

Global Change Assessment Model (GCAM) Tutorial

Page Kyle, Gokul Iyer, Haewon McJeon, Pralit Patel
GCAM Community Modeling Meeting
Joint Global Change Research Institute
College Park, MD

October 22, 2014

General Outline

- ▶ Preliminary: Software to Download
- ▶ Part 1: Running the GCAM Reference Scenario
 - Location of key files
 - How to run the model
 - Looking at, interpreting, and exporting the output
- ▶ Part 2: Running alternative scenarios
 - Adding new “add-on” files to the configuration
 - Running policies: advanced technology, carbon emissions pricing, and carbon emissions constraints
 - Running many scenarios in batch mode
- ▶ Part 3: Changing input files
 - CSV->XML conversion
- ▶ Part 4: Debugging
- ▶ Part 5: Theory and meaning of parameters
- ▶ Appendix: Additional resources

Preliminary: software to download

- ▶ GCAM: <http://www.globalchange.umd.edu/models/gcam/download/>
- ▶ Java Runtime Environment (64 bit)
<http://www.java.com/en/download/manual.jsp>
- ▶ To compile GCAM code:
 - Windows: Visual C++ Redistributable (x64):
<http://www.microsoft.com/download/en/details.aspx?id=14632>
 - Mac: Xcode: <https://developer.apple.com/xcode/downloads/>

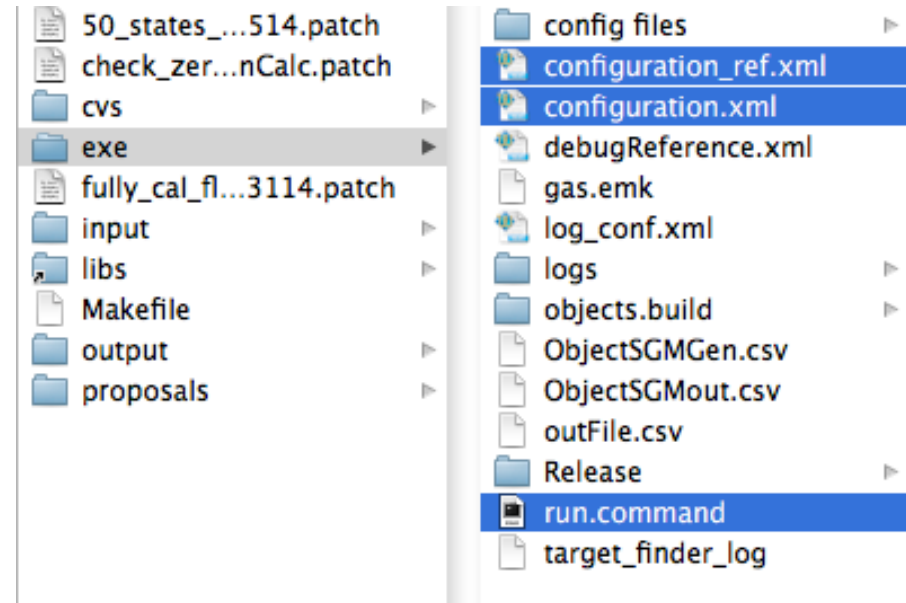
Optional but helpful

- ▶ XML files will open in a text editor, but better options exist
 - Windows: XML Marker: http://symbolclick.com/xmlmarker_1_1_setup.exe
 - Mac: XML Author (costs ~\$500): <http://www.oxygenxml.com/>
 - Mac: TextWrangler:
<http://www.barebones.com/products/textwrangler/download.html>
- ▶ A program to diff files
 - Windows: WinMerge: <http://winmerge.org/downloads/>
 - Windows: Tortoise SVN: <http://tortoisesvn.net/downloads>
 - Mac: DiffMerge: <https://sourcegear.com/diffmerge/downloads.php>

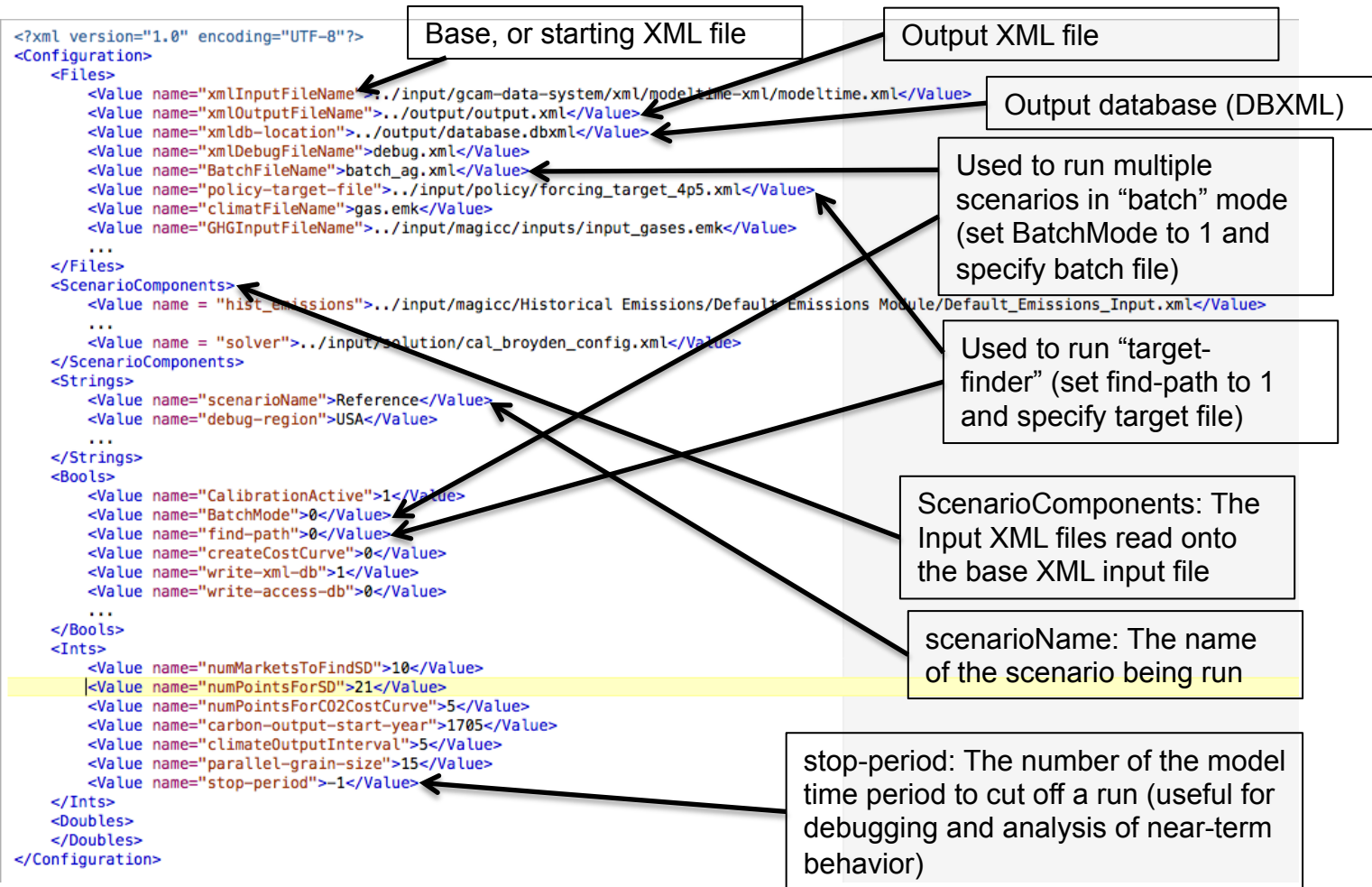
1: Running the Reference Scenario

- 1) Navigate to the exe folder
- 2) Open configuration_ref.xml
 - This is a base configuration file that reads in files for the reference, or main, scenario
- 3) Save this as configuration.xml
 - This is the control file that is called when the model is run; the configuration.xml file itself is usually over-written each time a new scenario is run. Configuration files that one wants to keep permanently should be saved under a different name
- 4) Windows: Double-click Objects.exe
 - 1) This is the executable file that runs GCAM
- 4) Mac: Double click run.command
 - 1) This will run Release/objects, the executable

Debug	4/25/2012 2:15 PM	File folder	
logs	4/25/2012 2:15 PM	File folder	
Release	6/28/2012 5:10 PM	File folder	
socioeconomics-agmip	4/25/2012 11:40 AM	File folder	
batch_ag.xml	11/2/2010 5:23 PM	XML File	2 KB
batch-csv-out.csv	8/28/2012 7:34 PM	Microsoft Excel Com...	0 KB
configuration.xml	6/28/2012 2:22 PM	XML File	6 KB
configuration_ref.xml	5/26/2012 2:34 PM	XML File	8 KB
dependency_finder_log	8/28/2012 7:35 PM	File	92 KB
dependency_finder_log2	2/6/2012 8:05 PM	File	93 KB
gas - Copy.emk	2/2/2012 5:24 PM	EMK File	18 KB
gas.emk	7/11/2012 12:09 PM	EMK File	25 KB
libdb48.dll	6/2/2011 2:52 PM	Application extension	1,276 KB
libdbxml25.dll	6/2/2011 2:52 PM	Application extension	1,757 KB
log_conf.xml	2/28/2012 6:03 PM	XML File	3 KB
MAGOUT.CSV	2/8/2011 10:55 AM	Microsoft Excel Com...	22 KB
ObjectSGMGen.csv	7/11/2012 12:09 PM	Microsoft Excel Com...	1 KB
ObjectSGMout.csv	6/27/2012 4:35 PM	Microsoft Excel Com...	1,991 KB
Objects-Main.exe	5/9/2012 12:35 PM	Application	2,178 KB



1: The configuration file



XML: a hierarchical structure for storing information

- Flexible
- Data in attributes (e.g. name=) and nodes may be used
- Note: the file above is excerpted, excluding many of the input files (under ScenarioComponents), and ancillary parameters that are never changed

restrictions or regulations (collectively the 'Export Laws'). Export of the Software may require some form of license or other authority from the U.S. Government, and failure to obtain such export control license may result in criminal liability under U.S. laws. In addition, if the Software is identified as export controlled items under the Export Laws, User represents and warrants that User is not a citizen, or otherwise located within, an embargoed nation (including without limitation Iran, Syria, Sudan, Cuba, and North Korea) and that User is not otherwise prohibited under the Export Laws from receiving the Software.

Copyright 2011 Battelle Memorial Institute. All Rights Reserved.
Distributed as open-source under the terms of the Educational Community License version 2.0 (ECL 2.0). <http://www.opensource.org/licenses/ecl2.php>

For further details, see: <http://www.globalchange.umd.edu/models/gcam/>

Running GCAM model code base version 4.0 revision 5450

Parsing input files...

Parsing ../input/magicc/Historical Emissions/Default Emissions Module/Default_Emissions_Input.xml scenario component.

Parsing ../input/gcam-data-system/xml/socioeconomics-xml/interest_rate.xml scenario component.

Parsing ../input/gcam-data-system/xml/socioeconomics-xml/socioeconomics_GCAM3.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/resources.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/en_supply.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/en_transformation.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/electricity.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/heat.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/hydrogen.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/en_distribution.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/industry.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/industry_incetas_gcam3.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/cement.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/cement_incetas_gcam3.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/en_Fert.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/HDDCDD_constdd_no_GCM.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/building_det.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/transportation_UCD.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/Ccoef.xml scenario component.

Parsing ../input/gcam-data-system/xml/energy-xml/Cstorage.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/ag_For_Past_bio_base.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/ag_cost.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/ag_prodchange_ref.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/resbio_input.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/an_input.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/ag_Fert.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/land_input_1.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/land_input_2.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/land_input_3.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/protected_land_input_2.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/protected_land_input_3.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/bio_hi.xml scenario component.

Parsing ../input/gcam-data-system/xml/aglu-xml/demand_input.xml scenario component.

Parsing ../input/solution/cal_broyden_config.xml scenario component.

XML parsing complete.

Starting a model run. Running all periods.
Model run beginning.
Period 0: 1975
Creating an uninitialized logger kate_log
Model solved with last period's prices.

Period 1: 1990
Model solved normally. Iterations period 1: 148. Total iterations: 149

Period 2: 2005
Model solved normally. Iterations period 2: 60. Total iterations: 208

Period 3: 2018

► Command prompt/terminal window contains log messages

► These are also written out to exe/logs/main_log.txt

► Input files are read in the order that they appear in the configuration.exe file.

► Where multiple files refer to the same parameter, the last one read in is the one whose value is used.

► Recursive and dynamic: each period is solved independently, but information from one period is passed forward to the next

► Deterministic: rerunning the model with no changes to input files will produce exactly the same outcome

1: Output

► Two forms of output

■ The XML output files

- output/output.xml (filename set in configuration.xml)
 - ◆ Merges all XML input files (XMLInputFileName and files in ScenarioComponents), with calibrated share-weights, in a new xml file
 - ◆ This can be used as a base input file for another run. Because the share-weights are calculated from actual base year shares, re-running this output.xml file with calibration off will reproduce the results
- exe/debugScenario.xml (filename set in config and merged with scenario name)
 - ◆ This writes out at the end of each time period, and contains a larger number of parameters for debugging
 - ◆ It is only written for one region, set in the configuration file

■ The output database

- output/database.dbxml (filename set in configuration.xml)
- Contains the results from the scenario in a database that can be queried



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

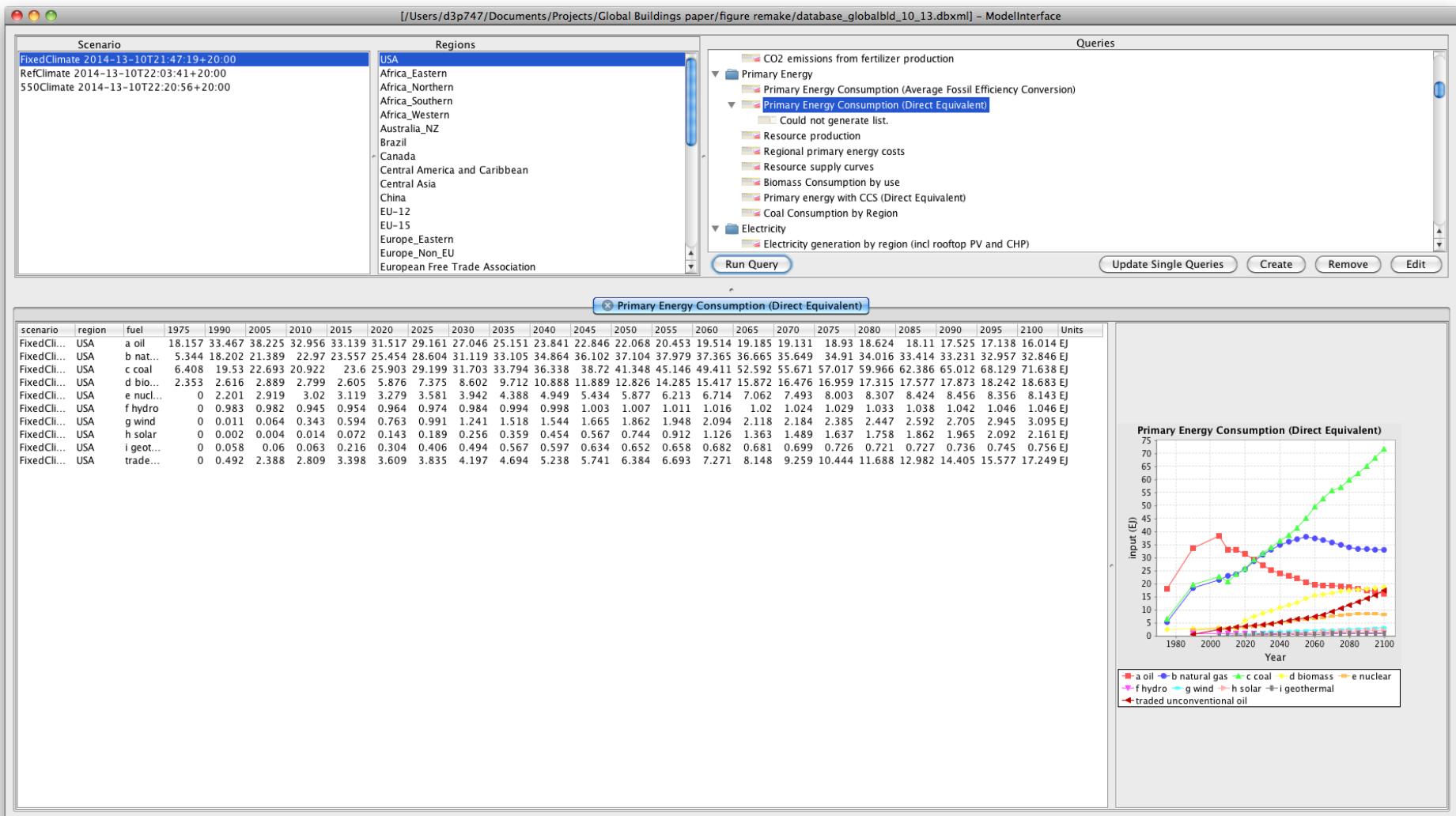
1: XML output

```
<?xml version="1.0" encoding="UTF-8">
<scenario>
  <modeltime>
    <start-year time-step="15">1975</start-year>
    <final-calibration-year>2010</final-calibration-year>
    <end-year>2100</end-year>
    <inter-year time-step="5">2005</inter-year>
  </modeltime>
  <world>
    <MagiccModel>
      <last-historical-year>2005</last-historical-year>
      <bc-unit-forcing>0</bc-unit-forcing>
      <carbon-model-start-year>1705</carbon-model-start-year>
    </MagiccModel>
  </world>
</scenario>
```

