trading Scheme (EU ETS), and the New South Wales (NSW) Greenhouse Gas Abatement Scheme. Within the US, two cap-and-trade systems—the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative (WCI)—are in advanced stages of development, while the proposed Boxer-Lieberman-Warner bill would establish a comprehensive federal program. The Chicago Climate Exchange (CCX), a voluntary but legally-binding cap and trade program, has been trading emission allowances among participating entities since 2003.

Despite the popularity of cap-and-trade systems as a regulatory means of managing GHGs, forecasting the future value of carbon in a carbon-constrained world is usually done through GHG price forecasting models that use a carbon tax proxy to forecast carbon prices even in a cap-and-trade scenario. This is the case because macro-economic models are the most useful way to forecast long-term carbon costs given the complexity of the impacts of a carbon constraint on national and global economies, and the many feedbacks that are involved. That said, the use of a carbon tax proxy in most modeling represents yet another complicating variable in confidently forecasting future GHG prices.

The models profiled in this review were chosen based on their relative transparency and credibility, and to reflect a range of models and approaches in order to provide a wider perspective on the forecasting of GHG prices.

2 GHG Price Forecasting Introduced

This section of the report attempts to highlight the key attributes of a variety of GHG price forecasting approaches.

2.1 The Various Approaches to GHG Price Forecasting

Many studies and observers have projected or are projecting GHG prices. These projections are commonly based on several approaches:

- *Top-down models* are usually macroeconomic in structure. Their estimates are highly influenced by economic growth, energy mix, and compliance system flexibilities assumed by the modeler. These models generally do not specifically incorporate supply and demand for carbon offsets, but instead rely on a carbon-tax proxy for purposes of estimating mitigation costs. As a result, a specific GHG “commodity” is generally not defined for purposes of these models. Top-down models often generate price projections ranging from $1 to $30 per ton, although some predict costs well in excess of $100 per ton.

- *Bottom-up models* are usually project- or technology- specific. They often utilize mitigation cost curves that suggest that large-scale mitigation is available cheaply, often less than $5/ton. These estimates, however, tend to be based on social costing rather than private cost methodologies (i.e., benefits such as the dollar savings associated with energy efficiency are included in the calculation, even though they don’t actually accrue to the private entity funding the mitigation project to generate a carbon credit). Thus, they are often hard to translate into GHG market price forecasts.

- *“By analogy” forecasting* extrapolates from experience with other environmental commodities to the GHG market. Many observers, for example, have argued that because SO_2 allowance prices were much lower than anticipated when a trading system was implemented, GHG credit prices will also fall from current levels once a formal trading system is implemented. Unfortunately, the conclusions commonly drawn from an analogy-based approach fundamentally mischaracterize the relationship between SO_2 and CO_2 emission reduction potentials. SO_2 allowance price projections, for example, were based on technology-based market clearing prices (e.g., FGD construction). Most CO2 price projections, however, are already based on assuming access to the lowest cost mitigation options, as opposed to assuming that mitigation will be accomplished through carbon capture and sequestration (CCS) or other “high tech” interventions. In terms of technologies that could cap GHG credit prices, a survey of many CO_2 avoidance technologies suggests that many technologies become available at costs of $50-100 per ton.

- *“Historical extrapolation” forecasting* is often used as the basis from which to project price trends. Given the early stages of the GHG market, however, and the fact that most of its key attributes remain to be finalized (including commodity definition, supply, and demand), looking to historical prices in voluntary or even limited regulatory markets to date is a risky approach.

- *“Expert surveys”* are often used in forecasting future GHG prices based on the premise that people familiar with the market have the most insight into where prices are likely to head. This approach, however, clearly suffers from a “groupthink” phenomenon, in which everyone tends to end up with the same forecast. In addition, it can be difficult to separate out an individual’s market projections from their own self-interest. For example, the brokerage community clearly has an interest in motivating near-term transactions by arguing that prices are rising, and that now is the time to buy. Some regulated industries in Canada and Europe have also had an interest in forecasting very high credit prices in an effort to get more generous allowance allocations or other favorable policy dispensations in the near term. Neither necessarily reflects supply and demand realities in the market.

It is important when forecasting GHG prices to understand the strengths and limitations of each approach profiled above, and the source of estimates used by advocates or in the press. Furthermore, it is important to assess how each approach can contribute to constructive policy and corporate planning and decision making. Table 1 provides a short review of the strengths and weaknesses of each approach. While each forecasting approach has its advantages, in the end none of the approaches alone is likely to be able to provide a sufficient foundation for carbon price forecasting for serious policy and corporate decision-making. A key limitation of each of these approaches is that they often do not provide a clear picture of the policy scenario associated with a given price projection. In reality, carbon markets and market-clearing prices will be profoundly dependent on the details of the policy scenario that is being implemented, since these details will largely determine both the demand for emissions reductions, and the shape of the emissions reduction supply curve. Carbon markets are truly policy-based markets, and are thus fundamentally different than conventional commodity markets.

Approach	Strengths	Limitations
Top Down Analysis	Assesses the economy-wide effects of a change in energy prices.	Does not define the project-level reductions being accomplished. Unable to differentiate between BAU and non-BAU reductions at the project level.
Bottom-up Analysis	Provides detailed insight into the mitigation opportunities of specific sector(s).	Generally unable to differentiate between BAU and non-BAU reductions. Often use social cost estimates that are difficult to compare, and don't reflect private sector investment costs. Unable to incorporate feedbacks.
Experience with Current Environmental Commodity Systems	Build upon the proven ability of trading systems to help lower overall implementation costs.	Many characteristics of the GHG market and eventual GHG commodity are fundamentally different than those encountered in previous environmental markets.
Extrapolating from Current Market Trends	Based on empirical evidence of what has been happening in the GHG marketplace.	The historic GHG market is not necessarily predictive of future GHG markets, and it does not incorporate policy decisions that will define the carbon market commodity.

Table 1: Summary Assessment of Common Approaches to GHG Price Forecasting

3 GHG Market Modeling: An Overview of Results

This section of the report reviews a range of analyses that have compared modeling results in forecasting carbon costs in a carbon-constrained world. The models discussed here are publicly available.

- The EMF 16 Study
    - Macro-economic study of a variety of models primarily producing pre-2020 carbon cost projections

- The DICE Model
    - Macro-economic model which utilizes a global average figure for emissions and project prices for a variety of scenarios out to 2025

- The CCSP Report
    - Integrated assessment using three models to predict carbon costs out to 2030, assuming alternative radiative forcing targets.

- The Pew Center Analysis
    - Report on six model outcomes (all using different assumptions) projecting the carbon costs associated with the proposed Lieberman-Warner Climate Security Act.

- The EMF 21 Study
    - Macro-economic study of a variety of models producing carbon cost projections out to 2025, assuming distinct radiative forcing targets

ECL focuses on these reports and models due to their time horizons, the variety of approaches reflected, the variety of assumptions made, and the different geographical scopes included. We have highlighted the range of predicted prices, and have included summary bullets regarding key assumptions underlying different modeling results.

3.1 Key Modeling Variables

Each model reviewed in this section differs in terms of its inherent structure. Apart from structural differences, however, several variables can be identified as the most significant in influencing estimates of the cost of achieving future carbon emissions constraints.

- *Socioeconomic assumptions, GDP growth, primary energy needs, and baseline emissions.* All other things being equal, higher GDP development, higher primary energy use, and higher baseline emissions will result in higher costs associated with achieving a given CO_2 concentration target. Reference scenarios were not identical among the models, and baseline emissions projections vary substantially.

- *Primary energy mix and available technology.* The cost of CO_2 controls also depends on the assumptions regarding the composition of the primary energy mix (i.e. fossil-fuel use vs. other fuels. The different models sometimes assume very different energy mixes, as well as energy prices).

- *Carbon sequestration and other carbon control technologies.* The third core determinant of CO_2 control costs involves differences in the assumed cost of carbon capture, and the relative reliance on this technology for CO_2 mitigation. Some models assume rapid “learning” in these two areas, and end up with much lower CO_2 control costs than models now making the same assumption.

- *Discount rates and assumptions that affect the timeframe or ease of implementing reductions.* The discount rate and timeframe over which models assume reductions to occur have a significant impact on the ultimate presumed value of carbon. Those models that assume low discount rates will typically generate higher net-present-values for carbon-credit projects, than models that assume greater discount rates for similar projects within the same time period.