- Data from the XML files read into the ScenarioComponents is written out in the output.xml file

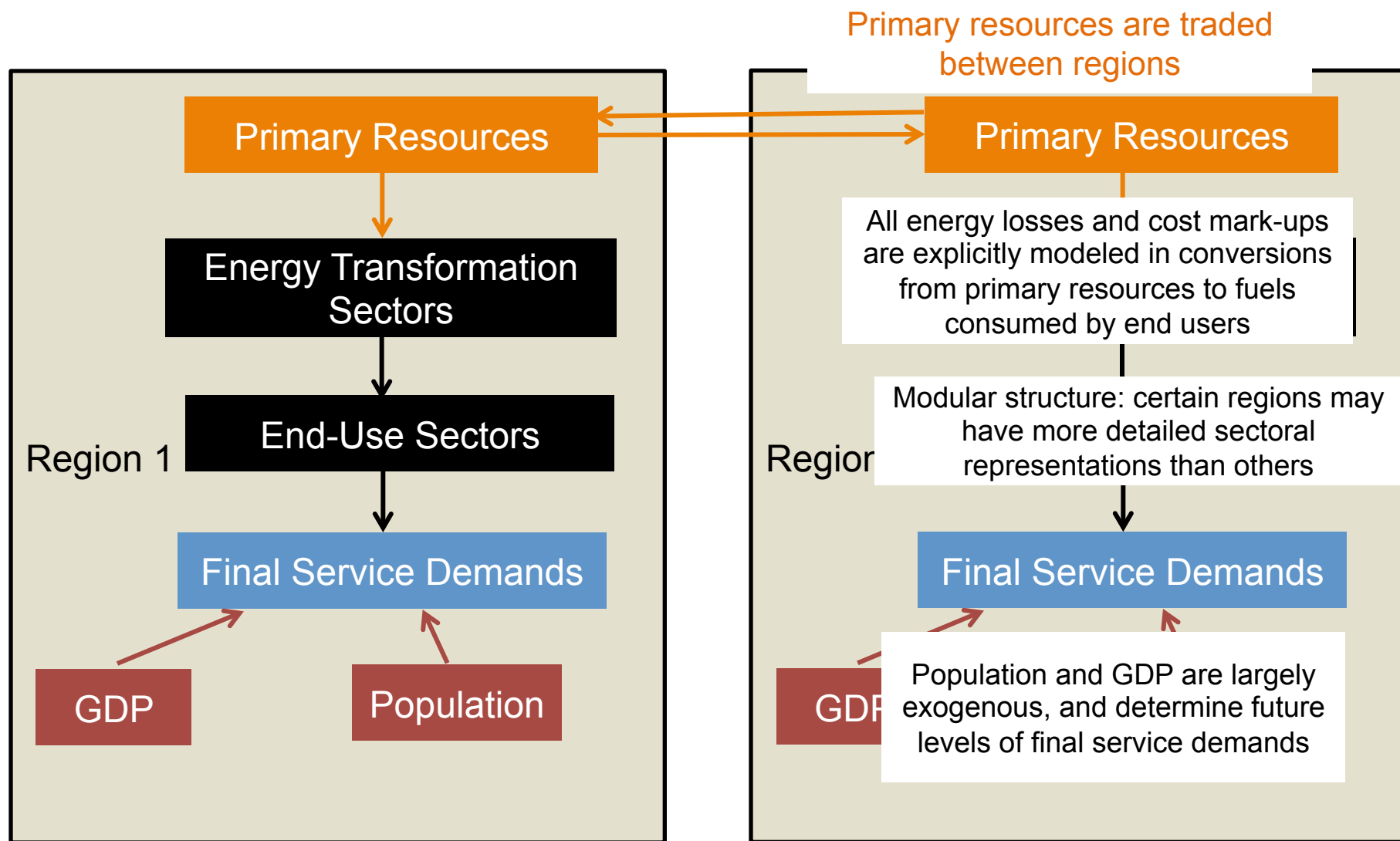
```
<?xml version="1.0" encoding="UTF-8">
<scenario name="Reference" date="2014-10T11:29:44-04:00">
  <modeltime>
    <start-year time-step="15">1975</start-year>
    <inter-year time-step="5">2005</inter-year>
    <end-year>2100</end-year>
    <final-calibration-year>2010</final-calibration-year>
  </modeltime>
  <world>
    <global-technology-database>
      <location-info sector-name="Beef" subsector-name="Imports">
        <technology name="Imports">
          <period year="1975">
            <lifetime>-1</lifetime>
            <CO2 name="CO2">
              <emissions-unit>MTC</emissions-unit>
            </CO2>
            <renewable-input name="renewable">
              </renewable-input>
            </period>
            <period year="1975">
              <share-weight>0</share-weight>
            </period>
            <period year="1990">
              <lifetime>-1</lifetime>
              <CO2 name="CO2">
```


1: DBXML output

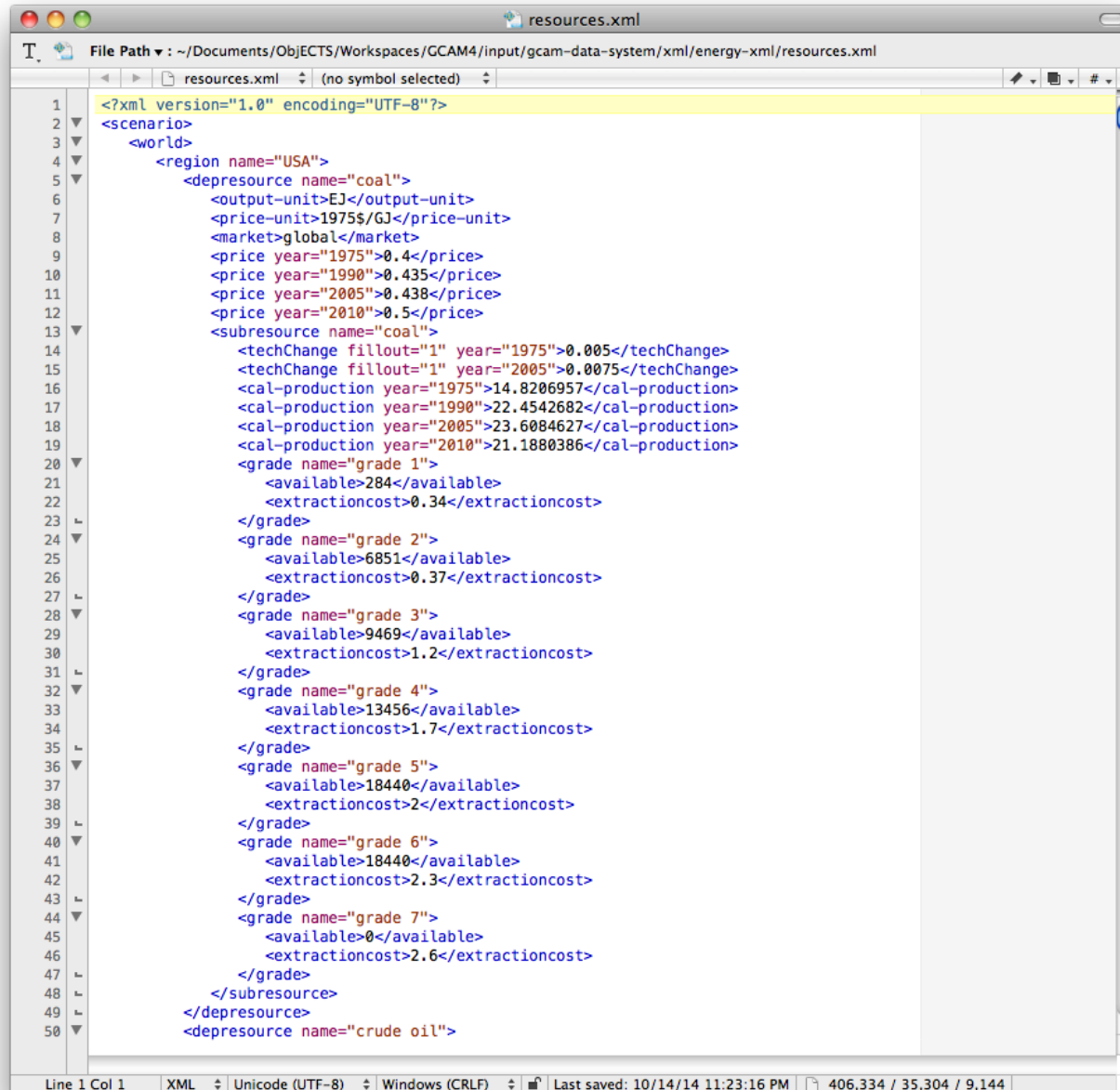


- ▶ Open ModelInterface/ModelInterface.jar
- ▶ File -> Open -> DB Open
- ▶ output/database.dbxml

1: General energy system structure



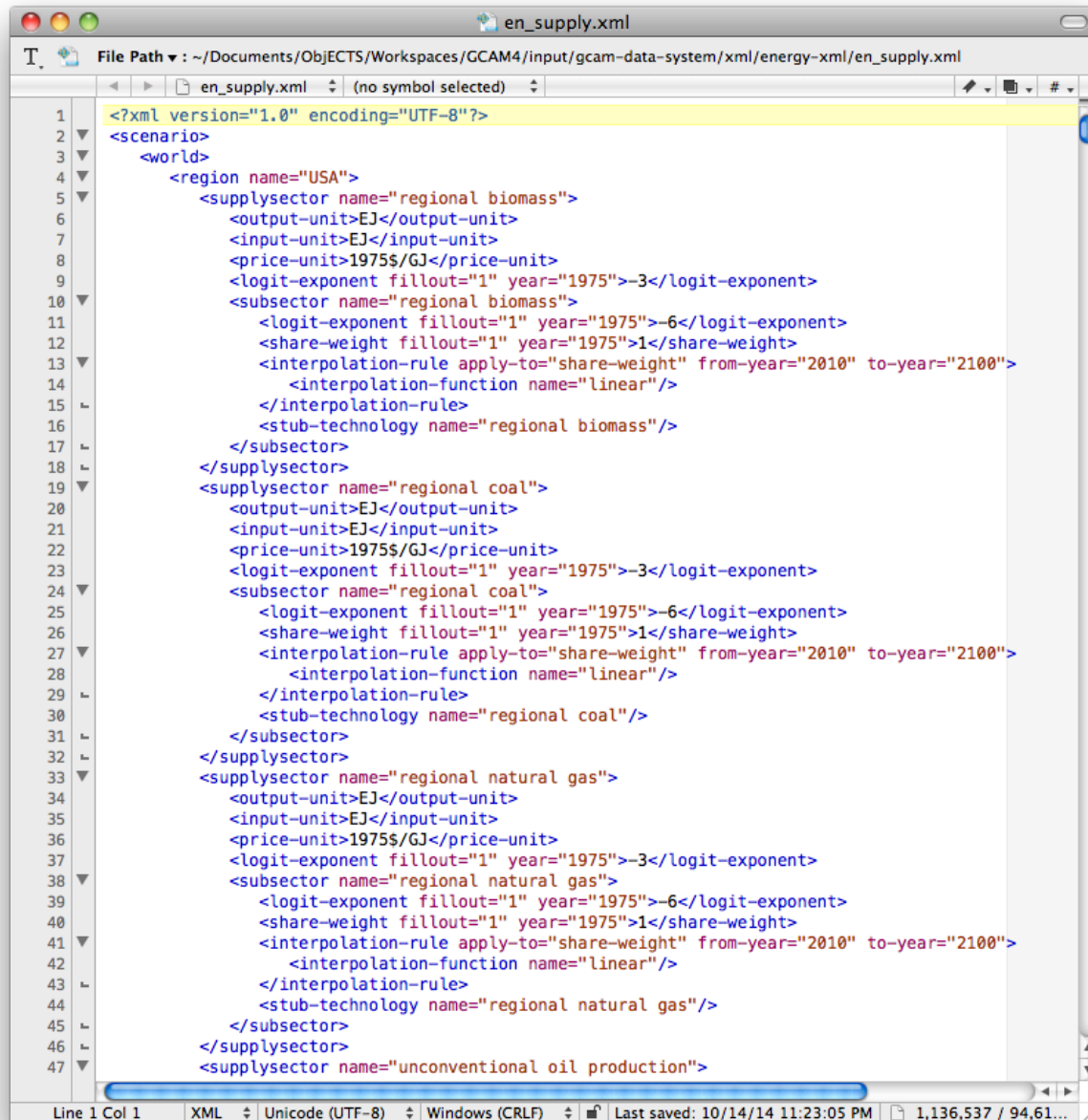
1: Resources



```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <depresource name="coal">
        <output-unit>EJ</output-unit>
        <price-unit>1975$/GJ</price-unit>
        <market>global</market>
        <price year="1975">0.4</price>
        <price year="1990">0.435</price>
        <price year="2005">0.438</price>
        <price year="2010">0.5</price>
        <subresource name="coal">
          <techChange fillout="1" year="1975">0.005</techChange>
          <techChange fillout="1" year="2005">0.0075</techChange>
          <cal-production year="1975">14.8206957</cal-production>
          <cal-production year="1990">22.4542682</cal-production>
          <cal-production year="2005">23.6084627</cal-production>
          <cal-production year="2010">21.1880386</cal-production>
          <grade name="grade 1">
            <available>284</available>
            <extractioncost>0.34</extractioncost>
          </grade>
          <grade name="grade 2">
            <available>6851</available>
            <extractioncost>0.37</extractioncost>
          </grade>
          <grade name="grade 3">
            <available>9469</available>
            <extractioncost>1.2</extractioncost>
          </grade>
          <grade name="grade 4">
            <available>13456</available>
            <extractioncost>1.7</extractioncost>
          </grade>
          <grade name="grade 5">
            <available>18440</available>
            <extractioncost>2</extractioncost>
          </grade>
          <grade name="grade 6">
            <available>18440</available>
            <extractioncost>2.3</extractioncost>
          </grade>
          <grade name="grade 7">
            <available>0</available>
            <extractioncost>2.6</extractioncost>
          </grade>
        </subresource>
      </depresource>
      <depresource name="crude oil">
```

- ▶ Coal, oil, gas, wind, solar, geothermal, uranium, MSW, limestone
- ▶ Resources are represented as supply curves: the level of production at a range of given prices
 - Prices are in 1975\$ / GJ produced. Quantities are in EJ.
 - Supply curves may be graded, smooth (input as parameters to a logistic power function), or unlimited (e.g. solar, limestone)
- ▶ Where markets are shared between regions (e.g. “global”), the supply curves of all contained regions are aggregated
- ▶ Resources may be depletable, renewable, or unlimited.
 - Cumulative resource extraction is tracked for depletable resources.