3.2 GHG Price Modeling Results

3.2.1 The EMF 16 Study (1999)

The most notable macroeconomic modeling studies concentrating on the pre-2020 period were featured in Stanford University's Energy Modeling Forum (EMF) 16 study, published in 1999. (See Table 2 for a summary of the study). The EMF 16 study contained a wide range of model results associated with implementation of the Kyoto Protocol. The range of results published in the EMF 16 reflects structural differences and differences in model assumptions. Although some models featured carbon taxes for the long term (e.g., AIM, RICE), most models in this study concentrated on near-term (pre-2020) price projections. The EMF study assumed that all Annex I countries would maintain their Kyoto targets throughout the analyzed period under three market scenarios: (1) without trading, (2) with trading between industrialized countries only, and (3) with global trading. The meta-analysis provided in the 1999 study uses carbon taxes as a proxy for measuring the economic costs of implementing the Kyoto Protocol. The carbon tax proxy is intended to provide a rough estimate of how much energy prices would have to be increased in order to stabilize emissions at 7 percent below 1990 emissions by 2012.

Model	2010 Carbon Price, US$1990		
	No trading	Annex I trading	Global trading
ABARE-GTEM	87.7	28.9	6.3
AIM	41.7	17.7	10.4
CETA	45.8	12.5	7.1
G-Cubed	20.4	14.4	5.4
MERGE3	71.9	36.8	23.4
MS-MRT	64.3	21.0	7.4
RICE	51.2	16.9	4.9
Median	51.2	16.9	7.1

Table 2: EMF 16 Carbon Price Forecasts

As shown in Table 3 there is a wide variance in the anticipated carbon costs between and within the models, with a price variance of nearly $70/ton in the 'no trading' scenario alone (which effectively amounts to a carbon tax, as emitters must purchase carbon permits), and similarly-high ranges in the 'Annex I' and 'global trading' model results. This range can be partially attributed to an element of the study that fixed an absolute Kyoto target relative to the 1990 base year. Different emission growth rates assumed by the different models therefore led to divergent cost estimates.

3.2.2 The DICE Model (2008)

Unlike the Regional Integrated model of Climate and the Economy (RICE) model (included in the EMF 16 study) the Dynamic Integrated model of Climate and the Economy (DICE) model aggregates emissions data from all major countries into a global average. (See Table 3 for a summary of the DICE model outputs.) DICE's near-term projections consider various scenarios for global carbon (Nordhaus, W., "A Question of Balance: Weighing the Options on Global Warming Policies," 2008), including prices for carbon where atmospheric stabilization occurs at 1.5, 2, and 2.5 times the current concentration of CO_2; various levels of increased temperature; Kyoto Protocol outcomes that include US participation and no US participation; and a number of carbon control proposals. Model results are detailed in Table 3 below.

Policy	Carbon Price, US$2005		
	2005	2015	2025
No controls			
250-year delay	0.02	0.01	0.01
50-year delay	0.02	0.01	0.01
Optimal	7.43	11.42	14.55
Concentration limits			
Limit to 1.5x CO_2	39.25	67.47	114.96
Limit to 2x CO_2	7.97	12.29	15.99
Limit to 2.5x CO_2	7.43	11.42	14.55
Temperature limits			
Limit to 1.5°C	29.02	47.60	73.28
Limit to 2°C	12.34	19.57	27.86
Limit to 2.5°C	8.53	13.21	17.45
Limit to 3°C	7.60	11.69	14.98
Kyoto Protocol			
Kyoto with US	0.02	4.09	4.28
Kyoto without US	0.02	0.43	0.29
Strengthened	0.02	5.40	14.48
Stern Review	67.84	91.66	111.36
Gore proposal	6.81	25.65	72.13
Low-cost backstop	1.36	1.33	0.75

Table 3: DICE Carbon Price Forecasts

In Table 3, the scenarios examined fall into seven general categories: no controls, optimal policy, concentration limits, temperature limits, Kyoto Protocol, ambitious proposals, and low-cost backstop technology. The following is a brief recap of the elements in Table 3:

- The 'No Controls' scenarios assume that governments take no action to stem carbon emissions.

- The 'Optimal Policy' scenario balances mitigation costs with the probable long-term damages from climate change (this scenario is based on an assumption of 100% participation and compliance).

- The ‘Concentration Limits’ and ‘Temperature Limits’ scenarios assume concentration limits of 1.5, 2, and 2.5 times preindustrial levels (420ppm, 560ppm, and 700ppm respectively) and temperature restraints of 1.5°C, 2°C, 2.5°C, and 3°C.