1: Domestic energy supply



```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <supplysector name="regional biomass">
        <output-unit>EJ</output-unit>
        <input-unit>EJ</input-unit>
        <price-unit>1975$/GJ</price-unit>
        <logit-exponent fillout="1" year="1975">-3</logit-exponent>
        <subsector name="regional biomass">
          <logit-exponent fillout="1" year="1975">-6</logit-exponent>
          <share-weight fillout="1" year="1975">1</share-weight>
          <interpolation-rule apply-to="share-weight" from-year="2010" to-year="2100">
            <interpolation-function name="linear"/>
          </interpolation-rule>
          <stub-technology name="regional biomass"/>
        </subsector>
      </supplysector>
      <supplysector name="regional coal">
        <output-unit>EJ</output-unit>
        <input-unit>EJ</input-unit>
        <price-unit>1975$/GJ</price-unit>
        <logit-exponent fillout="1" year="1975">-3</logit-exponent>
        <subsector name="regional coal">
          <logit-exponent fillout="1" year="1975">-6</logit-exponent>
          <share-weight fillout="1" year="1975">1</share-weight>
          <interpolation-rule apply-to="share-weight" from-year="2010" to-year="2100">
            <interpolation-function name="linear"/>
          </interpolation-rule>
          <stub-technology name="regional coal"/>
        </subsector>
      </supplysector>
      <supplysector name="regional natural gas">
        <output-unit>EJ</output-unit>
        <input-unit>EJ</input-unit>
        <price-unit>1975$/GJ</price-unit>
        <logit-exponent fillout="1" year="1975">-3</logit-exponent>
        <subsector name="regional natural gas">
          <logit-exponent fillout="1" year="1975">-6</logit-exponent>
          <share-weight fillout="1" year="1975">1</share-weight>
          <interpolation-rule apply-to="share-weight" from-year="2010" to-year="2100">
            <interpolation-function name="linear"/>
          </interpolation-rule>
          <stub-technology name="regional natural gas"/>
        </subsector>
      </supplysector>
      <supplysector name="unconventional oil production">
```

- ▶ en_supply.xml
- ▶ Domestic energy supply =
 - Sum of all consumption within a region
 - Production minus net exports
- ▶ These are generally uncalibrated “pass-through sectors” used for tracking purposes
- ▶ They can be used to implement region-specific energy price adders or subsidies
 - We currently apply the same cost adders in all regions in order to remain flexible to energy system changes in the future
 - Regional energy prices are not currently calibrated; instead, regional fuel prices are implicitly captured in the derived calibration parameters



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

1: Energy transformation sectors

► Four XML files

- electricity.xml
- hydrogen.xml
- heat.xml
- en_transformation.xml: refining, gas processing, and nuclear fuel enrichment

► Structure: supplysector / subsector / technology

- Subsector and technology market shares determined by two-level nested logit choice competition

► Technology parameters are specified in each period

- Much of the technology-level information is found in the global-technology-database, not in the technologies contained within each region

► All technologies must have at least one input (either a resource or another sector)

```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <supplysector name="gas processing">
        <output-unit>EJ</output-unit>
        <input-unit>EJ</input-unit>
        <price-unit>1975$/GJ</price-unit>
        <logit-exponent fillout="1" year="1975">-6</logit-exponent>
        <subsector name="natural gas">
          <logit-exponent fillout="1" year="1975">-6</logit-exponent>
          <share-weight fillout="1" year="1975">1</share-weight>
          <interpolation-rule apply-to="share-weight" from-year="2010" to-year="2100">
            <interpolation-function name="linear"/>
          </interpolation-rule>
          <stub-technology name="natural gas">
            <period year="1975">
              <share-weight>1</share-weight>
              <CalDataOutput>
                <calOutputValue>18.9158642</calOutputValue>
              </CalDataOutput>
            </period>
            <period year="1990">
              <share-weight>1</share-weight>
              <CalDataOutput>
                <calOutputValue>18.2014022</calOutputValue>
              </CalDataOutput>
            </period>
            <period year="2005">
              <share-weight>1</share-weight>
              <CalDataOutput>
                <calOutputValue>21.3888683</calOutputValue>
              </CalDataOutput>
            </period>
            <period year="2010">
              <share-weight>1</share-weight>
              <CalDataOutput>
                <calOutputValue>22.9698709</calOutputValue>
              </CalDataOutput>
            </period>
          </stub-technology>
          <share-weight year="1975">1</share-weight>
          <share-weight year="1990">1</share-weight>
          <share-weight year="2005">1</share-weight>
          <share-weight year="2010">1</share-weight>
        </subsector>
        <subsector name="biomass gasification">
```


1: Energy end-use sectors

- ▶ Sector-specific XML files
 - building_det.xml
 - industry.xml
 - cement.xml
 - en_Fert.xml
 - transportation_UCD.xml
- ▶ Each has its own structure
 - Goal is to represent technologies that consume energy and produce physical services and outputs

Keywords specify assignments of from specific to general end use sectors (bld, ind, trn)

```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <supplysector name="cement">
        <output-unit>Mt</output-unit>
        <input-unit>EJ or Mt</input-unit>
        <price-unit>1975$/kg</price-unit>
        <logit-exponent fillout="1" year="1975">-3</logit-exponent>
        <keyword final-energy="industry"/>
        <subsector name="cement">
          <logit-exponent fillout="1" year="1975">-12</logit-exponent>
          <share-weight fillout="1" year="1975">1</share-weight>
          <interpolation-rule apply-to="share-weight" from-year="2010" to-year="2100">
            <interpolation-function name="fixed"/>
          </interpolation-rule>
          <stub-technology name="cement">
            <period year="1975">
              <share-weight>1</share-weight>
              <CalDataOutput>
                <calOutputValue>72.0533118</calOutputValue>
              </CalDataOutput>
              <minicam-energy-input name="elect_td_ind">
                <coefficient>0.0005292</coefficient>
                <market-name>USA</market-name>
              </minicam-energy-input>
              <minicam-energy-input name="process heat cement">
                <coefficient>0.0042706</coefficient>
                <market-name>USA</market-name>
              </minicam-energy-input>
              <minicam-energy-input name="limestone">
                <coefficient>1.4922978</coefficient>
                <market-name>USA</market-name>
              </minicam-energy-input>
            </period>
            <period year="1990">
              <share-weight>1</share-weight>
              <CalDataOutput>
                <calOutputValue>81.3343011</calOutputValue>
              </CalDataOutput>
              <minicam-energy-input name="elect_td_ind">
                <coefficient>0.0005292</coefficient>
                <market-name>USA</market-name>
              </minicam-energy-input>
              <minicam-energy-input name="process heat cement">
                <coefficient>0.0039061</coefficient>
                <market-name>USA</market-name>
              </minicam-energy-input>
            </period>
          </stub-technology>
        </subsector>
      </supplysector>
    </region>
  </world>
</scenario>
```


1: Energy final demands

► Residential and commercial: specific representation

- Final demand (floorspace) and intermediate demands (heating, cooling, other) are driven by “satiated demand” functions designed to de-couple service demand from income as incomes increase

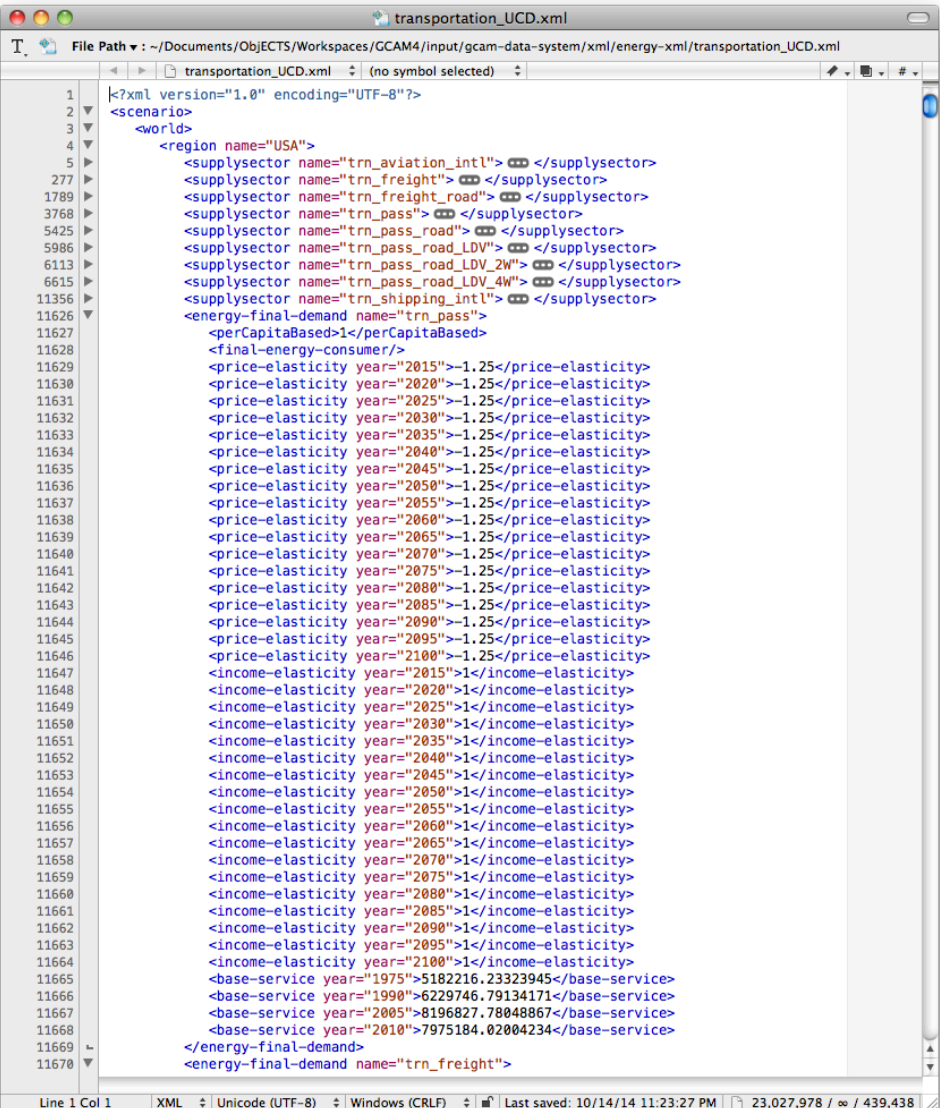
► Industry and cement: generic per-capita based demand functions

$$D_{i,t} = D_{i,2005} \cdot \left(\frac{pcGDP_t}{pcGDP_{2005}}\right)^{inc-el} \cdot \left(\frac{P_t}{P_{2005}}\right)^{p-el} \cdot \left(\frac{Pop_t}{Pop_{2005}}\right)$$

- Cement: output indicated in physical units
- Fertilizer: output is in physical units, and demand is endogenous (from regional agricultural sector)

► Passenger, freight, international shipping, and international aviation: generic per-capita-based demand

- Service is indicated in physical units (passenger-km, tonne-km)
- De-coupling between income and passenger mobility from including time value costs in service price



```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <supplysector name="trn_aviation_intl"></supplysector>
      <supplysector name="trn_freight"></supplysector>
      <supplysector name="trn_freight_road"></supplysector>
      <supplysector name="trn_pass"></supplysector>
      <supplysector name="trn_pass_road"></supplysector>
      <supplysector name="trn_pass_road_LDV"></supplysector>
      <supplysector name="trn_pass_road_LDV_2W"></supplysector>
      <supplysector name="trn_pass_road_LDV_4W"></supplysector>
      <supplysector name="trn_shipping_intl"></supplysector>
      <energy-final-demand name="trn_pass">
        <perCapitaBased>1</perCapitaBased>
        <final-energy-consumer/>
        <price-elasticity year="2015">-1.25</price-elasticity>
        <price-elasticity year="2020">-1.25</price-elasticity>
        <price-elasticity year="2025">-1.25</price-elasticity>
        <price-elasticity year="2030">-1.25</price-elasticity>
        <price-elasticity year="2035">-1.25</price-elasticity>
        <price-elasticity year="2040">-1.25</price-elasticity>
        <price-elasticity year="2045">-1.25</price-elasticity>
        <price-elasticity year="2050">-1.25</price-elasticity>
        <price-elasticity year="2055">-1.25</price-elasticity>
        <price-elasticity year="2060">-1.25</price-elasticity>
        <price-elasticity year="2065">-1.25</price-elasticity>
        <price-elasticity year="2070">-1.25</price-elasticity>
        <price-elasticity year="2075">-1.25</price-elasticity>
        <price-elasticity year="2080">-1.25</price-elasticity>
        <price-elasticity year="2085">-1.25</price-elasticity>
        <price-elasticity year="2090">-1.25</price-elasticity>
        <price-elasticity year="2095">-1.25</price-elasticity>
        <price-elasticity year="2100">-1.25</price-elasticity>
        <income-elasticity year="2015">1</income-elasticity>
        <income-elasticity year="2020">1</income-elasticity>
        <income-elasticity year="2025">1</income-elasticity>
        <income-elasticity year="2030">1</income-elasticity>
        <income-elasticity year="2035">1</income-elasticity>
        <income-elasticity year="2040">1</income-elasticity>
        <income-elasticity year="2045">1</income-elasticity>
        <income-elasticity year="2050">1</income-elasticity>
        <income-elasticity year="2055">1</income-elasticity>
        <income-elasticity year="2060">1</income-elasticity>
        <income-elasticity year="2065">1</income-elasticity>
        <income-elasticity year="2070">1</income-elasticity>
        <income-elasticity year="2075">1</income-elasticity>
        <income-elasticity year="2080">1</income-elasticity>
        <income-elasticity year="2085">1</income-elasticity>
        <income-elasticity year="2090">1</income-elasticity>
        <income-elasticity year="2095">1</income-elasticity>
        <income-elasticity year="2100">1</income-elasticity>
        <base-service year="1975">5182216.23323945</base-service>
        <base-service year="1990">6229746.79134171</base-service>
        <base-service year="2005">8196827.78048867</base-service>
        <base-service year="2010">7975184.02004234</base-service>
      </energy-final-demand>
      <energy-final-demand name="trn_freight">
```

1: GDP and population

```

1 <?xml version="1.0" encoding="UTF-8"?>
2 <scenario>
3   <world>
4     <region name="USA">
5       <demographics>
6         <populationMiniCAM year="1975">
7           <totalPop>215165</totalPop>
8         </populationMiniCAM>
9         <populationMiniCAM year="1990"></populationMiniCAM>
10        <populationMiniCAM year="2005"></populationMiniCAM>
11        <populationMiniCAM year="2010"></populationMiniCAM>
12        <populationMiniCAM year="2015"></populationMiniCAM>
13        <populationMiniCAM year="2020"></populationMiniCAM>
14        <populationMiniCAM year="2025"></populationMiniCAM>
15        <populationMiniCAM year="2030"></populationMiniCAM>
16        <populationMiniCAM year="2035"></populationMiniCAM>
17        <populationMiniCAM year="2040"></populationMiniCAM>
18        <populationMiniCAM year="2045"></populationMiniCAM>
19        <populationMiniCAM year="2050"></populationMiniCAM>
20        <populationMiniCAM year="2055"></populationMiniCAM>
21        <populationMiniCAM year="2060"></populationMiniCAM>
22        <populationMiniCAM year="2065"></populationMiniCAM>
23        <populationMiniCAM year="2070"></populationMiniCAM>
24        <populationMiniCAM year="2075"></populationMiniCAM>
25        <populationMiniCAM year="2080"></populationMiniCAM>
26        <populationMiniCAM year="2085"></populationMiniCAM>
27        <populationMiniCAM year="2090"></populationMiniCAM>
28        <populationMiniCAM year="2095"></populationMiniCAM>
29        <populationMiniCAM year="2100">
30          <totalPop>554807</totalPop>
31        </populationMiniCAM>
32      </demographics>
33      <GDP>
34        <baseGDP>3473910</baseGDP>
35        <laborforce fillout="1" year="1975">0.5</laborforce>
36        <laborproductivity year="1990">0.02354</laborproductivity>
37        <laborproductivity year="2005">0.01902</laborproductivity>
38        <laborproductivity year="2010">0.00351</laborproductivity>
39        <laborproductivity year="2015">0.01398</laborproductivity>
40        <laborproductivity year="2020">0.01273</laborproductivity>
41        <laborproductivity year="2025">0.01152</laborproductivity>
42        <laborproductivity year="2030">0.01119</laborproductivity>
43        <laborproductivity year="2035">0.01076</laborproductivity>
44        <laborproductivity year="2040">0.01274</laborproductivity>
45        <laborproductivity year="2045">0.01164</laborproductivity>
46        <laborproductivity year="2050">0.01364</laborproductivity>
47        <laborproductivity year="2055">0.01151</laborproductivity>
48        <laborproductivity year="2060">0.01311</laborproductivity>
49        <laborproductivity year="2065">0.01258</laborproductivity>
50        <laborproductivity year="2070">0.01377</laborproductivity>
51        <laborproductivity year="2075">0.01368</laborproductivity>
52        <laborproductivity year="2080">0.01372</laborproductivity>
53        <laborproductivity year="2085">0.01315</laborproductivity>
54        <laborproductivity year="2090">0.01459</laborproductivity>
55        <laborproductivity year="2095">0.01454</laborproductivity>
56        <laborproductivity year="2100">0.01449</laborproductivity>
57        <PPPConvert constRatio="1">0.96187</PPPConvert>
58      </GDP>
59    </region>
60  </world>
61 </scenario>

```

► Population is based on median UN forecasts through 2100.

- Population is strictly exogenous (i.e., not modified by other modeled variables)

► GDP is based on the formulation:

$$GDP_{R,t1} = GDP_{R,t0} \cdot \left(\frac{Pop_{t1} \cdot laborForceParticipation_{R,t1}}{Pop_{t0} \cdot laborForceParticipation_{R,t0}} \right) \cdot (1 + laborProdGrowthRate)^{(t1-t0)}$$

- All parameters to the GDP function are strictly exogenous



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

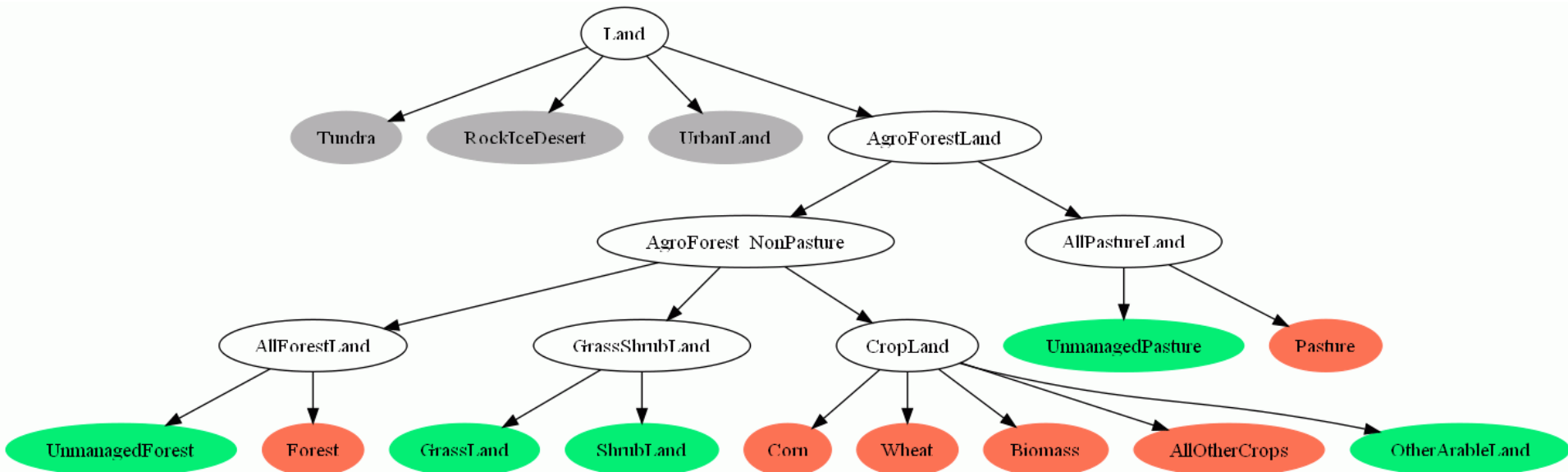
Agriculture and Land Use in GCAM 4.0



Pacific Northwest
NATIONAL LABORATORY

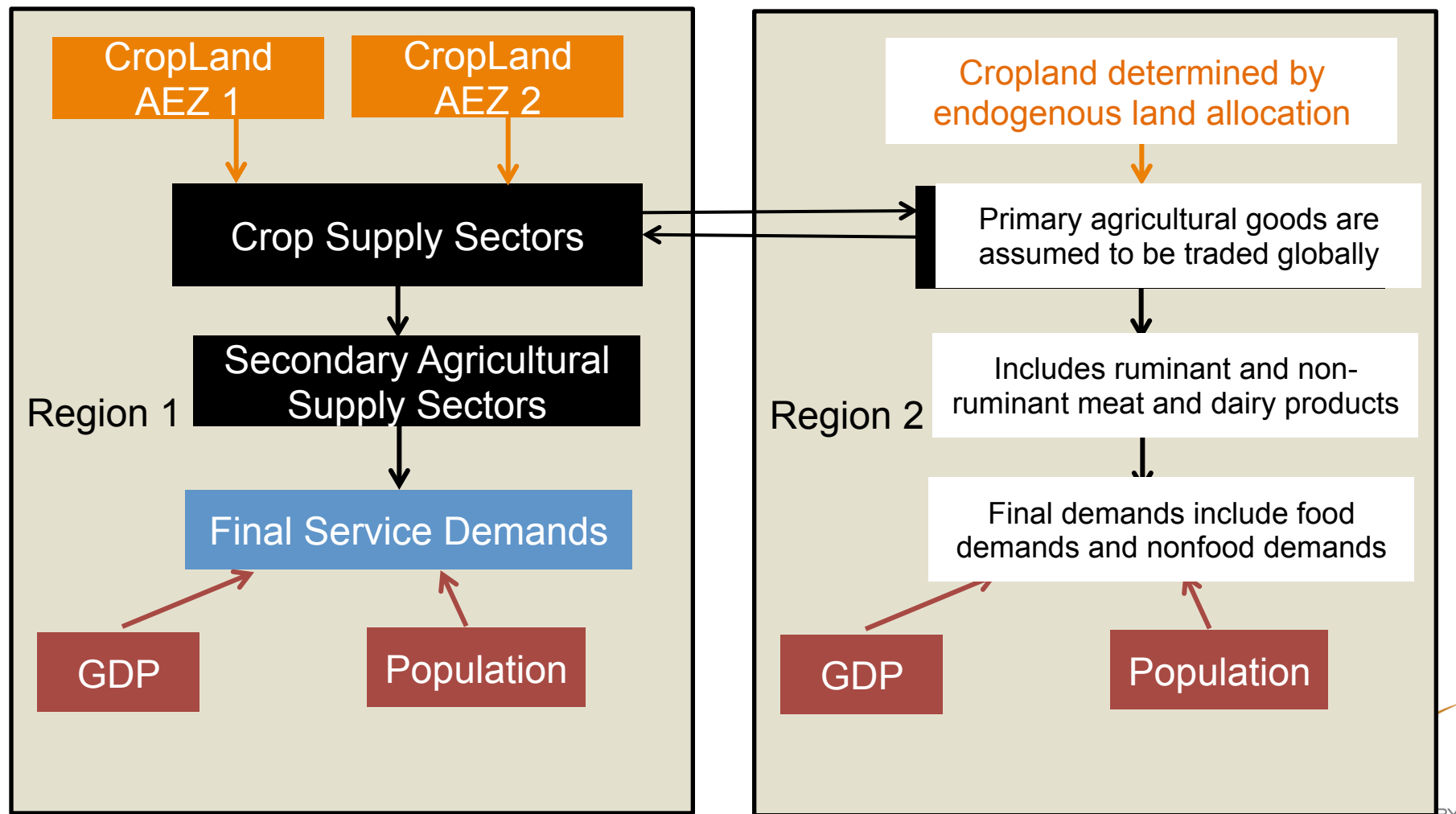
Proudly Operated by Battelle Since 1965

1: Land allocation within AEZ

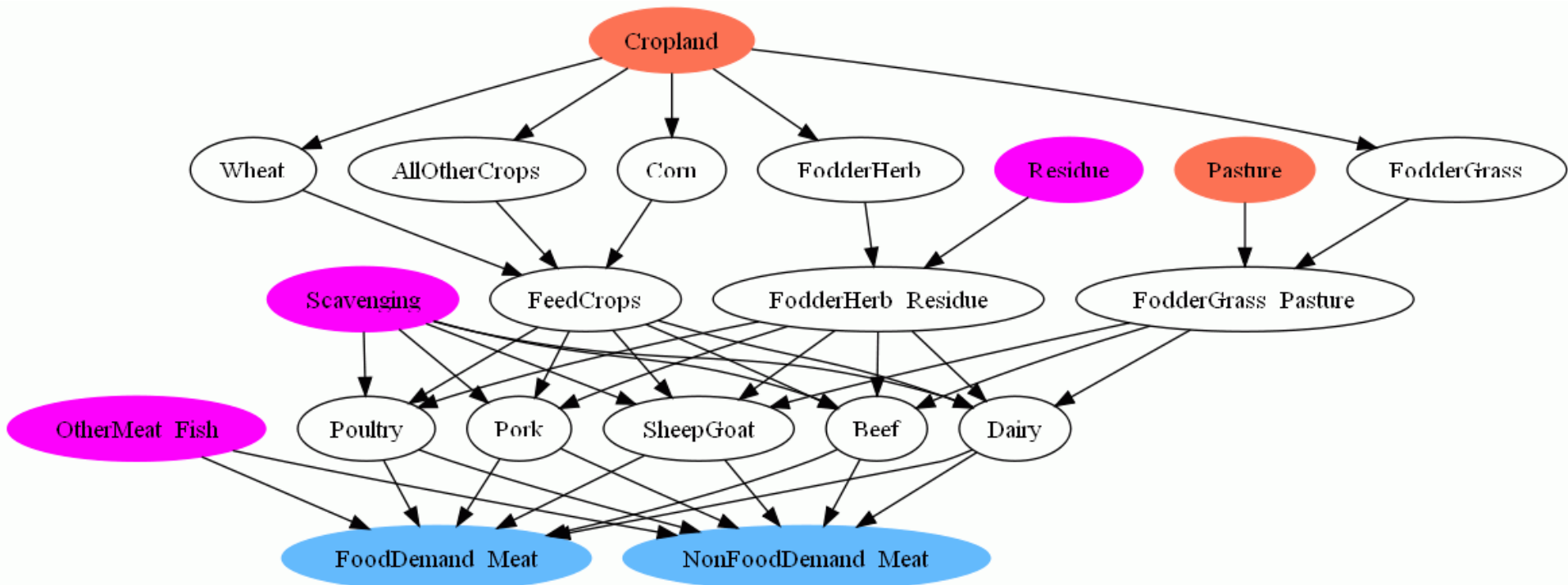
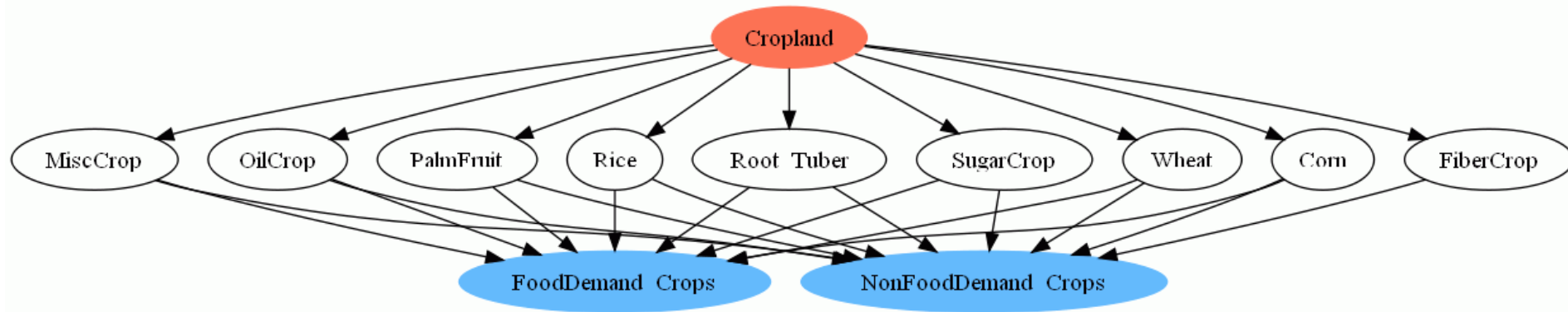


- ▶ Gray = exogenous; Green = unmanaged; Red = managed
- ▶ Managed land competes with unmanaged land based on profit rate

1: Agricultural system structure



1: Agricultural system structure



1: Land allocation

Land unit:
thousand km² =
billion m²

```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <LandAllocatorRoot name="root">
        <logit-exponent fillout="1" year="1975">0</logit-exponent>
        <landAllocation fillout="1" year="1975">8942.4</landAllocation>
        <soilTimeScale>50</soilTimeScale>
        <LandNode name="AgroForestLandAEZ07">
          <unManagedLandValue>12872995</unManagedLandValue>
          <logit-exponent fillout="1" year="1975">1</logit-exponent>
        </LandNode>
        <LandNode name="RockIceDesertAEZ07">
          <unManagedLandValue>12872995</unManagedLandValue>
          <logit-exponent fillout="1" year="1975">0</logit-exponent>
          <unManagedLandLeaf name="RockIceDesertAEZ07">
            <land-use-history>
              <allocation year="1700">14.8655563</allocation>
              <allocation year="1750">14.8297049</allocation>
              <allocation year="1800">14.7458457</allocation>
              <allocation year="1850">14.4917961</allocation>
              <allocation year="1900">12.7946154</allocation>
              <allocation year="1950">11.2356018</allocation>
              <allocation year="1975">10.9553652</allocation>
              <above-ground-carbon-density>0.1</above-ground-carbon-density>
              <below-ground-carbon-density>3.8</below-ground-carbon-density>
            </land-use-history>
            <landAllocation year="1975">10.9553652</landAllocation>
            <landAllocation year="1990">10.9990463</landAllocation>
            <landAllocation year="2005">11.2743317</landAllocation>
            <landAllocation year="2010">10.9442317</landAllocation>
            <minAboveGroundCDensity>0</minAboveGroundCDensity>
            <minBelowGroundCDensity>0</minBelowGroundCDensity>
            <land-carbon-densities>
              <above-ground-carbon-density>0.1</above-ground-carbon-density>
              <below-ground-carbon-density>3.8</below-ground-carbon-density>
              <mature-age fillout="1" year="1975">50</mature-age>
            </land-carbon-densities>
          </unManagedLandLeaf>
        </LandNode>
        <LandNode name="TundraAEZ07">
          <unManagedLandValue>12872995</unManagedLandValue>
          <logit-exponent fillout="1" year="1975">0</logit-exponent>
        </LandNode>
      </LandAllocatorRoot>
    </region>
  </world>
</scenario>
```

- ▶ Land data are read in 3 XML files that correspond to the 3 “node” levels of the land nesting diagram

- land_input_1.xml, land_input_2.xml, and land_input_3.xml

- ▶ Top-level base-year land allocations are fixed in all future periods

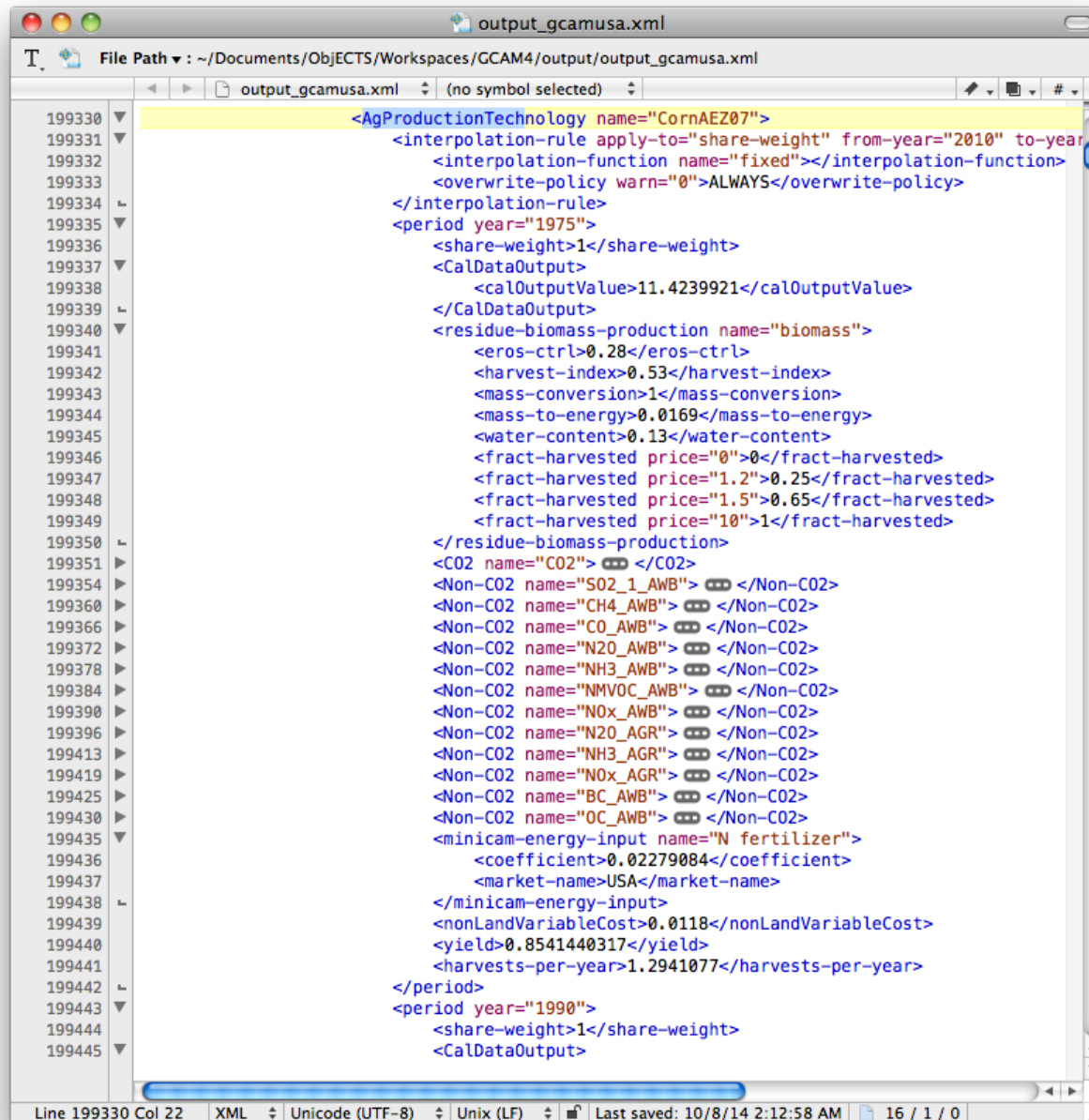
- ▶ At lower levels, calibration is still quite important for future land allocation due to the large number of non-modeled factors

- In GCAM, the land use shares shift in response to changes in relative land profit rates
- Calibration is performed on land use shares, not present-day rates of land use change