- The three ‘Kyoto Protocol’ scenarios profiled in this study include one in which current emission restrictions are extended out to the end of the modeling period and the United States *does* participate, one with Kyoto restrictions extended while the US does *not* participate, and one that assumes a strengthened Protocol with greater country participation (every region apart from sub-Saharan Africa) and greater emission reduction obligations (10% to start, and an additional 10% every 25 years).

- The ‘Ambitious Proposals’ scenarios (so called due to their requirement for material emission reductions within the short term) comprise suggested action plans from the *Stern Review* and from Al Gore.

- The ‘Stern Review’ scenario assumes the future damage from climate change to be material; this is reflected through a comparatively low discount rate in its model run. The Gore scenario assumes a 90% emission-control rate by 2050, and that country participation in the reduction scheme becomes universal within the same time period.
  The ‘Low-cost Backstop’ scenario models the repercussions of a climate-friendly technology that can replace fossil fuel use at comparable costs. The numbers are low given the relative “cheapness” of the technologies assumed.

3.2.3 The CCSP Report (2007)

The Climate Change Science Program’s (CCSP) “Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations” employs three integrated assessment models—the Integrated Global Systems Model (IGSM), the Model for Evaluating the Regional and Global Effects (MERGE) of GHG reduction policies, and the MiniCAM Model—to analyze the effect of four increasingly-stringent radiative forcing targets in the year 2100. (See Table 4 for a summary of the CCSP report.) The targets range from 3.4 W/m^2, 4.7 W/m^2, 5.8 W/m^2, and 6.7 W/m^2. (Watts per square meter is a measure of energy in a given area.) These targets translate roughly into CO_2 concentrations of 450, 550, 650, and 750 ppm respectively. It should be noted that these equivalencies are approximate and tend to vary among the models. Each model has different assumptions regarding the quantity and behaviour of the GHGs that would lead to these levels. The MERGE model utilized in the CCSP report is an updated version from that used in the EMF 16 study.

Model	Carbon Price, US$2000			
	6.7 W/m^2	5.8 W/m^2	4.7 W/m^2	3.4 W/m^2
2020				
IGSM	4.9	8.2	20.4	70.6
MERGE	0.3	0.5	2.2	30.0
MiniCAM	0.3	1.1	4.1	25.3
2030				
IGSM	7.1	12.0	30.5	104.6
MERGE	0.5	1.1	3.5	52.0
MiniCAM	0.5	1.9	7.1	46.3

Table 4: CCSP Carbon Price Forecasts

The range in carbon prices in the CCSP report stem from the differing assumptions that form the basis of each of the models used for the study. Each model worked with different expectations regarding probable CO_2 emissions over the next century, the role that technology will play, and the ease of mitigating non-CO_2 greenhouse gases.

3.2.4 Pew Center Analysis (2008)

A Pew Center analysis of the recent Lieberman-Warner Climate Security Act (an amended version of which was recently proposed to Congress) compares allowance price estimates derived from each of the models listed in Table 5. Lieberman-Warner would reduce emissions to 71% below the 2005 level by 2050 through caps on coal-consuming and high-emitting entities (facilities that use over 5,000 tons of coal or over 10,000 t CO_2e of GHGs per year), and those entities producing or importing certain fuels. Flexible mechanisms included in the Act include the trading, banking, and (limited) borrowing of allowances, the limited use of offsets, and limited linkages with international carbon trading systems.

Model	Carbon Price US $2005	
	2020	2030
EIA: Core Scenario	29	59
CATF	22	48
ACCF/NAM: Low Cost	52	216
ACCF/NAM: High Cost	61	257
MIT: Offsets + CCS	58	86
EPA (ADAGE): Scenario 2	37	61
EPA (ADAGE): Scenario 10	28	46
CRA: Scenario with Banking	58	84

Table 5: Lieberman-Warner Compliance Carbon Price Forecasts

Prices in Table 5 range from $22 to $61 per t CO_2 in 2020 and $48 and $257 per t CO_2 in 2030. This variation can be accounted for in a number of ways: the models each used different assumptions regarding the use of offsets, for example (the CATF model assumed that up to 30% of emissions could be covered with offsets, while the ACCF/NAM model's high-cost scenario assumed only 14%), and each used a different assumption regarding the role of technology, banking, and the use of revenues from the auctioning of allowances.