Carbon density unit:
kg C / m²

Land value unit:
1975\$ / thous km²

1: Agricultural production



The screenshot shows a text editor window titled 'output_gcamusa.xml'. The file path is '~\Documents\ObjECTS\Workspaces\GCAM4\output\output_gcamusa.xml'. The code is XML and defines an 'AgProductionTechnology' for 'CornAEZ07'. It includes parameters for interpolation, share-weight, biomass production, CO2 emissions, and fertilizer inputs. The code is color-coded with blue for tags, black for text, and red for attributes. The editor has a line and column number display at the bottom, showing 'Line 199330 Col 22'.

```
<AgProductionTechnology name="CornAEZ07">
  <interpolation-rule apply-to="share-weight" from-year="2010" to-year="1990">
    <interpolation-function name="fixed"></interpolation-function>
    <overwrite-policy warn="0">ALWAYS</overwrite-policy>
  </interpolation-rule>
  <period year="1975">
    <share-weight>1</share-weight>
    <CalDataOutput>
      <calOutputValue>11.4239921</calOutputValue>
    </CalDataOutput>
    <residue-biomass-production name="biomass">
      <eros-ctrl>0.28</eros-ctrl>
      <harvest-index>0.53</harvest-index>
      <mass-conversion>1</mass-conversion>
      <mass-to-energy>0.0169</mass-to-energy>
      <water-content>0.13</water-content>
      <fract-harvested price="0">0</fract-harvested>
      <fract-harvested price="1.2">0.25</fract-harvested>
      <fract-harvested price="1.5">0.65</fract-harvested>
      <fract-harvested price="10">1</fract-harvested>
    </residue-biomass-production>
    <CO2 name="CO2"></CO2>
    <Non-CO2 name="SO2_1_AWB"></Non-CO2>
    <Non-CO2 name="CH4_AWB"></Non-CO2>
    <Non-CO2 name="CO_AWB"></Non-CO2>
    <Non-CO2 name="N2O_AWB"></Non-CO2>
    <Non-CO2 name="NH3_AWB"></Non-CO2>
    <Non-CO2 name="NMVOC_AWB"></Non-CO2>
    <Non-CO2 name="NOx_AWB"></Non-CO2>
    <Non-CO2 name="N2O_AGR"></Non-CO2>
    <Non-CO2 name="NH3_AGR"></Non-CO2>
    <Non-CO2 name="NOx_AGR"></Non-CO2>
    <Non-CO2 name="BC_AWB"></Non-CO2>
    <Non-CO2 name="OC_AWB"></Non-CO2>
    <minicam-energy-input name="N fertilizer">
      <coefficient>0.02279084</coefficient>
      <market-name>USA</market-name>
    </minicam-energy-input>
    <nonLandVariableCost>0.0118</nonLandVariableCost>
    <yield>0.8541440317</yield>
    <harvests-per-year>1.2941077</harvests-per-year>
  </period>
  <period year="1990">
    <share-weight>1</share-weight>
    <CalDataOutput>
```

- ▶ Each ag production technology has a corresponding land leaf of the same name
 - The sharing/competition takes place in the land allocator, not in the ag sectors
- ▶ Exogenous variables
 - Calibrated commodity price (1975\$/kg)
 - Calibrated output (Mt/yr)
 - Calibrated land quantity (bm²)
 - Residue biomass supply curve
 - Non-CO₂ coefficients (kg gas per kg crop)
 - MAC curves
 - Fertilizer inputs (kg N per kg crop)
 - Costs (1975\$/kg)
 - Future agricultural productivity growth rate (and therefore yield)
 - Annual harvested area: cropland
- ▶ Key endogenous variables
 - Future commodity prices
 - Future profit rates and production volumes

1: Non-CO₂ gases

- ▶ Non-CO₂ gases are modeled as a by-product on existing activities, either driven by “input” (e.g. fuel consumption) or “output” (e.g. service or energy production)
- ▶ Can be read in as input-emissions (Tg/yr) or as emissions coefficients (kg/GJ)
- ▶ GDP control function: emissions coefficients are reduced as GDP increases
- ▶ MAC = marginal abatement cost curve; decreases coefficients as carbon price increases.

```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
  <world>
    <region name="USA">
      <supplysector name="comm cooling" nocreate="1">
        <subsector name="gas" nocreate="1">
          <stub-technology name="gas" nocreate="1">
            <period year="1975">
              <Non-CO2 name="S02_1">
                <input-emissions>1.55e-05</input-emissions>
                <input-driver/>
              </Non-CO2>
              <Non-CO2 name="CO">
                <input-emissions>0.011917</input-emissions>
                <input-driver/>
                <gdp-control name="GDP_control">
                  <max-reduction>68.5446345299613</max-reduction>
                  <steepness>3.5</steepness>
                </gdp-control>
              </Non-CO2>
              <Non-CO2 name="NH3"></Non-CO2>
              <Non-CO2 name="NMVOC"></Non-CO2>
              <Non-CO2 name="NOx"></Non-CO2>
              <Non-CO2 name="CH4"></Non-CO2>
              <Non-CO2 name="N2O"></Non-CO2>
              <Non-CO2 name="BC"></Non-CO2>
              <Non-CO2 name="OC">
                <emiss-coef>5.08e-05</emiss-coef>
                <input-driver/>
                <gdp-control name="GDP_control">
```

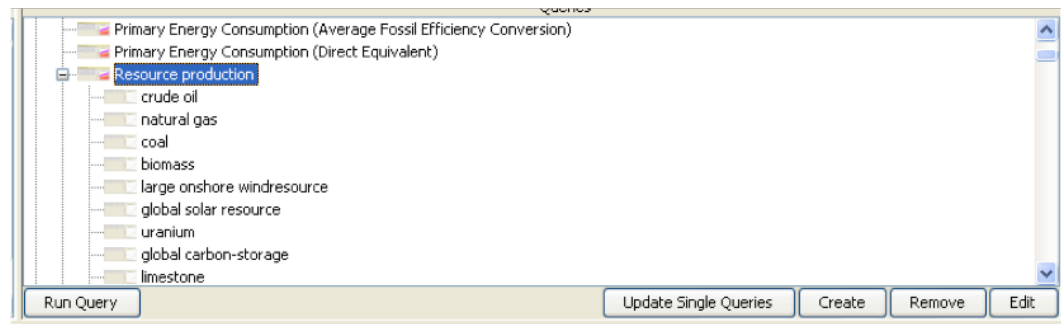
$$Coef_{t1} = Coef_{t0} \cdot \left(1 - \min(\max \text{ Reduction}, 1 - \frac{1}{1 + \frac{(pcGDP_{t1} - pcGDP_{t0})}{Steepness}})\right)$$

1: Queries

► Update single queries: allows a query to focus on an individual element

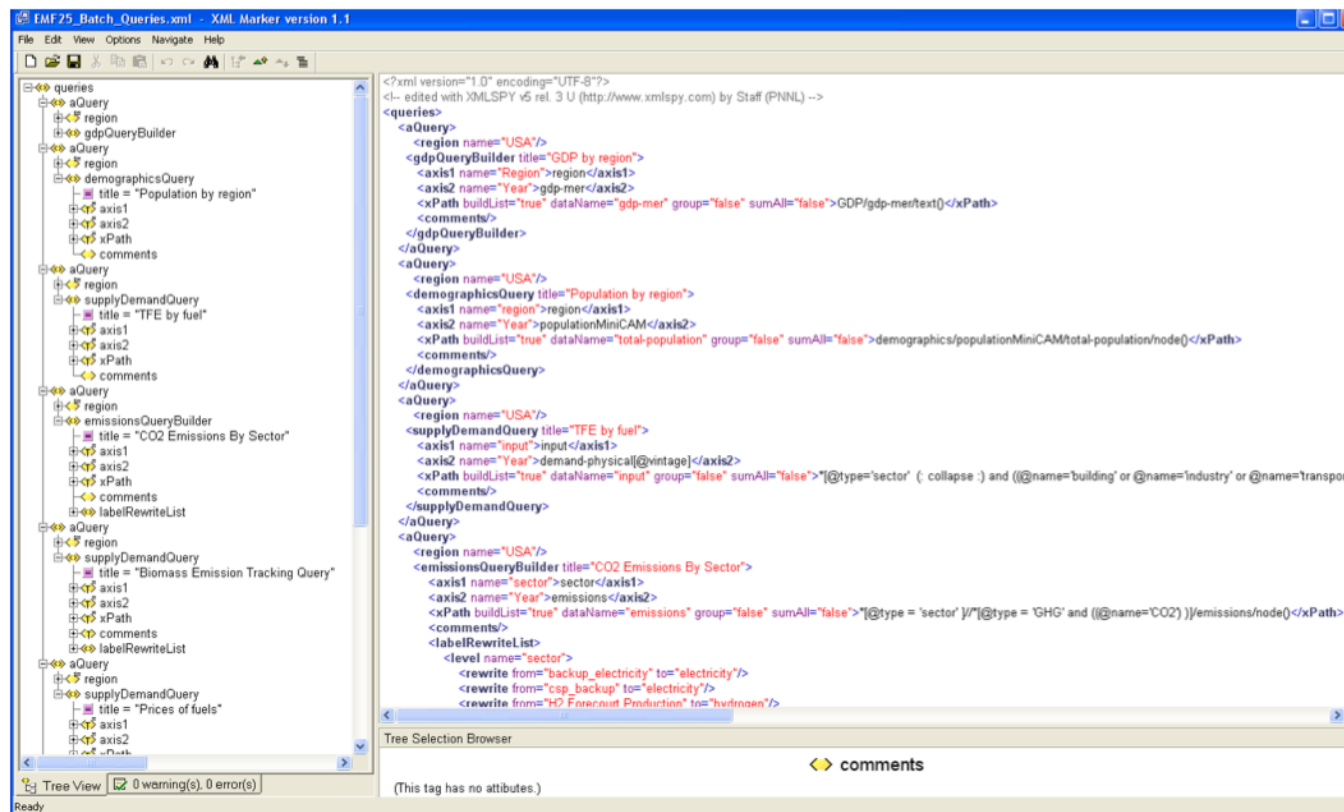
► Edit query window

- Sum All: adds all types of the given element together
- Group: builds an area chart and separates each region into a separate chart
- XPATH: this is the syntax of the given query.
- Note that label re-write lists used in “aggregated” queries are only accessible through the query XML file.

A screenshot of the 'Edit Query' dialog box. It has a title bar with a close button. The fields are: Title (Resource production), Y-Axis Name (resource), X-Axis Name (Year), Data Name (output), and XPATH (*[@type='resource']/output/node()). There are checkboxes for 'Sum All' (unchecked), 'Group' (checked), and 'Build List' (checked). A 'Chart Label Column' field is empty. A 'Comments' text area is at the bottom. 'OK' and 'Cancel' buttons are at the bottom right.

1: Exporting data

- ▶ Drag and drop (e.g. into Excel)
- ▶ Highlight cells and cut and paste
- ▶ Use a batch query to export a large number of queries directly into an Excel spreadsheet
 - The dbxml file needs to be open for this to work
 - File -> Batch File. Select batch query file and output workbook.
 - This won't work if the Excel workbook selected is open while running the batch query

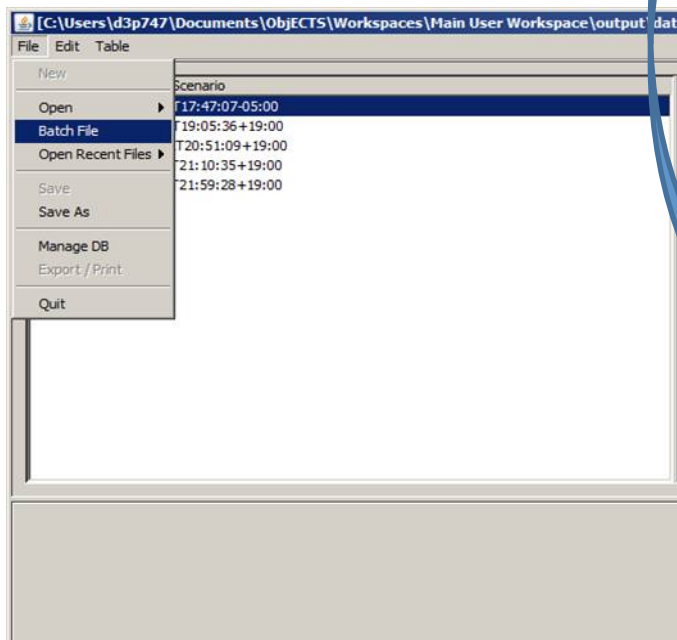


Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

1: Exporting data with a batch query

- ▶ Create a batch XML query file and a blank XLS workbook
- ▶ Open DBXML file first, and then select Batch File
- ▶ Select batch query file and XLS workbook for export, making sure that this workbook is closed



```
<?xml version="1.0" encoding="UTF-8"?>
<queries>

  <aQuery>
    <region name="USA"/>
    <supplyDemandQuery title="Building final energy by technology and fuel">
      <axis1 name="technology">technology</axis1>
      <axis2 name="Year">demand-physical[@vintage]</axis2>
      <xPath buildList="true" dataName="input" group="false" sumAll="false">*[@tyr
    <comments/>
    </supplyDemandQuery>
  </aQuery>
  <aQuery>
    <region name="USA"/>
    <supplyDemandQuery title="Building service output by technology">
      <axis1 name="technology">technology</axis1>
      <axis2 name="Year">physical-output[@vintage]</axis2>
      <xPath buildList="true" dataName="output" group="false" sumAll="false">*[@t
    <comments/>
    </supplyDemandQuery>
  </aQuery>
  <aQuery>
    <region name="USA"/>
    <supplyDemandQuery title="Fuel prices to buildings">
```

This portion is pasted from model interface queries, or Main_queries.xml file. Only need to add region and aQuery tags to make the batch query file.



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

1: Running the diagnostics package (new with GCAM 4.0)

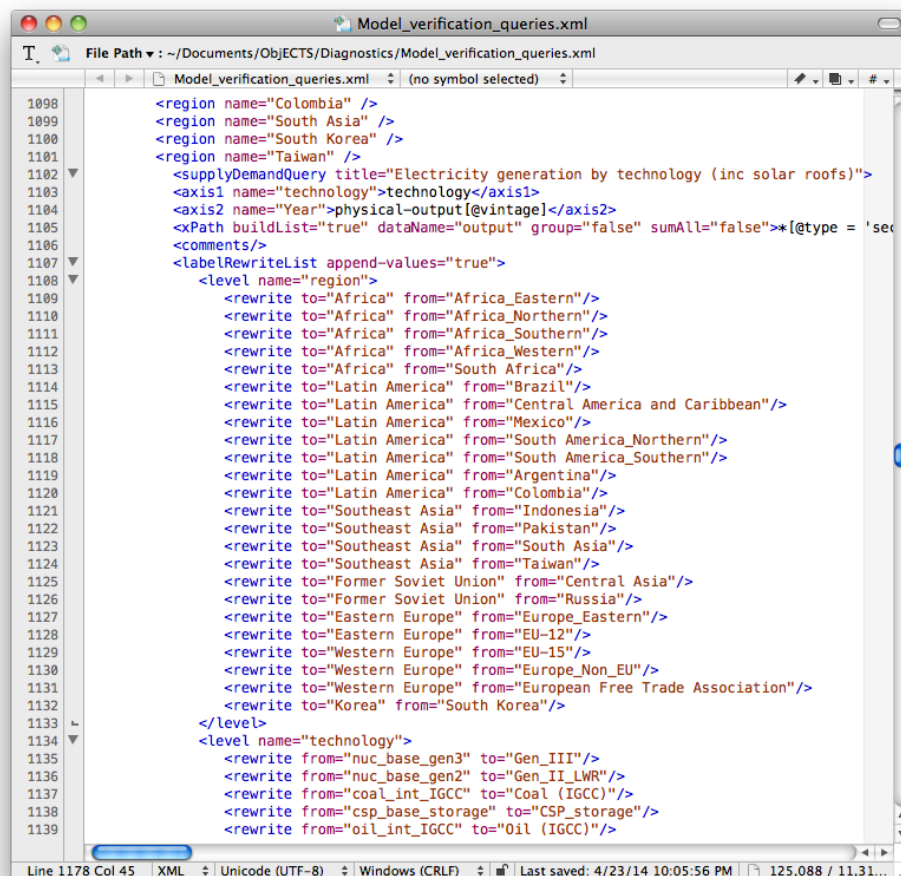
- ▶ The diagnostics package runs R scripts that generate a large number of figures
 - Can be used for individual scenario analysis or comparisons between a “reference” and alternative scenarios
 - Currently, queries address end-use energy consumption, electricity, refining, primary energy consumption, land use, emissions, fuel prices, GDP, and population
 - More can be added in the Model_verification_queries.xml batch query file
- ▶ The diagnostics package is located in the output/gcam_diagnostics folder
 - Instructions are found in the readme.txt file



Pacific Northwest
NATIONAL LABORATORY

1: Running the diagnostics package

- ▶ Regions may be combined from the 32 in the DBXML to a more convenient number for analysis and visualization
 - use a label re-write list in the model_verification_queries file