3.2.5 EMF 21 Model (2006)

Stanford University's Energy Modeling Forum (EMF) 21 study features the most relevant macro-economic studies regarding the post-2020 period (Weyant, J.P., "Overview of EMF-21: Multigas Mitigation and Climate Policy," Energy Journal, Volume 27—Multi-Greenhouse Gas Mitigation and Climate Policy Special Issue, 2006). (See Table 6 for a summary of the EMF 21.) The modeling teams in the EMF 21 study ran two main scenarios:

1. An emission target for the year 2150 that stabilizes radiative forcing at 4.5 W/m^2 using only CO_2 mitigation, and

2. An emission target for the year 2150 that stabilizes radiative forcing at 4.5 W/m^2 using multi-gas mitigation.

Model	2025 Carbon Price, US$2000	
	CO_2 only	Multigas
AIM	30.52	17.71
AMIGA	19.75	13.35
COMBAT	21.58	18.31
EDGE	1.50	0.79
EPPA	30.16	11.50
FUND	131.39	107.36
GEMINI-E3	24.22	8.58
GRAPE	3.38	1.88
GTEM	59.86	32.59
IMAGE	27.74	14.47
IPAC	23.84	10.22
MERGE	6.21	2.92
MESSAGE	11.47	3.57
MiniCAM	6.84	2.78
PACE	0.76	0.41
POLES	23.46	14.69
SGM	62.94	17.71
WIAGEM	11.31	4.41
Mean	27.60	15.75

Table 6: EMF 21 Carbon Price Forecasts for 2025

The models employed in EMF 21 each operate based on a different set of assumptions regarding future population estimates, energy prices, economic growth, technology advancements, and mitigation options. Baselines varied accordingly among the models: models such as AIM, IMAGE, IPAC, and MESSAGE project that emissions will be roughly twice their current level by 2100, while models such as FUND project emissions will be 5 times their current level within the same time period. Treatment of "natural" (i.e., non-anthropogenic) emissions was similarly varied, and led to considerable differences between carbon price projections.

4 Conclusions

The highest price projection found in this survey resulted from the ACCF/NAM model, estimating that a carbon price of $257 would be needed by 2025 to accomplish the emissions reduction objective in its “High Cost” scenario. This model’s “High Cost” scenario assumed that only 14% of GHG emissions could be offset, while the remaining emissions had to be internally mitigated. This scenario also strictly limited the rate at which technologies are developed and implemented, including a constraint on nuclear by allowing only 10-25 GW of additional capacity by 2030.

The lower price projections profiled in this report resulted from the PACE model, estimating that a carbon price of only $0.41 would be needed by 2025 to accomplish the emissions reduction objective in its “Multigas” scenario, and the MERGE and MiniCAM models, estimating a required carbon price of only $0.30 in 2020 for the “6.7 W/m2” scenario. The PACE model gave low values partially as a result of assuming a relatively low GHG emissions baseline and emissions growth over time.

This survey provides useful insight into the range of carbon values that are being talked about in the medium- to long-terms, and some of the key assumptions that contribute to this range, including:

- Socioeconomic Baseline and Associated GHG Emissions
- Emissions Reduction Target, Timeframe of Analysis, and Geographic Scope
- Covered GHG Gases
- Carbon Tax vs. Cap and Trade
- Emissions Trading Rules, Including Access to Carbon Offsets
- Technology Advancement Rates and Associated Mitigation Costs

The survey illustrates that the range of forecasts is wide, based on variations not only in the structure of the models, but in the treatment of key variables. It should not be surprising that based on widely varying inputs and assumptions, different models will give very different results. It would therefore be a mistake to draw the conclusion from this survey that carbon price forecasting is fundamentally so uncertain that we can’t learn anything from it. As one zeroes in on a specific set of assumptions, many of the model results become much more consistent.

Making GHG market modeling useful for corporate and policy planning purposes requires building a preferred policy scenario around which a market forecast can be built. With a detailed enough specification of key policy and market variables, one can often generate a Best

Available Forecast that can provide considerable insight into how carbon markets may function to generate carbon prices in such a scenario. EcoSecurities Consulting Ltd. was not asked to develop such a scenario or forecast for NWPCC, although one of the reports prepared for NWPCC does profile potential carbon prices under a variety of high-level policy scenarios.