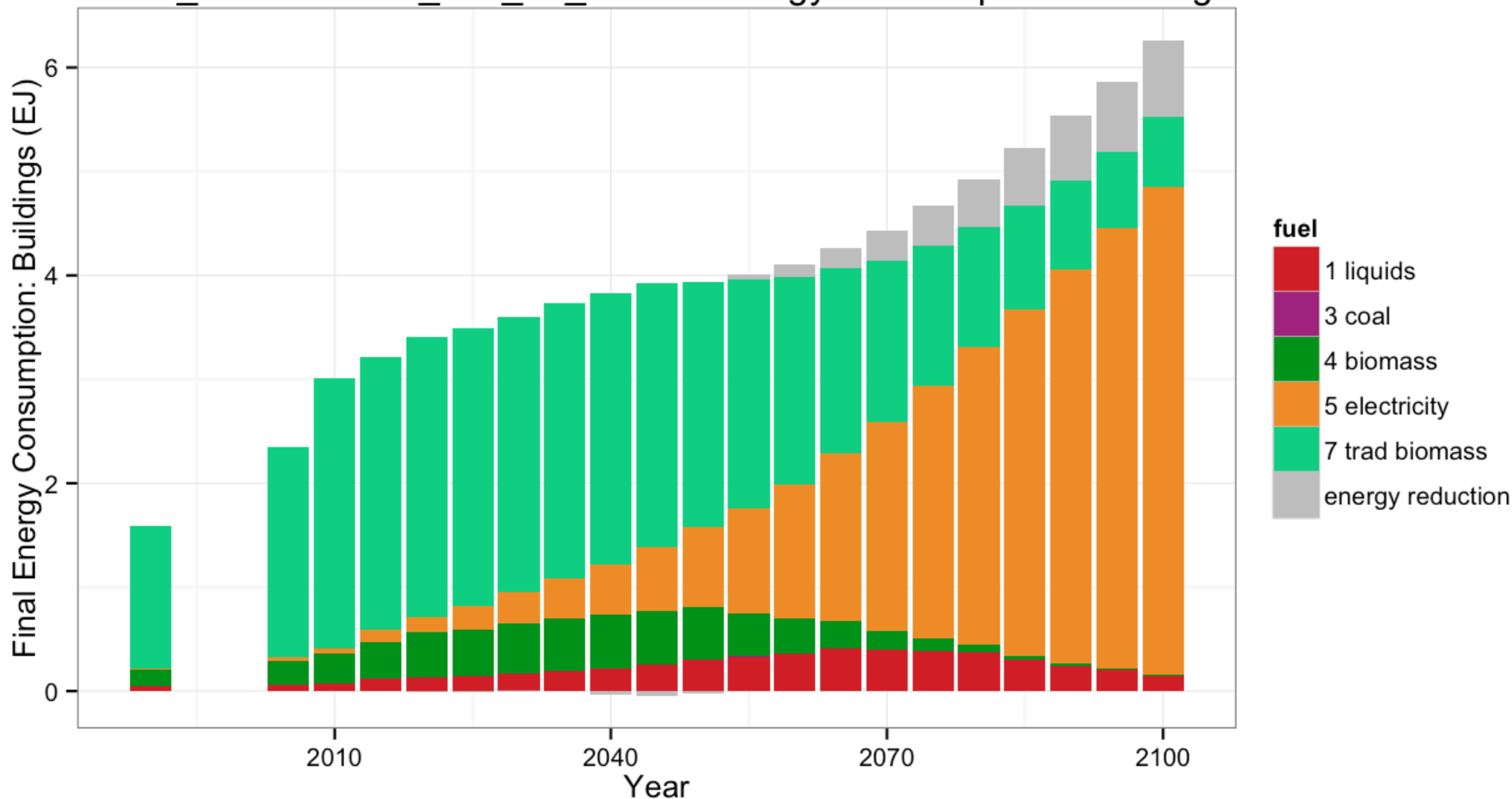
```
1098 <region name="Colombia" />
1099 <region name="South Asia" />
1100 <region name="South Korea" />
1101 <region name="Taiwan" />
1102 <supplyDemandQuery title="Electricity generation by technology (inc solar roofs)">
1103   <axis1 name="technology">technology</axis1>
1104   <axis2 name="Year">physical-output[@vintage]</axis2>
1105   <xPath buildList="true" dataName="output" group="false" sumAll="false">*[@type = 'sec
1106 <comments/>
1107 <labelRewriteList append-values="true">
1108   <level name="region">
1109     <rewrite to="Africa" from="Africa_Eastern"/>
1110     <rewrite to="Africa" from="Africa_Northern"/>
1111     <rewrite to="Africa" from="Africa_Southern"/>
1112     <rewrite to="Africa" from="Africa_Western"/>
1113     <rewrite to="Africa" from="South Africa"/>
1114     <rewrite to="Latin America" from="Brazil"/>
1115     <rewrite to="Latin America" from="Central America and Caribbean"/>
1116     <rewrite to="Latin America" from="Mexico"/>
1117     <rewrite to="Latin America" from="South America_Northern"/>
1118     <rewrite to="Latin America" from="South America_Southern"/>
1119     <rewrite to="Latin America" from="Argentina"/>
1120     <rewrite to="Latin America" from="Colombia"/>
1121     <rewrite to="Southeast Asia" from="Indonesia"/>
1122     <rewrite to="Southeast Asia" from="Pakistan"/>
1123     <rewrite to="Southeast Asia" from="South Asia"/>
1124     <rewrite to="Southeast Asia" from="Taiwan"/>
1125     <rewrite to="Former Soviet Union" from="Central Asia"/>
1126     <rewrite to="Former Soviet Union" from="Russia"/>
1127     <rewrite to="Eastern Europe" from="Europe_Eastern"/>
1128     <rewrite to="Eastern Europe" from="EU-12"/>
1129     <rewrite to="Western Europe" from="EU-15"/>
1130     <rewrite to="Western Europe" from="Europe_Non_EU"/>
1131     <rewrite to="Western Europe" from="European Free Trade Association"/>
1132     <rewrite to="Korea" from="South Korea"/>
1133   </level>
1134   <level name="technology">
1135     <rewrite from="nuc_base_gen3" to="Gen_III"/>
1136     <rewrite from="nuc_base_gen2" to="Gen_II_LWR"/>
1137     <rewrite from="coal_int_IGCC" to="Coal (IGCC)"/>
1138     <rewrite from="csp_base_storage" to="CSP_storage"/>
1139     <rewrite from="oil_int_IGCC" to="Oil (IGCC)"/>

```

1: Running the diagnostics package

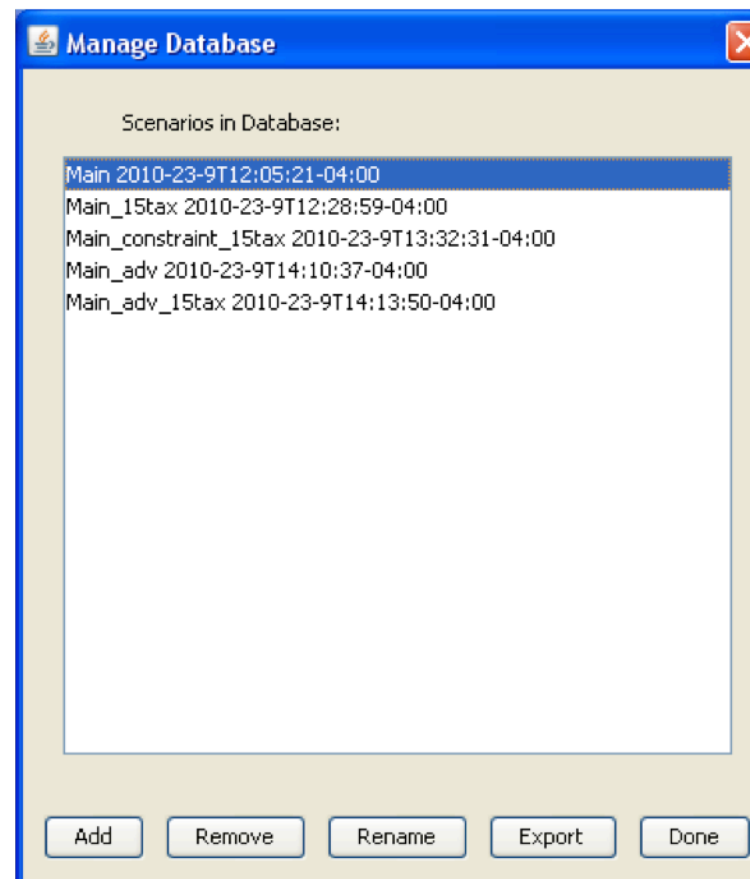
- ▶ The default is to compare an “alternative” scenario to a “baseline”, or reference, scenario.

Africa_Eastern.Core_Tax_25_5.Final Energy Consumption: Buildings



1: Exporting, importing runs

- ▶ File -> Manage DB
- ▶ This allows one to rename, export (as an xml file, that can be imported into another .dbxml file), import, or remove a run from the database
- ▶ The exported .xml files can also be useful for writing queries, as they contain all available information that could be queried



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

1: Useful Miscellaneous Info

- ▶ All energy flows are represented in EJ/yr. Note that the “year” denominator is implicit, not written out.
- ▶ Fuel carbon contents are in kgC/GJ.
- ▶ Emissions units
 - CO₂ is in Mt C. Multiply by 44/12 to convert to CO₂
 - Non-CO₂ gases are generally in Tg (same as Mt). Exceptions are the hi-GWP gases (e.g. HFCs, PFCs, SF₆), which are in Gg (same as kt).
- ▶ Dollar units
 - Prices of all energy goods and services are in 1975\$/GJ
 - GDP is in 1990\$/yr
 - Carbon prices are in 1990\$/tC. Multiply by 12/44 to convert to 1990\$/tCO₂.
 - Fuel prices in policy scenarios do not include the emissions penalties. After converting to the desired dollar year, these may be added to any technology as:
 - $\text{C price (\$/tC)} * 1\text{t} / 1000\text{kg} * \text{Fuel C content (kgC/GJ)} * (1 - \text{sequestration fraction})$

2: Running alternative scenarios

- ▶ Pretty much any study using GCAM will run alternative scenarios
 - Not an optimization model
 - “Reference” scenario should not be seen as a most likely scenario, or even business as usual: it is only a starting point
- ▶ Many possible variables of interest:
 - Different technology RD&D futures
 - Technology policies (e.g., standards, subsidies)
 - CO₂ and other GHG emissions pricing
 - Emissions constraints
 - Land use policies
 - Future energy prices or taxation
 - Different population, GDP pathways
- ▶ This section will focus on technology RD&D (Advanced and reference), carbon emissions pricing, and carbon emissions constraints

2: Configuration

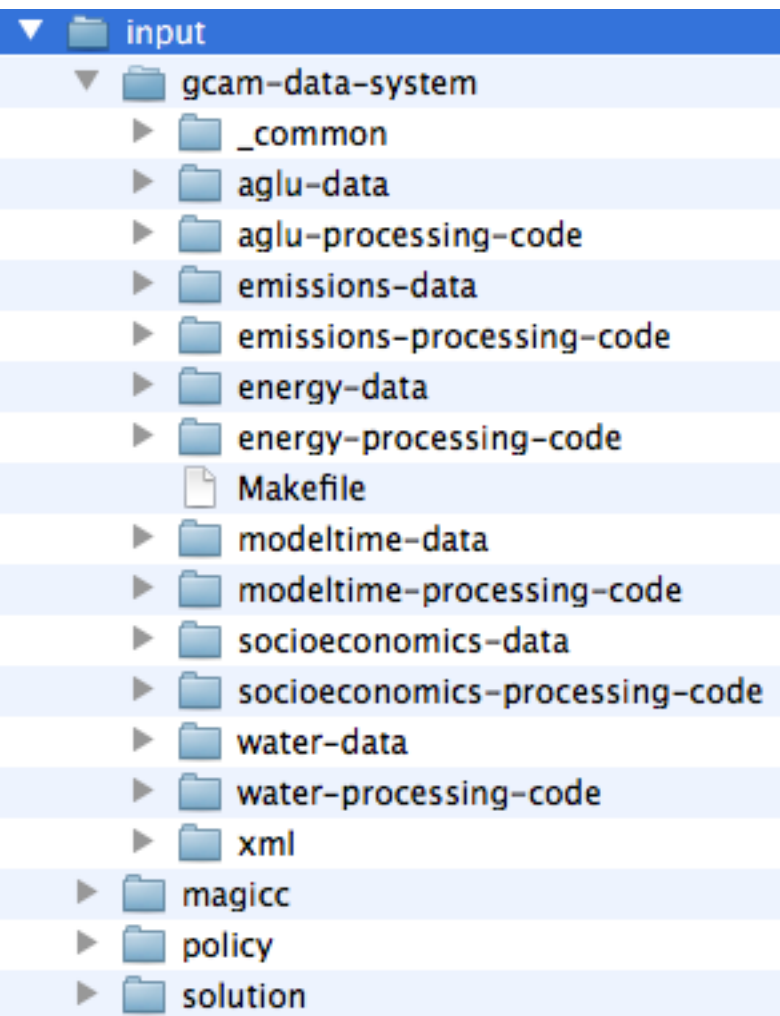
► Alternative scenarios may be run as follows:

- add additional XML files at the end of the existing ScenarioComponents
- Change the scenarioName
- Indicate whether to use target-finder (if running an end-of-century climate target)
- Indicate whether to calculate abatement cost curves

```
<Value name = "ind_urb_proc">../input/gcam-data-system/xml/emissions-  
<Value name = "nonco2_aglu">../input/gcam-data-system/xml/emissions-  
<Value name = "nonco2_energy">../input/gcam-data-system/xml/emission  
<Value name = "nonco2_fgas">../input/gcam-data-system/xml/emissions-  
<Value name = "nonco2_unmgd">../input/gcam-data-system/xml/emissions  
<Value name = "solver">../input/solution/cal_broyden_config.xml</Val  
  
<Value name = "policy">../input/policy/carbon_tax_25_5.xml</Value>  
</ScenarioComponents>  
<Strings>  
<Value name="scenarioName">CarbonTax25</Value>  
<Value name="debug-region">USA</Value>  
<Value name="MAGICC-input-dir">../input/magicc/inputs</Value>  
<Value name="MAGICC-output-dir">../output</Value>  
</Strings>  
<Bools>  
<Value name="CalibrationActive">1</Value>  
<Value name="BatchMode">0</Value>  
<Value name="find-path">0</Value>  
<Value name="createCostCurve">0</Value>  
<Value name="write-xml-db">1</Value>  
<Value name="write-access-db">0</Value>  
<Value name="print-debug-file">1</Value>  
<Value name="write-gas-emk">1</Value>  
<Value name="debugChecking">0</Value>  
<Value name="debugFindSD">0</Value>  
<Value name="simulActive">1</Value>  
<Value name="PrintDependencyGraphs">0</Value>  
<Value name="PrintValuesOnGraphs">1</Value>  
<Value name="ShowNullPaths">0</Value>  
<Value name="PrintPrices">1</Value>  
</Bools>  
<Ints>
```

2: The input folder

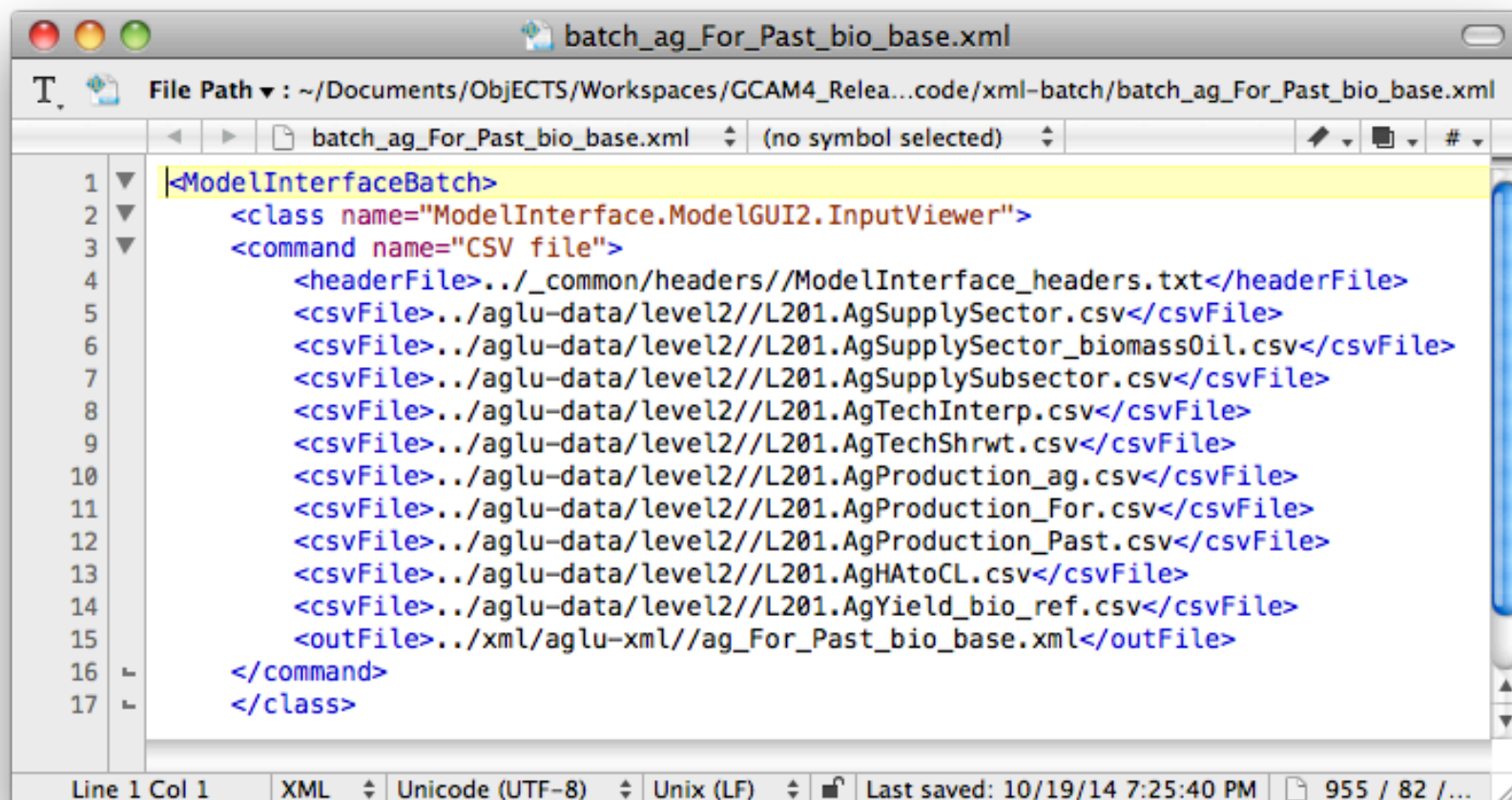
- ▶ All input xml files for a model run are stored in the input folder



- ▶ All input xml files for a model run are stored in the input folder
 - gcam-data-system generates the XML files from CSV files in the *-data folders, a header file in _common/headers, and batch XML files located in the *-code folders
 - magicc: information for the climate model
 - policy: selected policies that can be run
 - solution:

2: The gcam-data-system folder

- ▶ Batch XML files script the construction of the XML files
 - Alternative XML files can be made by creating modified and re-named batch XML files with different outFiles and that take data from modified and re-named CSV files



```
<?xml version="1.0" encoding="UTF-8" ?>
<ModelInterfaceBatch>
  <class name="ModelInterface.ModelGUI2.InputViewer">
    <command name="CSV file">
      <headerFile>../_common/headers//ModelInterface_headers.txt</headerFile>
      <csvFile>../aglu-data/level2//L201.AgSupplySector.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgSupplySector_biomassOil.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgSupplySubsector.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgTechInterp.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgTechShrwt.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgProduction_ag.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgProduction_For.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgProduction_Past.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgHAtoCL.csv</csvFile>
      <csvFile>../aglu-data/level2//L201.AgYield_bio_ref.csv</csvFile>
      <outFile>../xml/aglu-xml//ag_For_Past_bio_base.xml</outFile>
    </command>
  </class>
</ModelInterfaceBatch>
```

Line 1 Col 1 XML Unicode (UTF-8) Unix (LF) Last saved: 10/19/14 7:25:40 PM 955 / 82 / ...

```

<world>
  <region name="USA">
    <ghgpolicy name="CO2">
      <market>global</market>
      <isFixedTax>1</isFixedTax>
      <fixedTax year="2020">20</fixedTax>
      <fixedTax year="2035">41.6</fixedTax>
      <fixedTax year="2050">86.4</fixedTax>
      <fixedTax year="2065">179.7</fixedTax>
      <fixedTax year="2080">373.6</fixedTax>
      <fixedTax year="2095">776.7</fixedTax>
      <fixedTax year="2100">991.3</fixedTax>
    </ghgpolicy>
  </region>
  <region name="Canada">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="EU-15">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="Europe_Non_EU">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="European Free Trade Association">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="Japan">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>

```

```

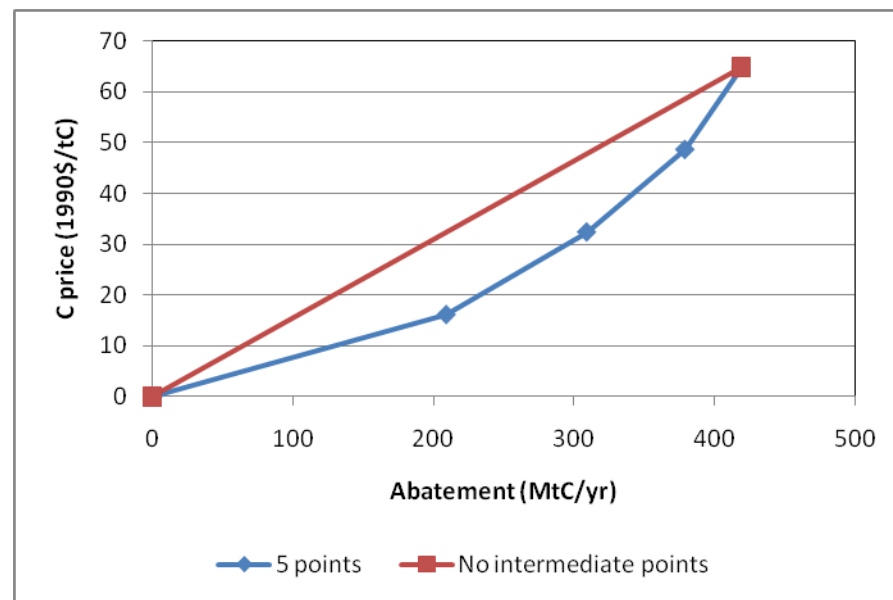
<world>
  <region name="USA">
    <ghgpolicy name="CO2">
      <market>global</market>
      <constraint year="2020">7912</constraint>
      <constraint year="2035">7880</constraint>
      <constraint year="2050">6834</constraint>
      <constraint year="2065">4980</constraint>
      <constraint year="2080">3561</constraint>
      <constraint year="2095">3191</constraint>
      <constraint year="2100">3191</constraint>
    </ghgpolicy>
  </region>
  <region name="Canada">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="EU-15">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="Europe_Non_EU">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="European Free Trade Association">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>
  <region name="Japan">
    <ghgpolicy name="CO2">
      <market>global</market>
    </ghgpolicy>
  </region>

```

- ▶ A global policy is specified in one region, and all others share in the market.
 - Regional policies can be specified in individual regions
- ▶ Carbon price: model solves for emissions, given a fixed price
- ▶ Carbon constraint: model solves for carbon price, given emissions pathway.
- ▶ *Economic equilibrium is not influenced by which factor was specified*

2: Cost curves

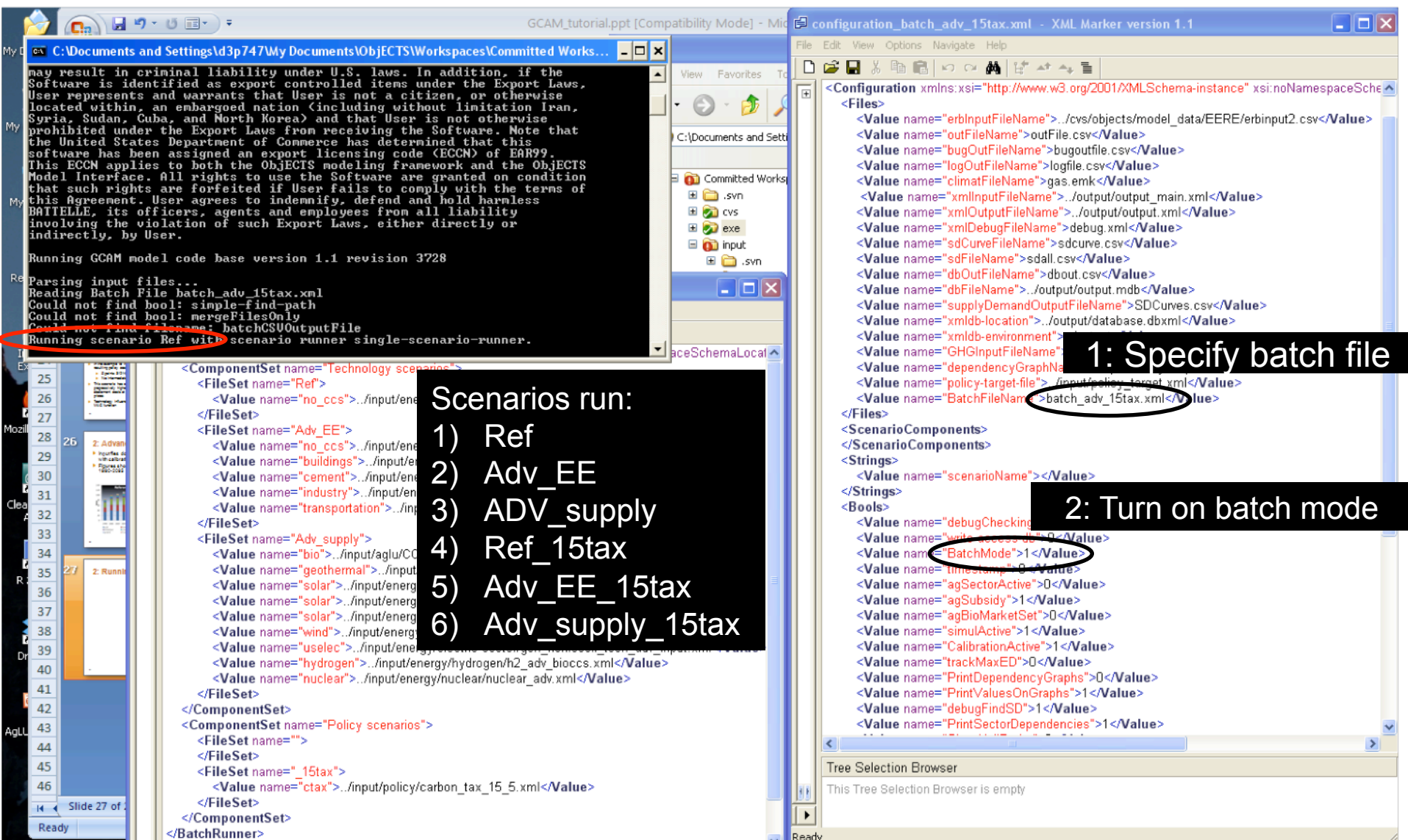
- ▶ Emissions abatement costs are calculated as the integral under the marginal abatement cost schedule.
 - By default, this is calculated as the area underneath the marginal abatement curve with five points. This setting can be changed in the configuration file; each “point” greater than 2 corresponds to a new scenario run.
- ▶ In the example to the right, the resulting policy costs are as follows:
 - ▶ 5 points: \$12148
 - ▶ No intermediate points: \$13578
- ▶ This scenario exhibits progressively higher marginal abatement costs with respect to abatement level
- ▶ Technology influences the shape of the MAC function



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

2: Running in batch mode



3: Changing input files

- ▶ XML files may be built from individual CSV files
 - Each CSV is only one table, so these will tend to be single-parameter XML files
- ▶ XML files may be built from provided or modified CSV files using batch XML files
 - All batch XML files can be run simultaneously using the provided makefiles
- ▶ XML files may be changed by hand
 - Search and replace may be useful
 - However:
 - This can be tedious
 - Directly changing XML files leaves no paper trail

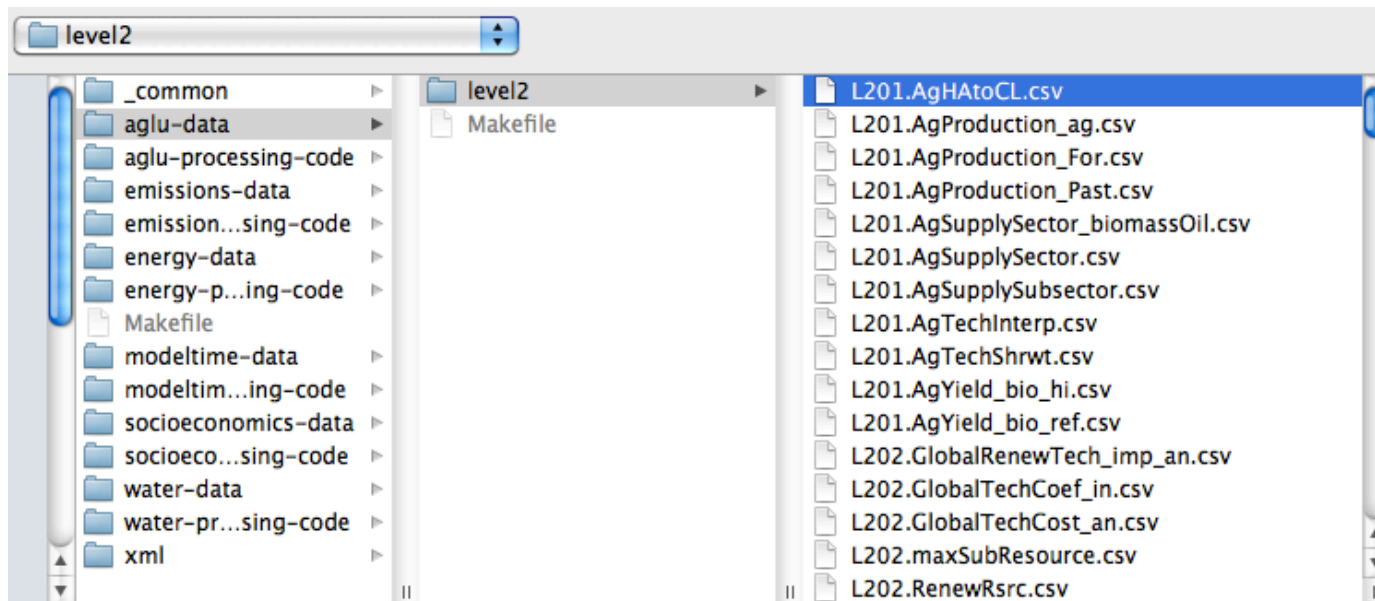
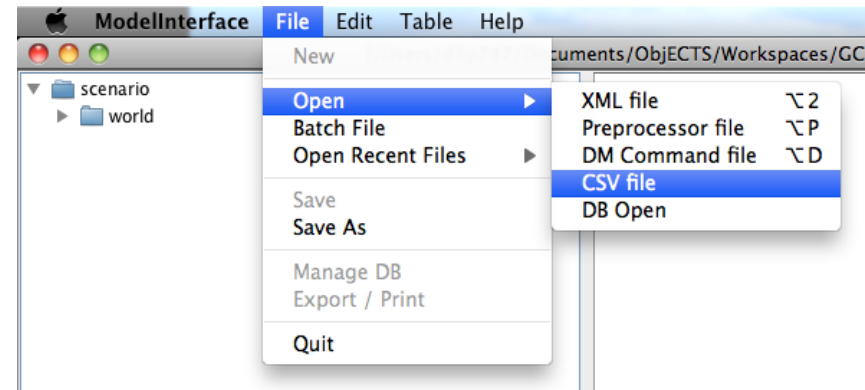


Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

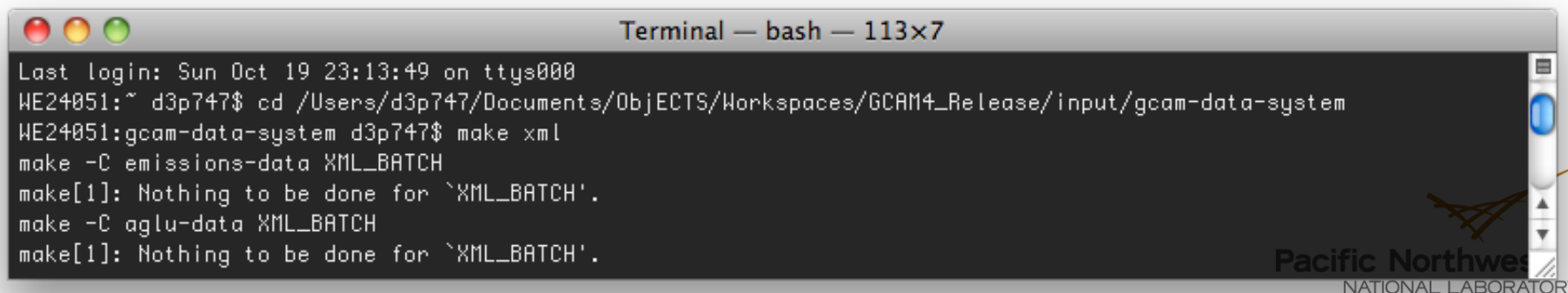
3: Building XML files from individual CSVs

1. Make desired changes to `*-data/level2/*.csv` file, and re-save (probably with a different file name)
2. In ModelInterface: File -> Open -> Open CSV File
3. Select CSV file
4. Select header file: `_common/headers/ModelInterface_headers.txt`
5. Save the resulting XML file



3: Building new XML files from batch XML files

- ▶ Batch XML files can be run individually after re-setting the file paths from the model interface to the specified locations
 - Could also copy a model interface application folder into the gcam-data-system folder
- ▶ Users can build the full suite of XML files by running all batch XML files from a command prompt, but this may require some additional software that is not part of the release package
 - Mac users will need to install Xcode
 - PC users will need to install GnuWin

A screenshot of a macOS Terminal window titled "Terminal — bash — 113x7". The window shows a user logging in on Sun Oct 19 23:13:49 on ttys000. The user runs the command `cd /Users/d3p747/Documents/ObJECTS/Workspaces/GCAM4_Release/input/gcam-data-system`. Then, inside the `gcam-data-system` directory, the user runs `make xml`. The terminal output shows `make -C emissions-data XML_BATCH` and `make[1]: Nothing to be done for `XML_BATCH'.`, followed by `make -C aglu-data XML_BATCH` and another `make[1]: Nothing to be done for `XML_BATCH'.`. The Pacific Northwest National Laboratory logo is visible in the bottom right corner of the terminal window.

```
Terminal — bash — 113x7
Last login: Sun Oct 19 23:13:49 on ttys000
WE24051:~ d3p747$ cd /Users/d3p747/Documents/ObJECTS/Workspaces/GCAM4_Release/input/gcam-data-system
WE24051:gcam-data-system d3p747$ make xml
make -C emissions-data XML_BATCH
make[1]: Nothing to be done for `XML_BATCH'.
make -C aglu-data XML_BATCH
make[1]: Nothing to be done for `XML_BATCH'.
```