Annex 1 GHG Price Modeling Featured in the EMF 16 and 21 Studies

Acronym	Full Model Name	Author(s)/Home Institution(s)	Featured In
ABARE-GTEM	Global Trade and Environment Model	B. Fisher and V. Tulpulé	EMF 16
AIM	Asian Pacific Integrated Model	M. Kainuma, T. Morita, T. Masui, K. Takahashi (NIES) and Y. Matsuoka (Kyoto University)	EMF 16, EMF 21, and EMF 19 (not discussed in this report)
AMIGA	All Modular Industry Growth Assessment	D. Hansen (Argonne National Laboratory, U.S.), J. Laitner (U.S. EPA)	EMF 21
COMBAT	Comprehensive Abatement	H.A. Aahaim, J.S. Fuglestvedt, and O. Godal (CICERO, Norway)	EMF 21
EDGE	European Dynamic Equilibrium Model	J. Jensen (TECA TRAINING ApS)	EMF 21
EPPA	Emissions Projection & Policy Analysis Model	J. McFarland, J. Reilly, H. Herzog (MIT)	EMF 16, EMF 21, and EMF 19 (not discussed in this report)
FUND	Climate Framework for Uncertainty, Negotiation, and Distribution	Richard Tol (Economic and Social Research Institute, Ireland and Hamburg, Vrije & Carnegie Mellon Universities)	EMF 21
GEMINI-E3	General Equilibrium Model of International Interaction for Economy-Energy-Environment	A. Bernard (Min. of Equipment, Transport, and Housing, France), M. Vielle (CEA-LERNA, France), and L. Viguier (HEC Geneva and Swiss Federal Institute of Technology)	EMF 21
GRAPE	Global Relationship Assessment to Protect the Environment	A. Kurosawa (Institute of Applied Energy, Japan)	EMF 16, EMF 21, and EMF 19 (not discussed in this report)
GTEM	Global Trade and Environment Model	G. Jakeman and B. Fisher (Australian Bureau of Agricultural and Resource Economics)	EMF 21
IMAGE	Integrated Model to Assess The Global Environment	D.P. van Vuuren, B. Eickhout, P.L. Lucas and M.G.J. den Elzen (National Institute for Public Health and the Environment, The Netherlands)	EMF 21
IPAC	Integrated Projection Assessments for China	K. Jiang, X. Hu, & S. Zhu (Energy Research Institute, China)	EMF 21
MARIA	Multiregional Approach for Resource and Industry Allocation	S. Mori (Tokyo University) and T. Saito (Hitachi)	EMF19 (not discussed in this report)
MERGE	Model for Evaluating Regional and Global Effects of GHG	A. Manne (Stanford University) and R. Richels (Electric Power Research Institute)	EMF 16, EMF 21, and EMF 19 (not

	Reductions Policies		discussed in this report)
MESSAGE	Model for Energy Supply Strategy Alternatives and Their General Environmental Impact	K. Riahi, L. Schrattenholzer (ECESP) and E. Rubin, D. Hounshell (Carnegie Mellon University) and M. Taylor (UC Berkeley)	EMF 21 and EMF 19 (not discussed in this report)
MiniCAM	Mini-Climate Assessment Model	J. Edmonds, J. Clarke, J. Dooley, S. Kim, Steven Smith (University of Maryland)	EMF 21 and EMF 19 (not discussed in this report)
PACE	Policy Analysis with Computable Equilibrium	C. Böhringer, (University of Heidelberg), A. Löschel (Centre for European Economic Research – ZEW, and T. Rutherford (University of Colorado)	EMF 21
POLES	Prospective Outlook on Long-Term Energy Systems-Global Emissions Control Strategies	P. Criqui (Institute of Energy Policy and Economics, France), Peter Russ (EC- Institute for Prospective Technological Studies, Spain), and Daniel Deybe (EC Environment DG)	EMF 21
MS-MRT	Multi-Sector – Multi-Region Trade Model	Charles River Associates, University of Colorado	EMF 16
Oxford	Oxford Economic Forecasting	Oxford Economic Forecasting	EMF 16
RICE	Regional Integrated Climate and Economy Model	Yale University	EMF 16
SGM	Second Generation Model	Batelle Pacific Northwest National Laboratory	EMF 16
TIMER	TARGETS-IMAGE Energy Regional model	D. van Vuuren, B. de Vries, B. Eickhout, T. Kram (National Institute of Public Health and the Environment)	EMF 19 (not discussed in this report)
WIAGEM	World Integrated Applied General Equilibrium Model	C. Kemfert (German Inst. of Economic Research & Humboldt University), T. P. Truong (Univ. of New South Wales, Australia) and T. Bruckner (Institute for Energy Engineering, Tech Univ, Germany)	EMF 21
WorldScan	WorldScan	Central Planning Bureau (Netherlands)	EMF 16