3: Run adjusted file

- ▶ Add the new file(s) to the configuration file
- ▶ Make sure the order among other add-on files in the configuration is correct; the last file to over-write a given parameter is the one that takes precedence

```
<Value name = "demand">../input/gcam-data-system/xml/aglu/xml/demand_input.xml</Value>
<Value name = "ind_urb_proc">../input/gcam-data-system/xml/emissions-xml/ind_urb_processing_sectors.xml</Value>
<Value name = "nonco2_aglu">../input/gcam-data-system/xml/emissions-xml/all_aglu_emissions.xml</Value>
<Value name = "nonco2_energy">../input/gcam-data-system/xml/emissions-xml/all_energy_emissions.xml</Value>
<Value name = "nonco2_fgas">../input/gcam-data-system/xml/emissions-xml/all_fgas_emissions.xml</Value>
<Value name = "nonco2_unmgd">../input/gcam-data-system/xml/emissions-xml/all_unmgd_emissions.xml</Value>
<Value name = "solver">../input/solution/cal_broyden_config.xml</Value>

<Value name = "ag_prodchange">../input/gcam-data-system/xml/aglu-xml/ag_prodchange_rcp45_noresm_gepic.xml</Value>

</ScenarioComponents>
<Strings>
  <Value name="scenarioName">AgImpacts_4p5_NorESM_GEPIC</Value>
  <Value name="debug-region">USA</Value>
  <Value name="MAGICC-input-dir">../input/magicc/inputs</Value>
```



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

4: Debugging

- ▶ This section will focus on the most common problems
- ▶ It will not attempt to cover everything that could happen, because there would be way too much to cover
- ▶ It will proceed accordingly
 1. Running the model
 2. Querying output
 3. Building XML files

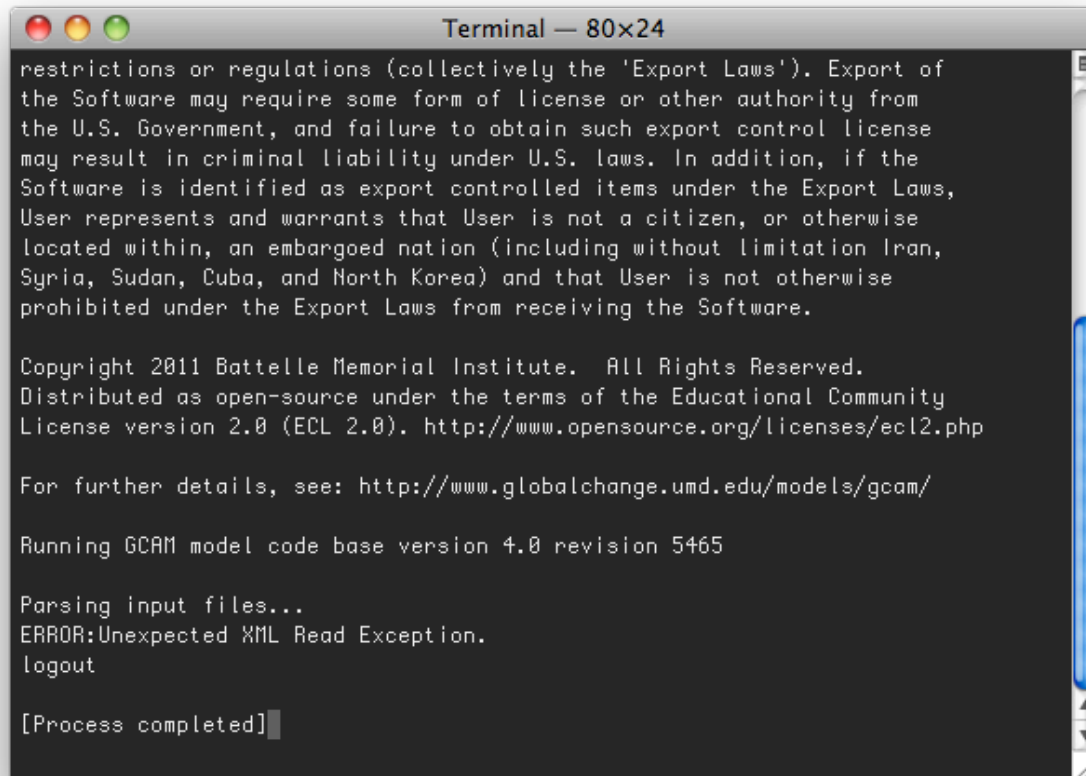


Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

4: Configuration/input errors

► Problem: Immediate crash

A screenshot of a macOS Terminal window titled "Terminal — 80x24". The window has a dark background with light gray text. The text inside the terminal shows a series of lines: a paragraph about export laws, copyright information for Battelle Memorial Institute, a URL for the Educational Community License, another URL for further details, the version of the GCAM model code, a message about parsing input files, an error message "ERROR:Unexpected XML Read Exception.", a "logout" message, and finally "[Process completed]".

```
Terminal — 80x24
restrictions or regulations (collectively the 'Export Laws'). Export of
the Software may require some form of license or other authority from
the U.S. Government, and failure to obtain such export control license
may result in criminal liability under U.S. laws. In addition, if the
Software is identified as export controlled items under the Export Laws,
User represents and warrants that User is not a citizen, or otherwise
located within, an embargoed nation (including without limitation Iran,
Syria, Sudan, Cuba, and North Korea) and that User is not otherwise
prohibited under the Export Laws from receiving the Software.

Copyright 2011 Battelle Memorial Institute. All Rights Reserved.
Distributed as open-source under the terms of the Educational Community
License version 2.0 (ECL 2.0). http://www.opensource.org/licenses/ecl2.php

For further details, see: http://www.globalchange.umd.edu/models/gcam/

Running GCAM model code base version 4.0 revision 5465

Parsing input files...
ERROR:Unexpected XML Read Exception.
logout

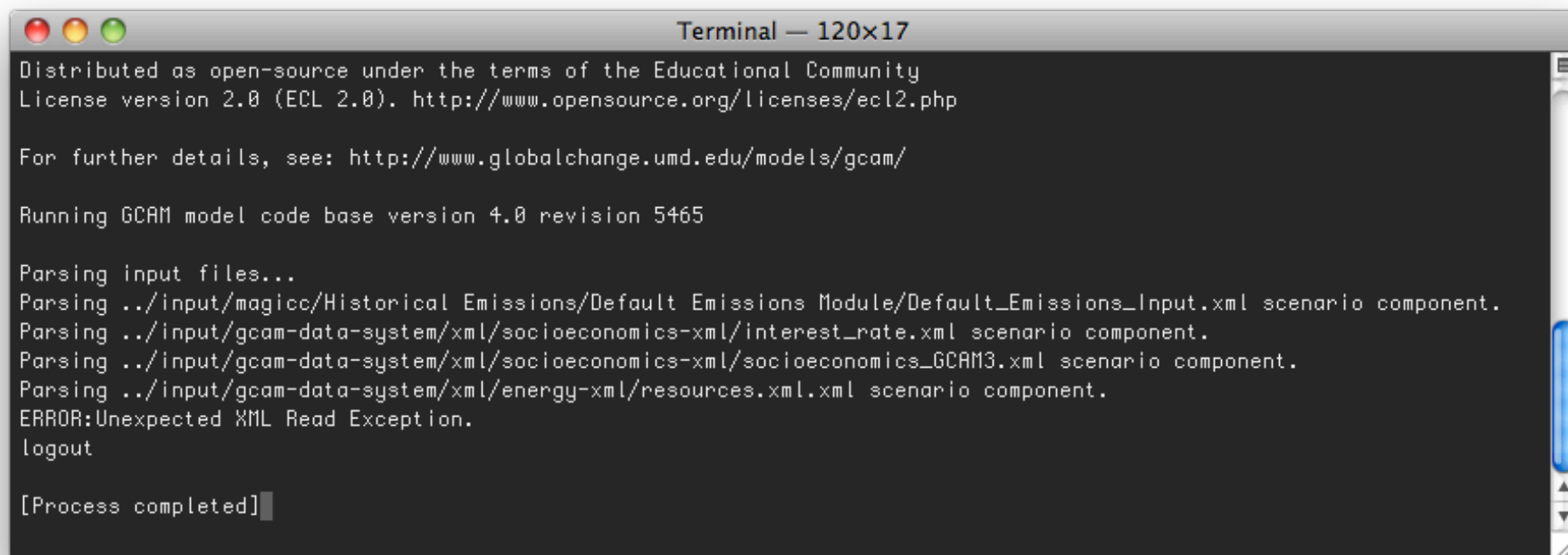
[Process completed]
```

► Possible causes

- The XMLInputFileName or BatchFileName (or their pathways) are incorrect
- The project's working directory needs to be set to the exe/ folder. Sometimes it defaults to the cvs/objects/build/*/ folder

4: Configuration/input errors

- Problem: crash while reading in the ScenarioComponents XML files



```
Terminal — 120x17
Distributed as open-source under the terms of the Educational Community
License version 2.0 (ECL 2.0). http://www.opensource.org/licenses/ecl2.php

For further details, see: http://www.globalchange.umd.edu/models/gcam/

Running GCM model code base version 4.0 revision 5465

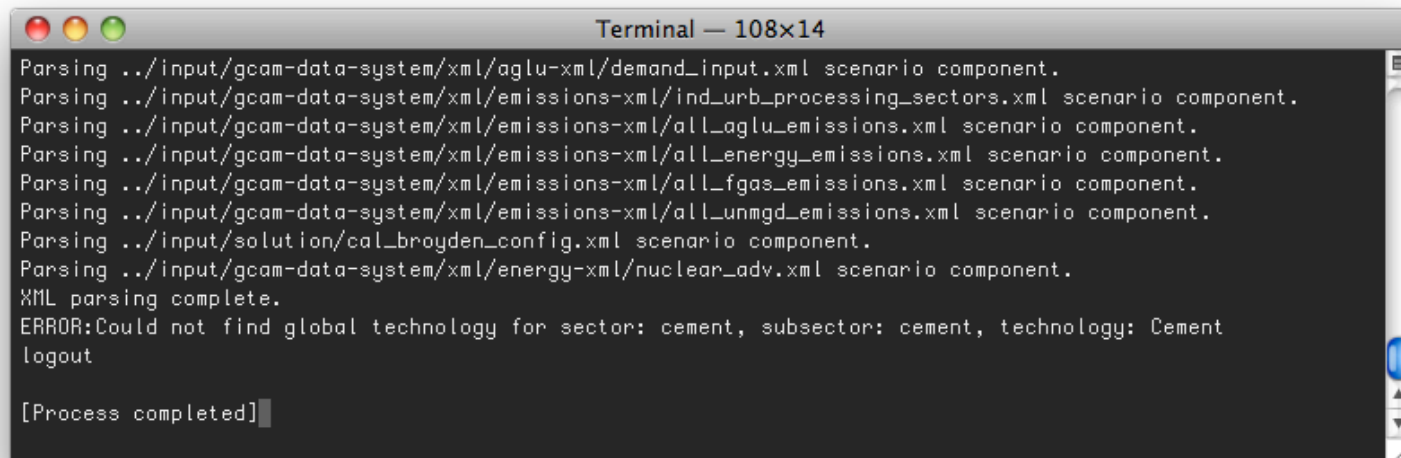
Parsing input files...
Parsing ../input/magicc/Historical Emissions/Default Emissions Module/Default_Emissions_Input.xml scenario component.
Parsing ../input/gcam-data-system/xml/socioeconomics-xml/interest_rate.xml scenario component.
Parsing ../input/gcam-data-system/xml/socioeconomics-xml/socioeconomics_GCAM3.xml scenario component.
Parsing ../input/gcam-data-system/xml/energy-xml/resources.xml.xml scenario component.
ERROR:Unexpected XML Read Exception.
logout

[Process completed]
```

- The problem: the last file read was mis-typed. Note the second “.xml”—this is a common error.

4: Configuration/input errors

- Problem: crash after XML parsing, before first period



```
Terminal — 108x14
Parsing ../input/gcam-data-system/xml/aglu-xml/demand_input.xml scenario component.
Parsing ../input/gcam-data-system/xml/emissions-xml/ind_urb_processing_sectors.xml scenario component.
Parsing ../input/gcam-data-system/xml/emissions-xml/all_aglu_emissions.xml scenario component.
Parsing ../input/gcam-data-system/xml/emissions-xml/all_energy_emissions.xml scenario component.
Parsing ../input/gcam-data-system/xml/emissions-xml/all_fgas_emissions.xml scenario component.
Parsing ../input/gcam-data-system/xml/emissions-xml/all_unmgd_emissions.xml scenario component.
Parsing ../input/solution/cal_broyden_config.xml scenario component.
Parsing ../input/gcam-data-system/xml/energy-xml/nuclear_adv.xml scenario component.
XML parsing complete.
ERROR:Could not find global technology for sector: cement, subsector: cement, technology: Cement
logout

[Process completed]
```

- The problem: mis-spelled a technology name (Cement instead of cement). Strings in GCAM are case-sensitive.

```
<scenario>
  <world>
    <region name="USA">
      <supplysector name="cement">
        <output-unit>Mt</output-unit>
        <input-unit>EJ or Mt</input-unit>
        <price-unit>1975$/kg</price-unit>
        <logit-exponent fillout="1" year="197">
          <keyword final-energy="industry"/>
        <subsector name="cement">
          <logit-exponent fillout="1" year="197">
            <share-weight fillout="1" year="197">
              <interpolation-rule apply-to="share">
                <interpolation-function name="f">
                  </interpolation-function>
                </interpolation-rule>
              <stub-technology name="Cement">
```

4: Errors from changes to input files

- The model does not calibrate or solve the base years:

```
Terminal — objects — 194x32

Model run beginning.
Period 0: 1975
Model solved with last period's prices.

Period 1: 1990
Calibration failed by 2.4 % Technology: crude oil      Region: USA      Sector: regional oil Subsector: crude oil      Output: 34.26      Calibration: 33.47      relativeDiff: 0.02361 Sect
orOutput: 34.76      SectorShare: 0.9628
Calibration failed by 1.5 % Technology: Canada unconventional oil Region: USA      Sector: traded unconventional oil Subsector: Canada unconventional oil Output: 0.7938      Calibration: 0.7
822      relativeDiff: 0.01482      SectorOutput: 0.7938      SectorShare: 0.9854
Calibration failed by 10 % Technology: natural gas      Region: USA      Sector: gas processing Subsector: natural gas      Output: 20.09      Calibration: 18.2      relativeDiff: 0.104 Se
ctorOutput: 20.19      SectorShare: 0.9014
Calibration failed by 2.4 % Technology: oil refining      Region: USA      Sector: refining      Subsector: oil refining Output: 32.44      Calibration: 31.69      relativeDiff: 0.02361 Sect
orOutput: 32.44      SectorShare: 0.9769
Calibration failed by 66 % Technology: coal (conv pul)      Region: USA      Sector: electricity Subsector: coal      Output: 9.997      Calibration: 6.029      relativeDiff: 0.6581 Sect
orOutput: 15.88      SectorShare: 0.3797
Calibration failed by 66 % Technology: gas (steam/CT)      Region: USA      Sector: electricity Subsector: gas      Output: 0.7229      Calibration: 0.436      relativeDiff: 0.6581 Sect
orOutput: 15.88      SectorShare: 0.02746
Calibration failed by 66 % Technology: gas (CC)      Region: USA      Sector: electricity Subsector: gas      Output: 0.9788      Calibration: 0.5903      relativeDiff: 0.6581 Sect
orOutput: 15.88      SectorShare: 0.03717
Calibration failed by 66 % Technology: refined liquids (steam/CT) Region: USA      Sector: electricity Subsector: refined liquids Output: 0.7474      Calibration: 0.4507      relativeDiff: 0.
6581      SectorOutput: 15.88      SectorShare: 0.02839
Model did not calibrate successfully in period 1
ERROR:Model did not solve within set iteration 507
ERROR:Currently Unsolved Markets:
ERROR:Unsolved Part 1: Solvable Markets
ERROR:Market,      X,      XL,      XR,      ED,      EDL,      EDR,      RED,      brk, Supply,      Demand,      Mrk Type,
ERROR:Unsolved Part 2: Unsolvable Markets Not Cleared
ERROR:Market,      X,      XL,      XR,      ED,      EDL,      EDR,      RED,      brk, Supply,      Demand,      Mrk Type,
ERROR:globalcoal      , 0.435      , 0.435      , 0.435      , 10.799      , -19.6771      , -19.6771      , 0.104262      , 0      , 92.7763      , 103.575      , Normal      ,
ERROR:globalcrude oil      , 1.37      , 1.37      , 1.37      , 0.785469      , 10.0966      , 10.0966      , 0.00574971      , 0      , 135.825      , 136.61      , Normal      ,
ERROR:globalnatural gas      , 0.812      , 0.812      , 0.812      , 1.09473      , 4.39427      , 4.39427      , 0.0262305      , 0      , 70.3391      , 72.2339      , Normal      ,
ERROR:
```

- The problem: The base-year electricity input-output coefficient of cement production was changed, causing system-wide imbalances between electricity demand and supply. Note that the sectors that “fail” calibration and the markets that don’t solve are unrelated to the cause of the problem.

4: Model not solving with policy

- The model fails to solve in some period

```
Terminal — 187x23
Error adding to supply in marketplace for: OtherMeat_Fish, region: Russia, value: nan
Error adding to supply in marketplace for: OtherMeat_Fish, region: EU-12, value: nan
Error adding to supply in marketplace for: OtherMeat_Fish, region: Europe_Eastern, value: nan
Error adding to supply in marketplace for: OtherMeat_Fish, region: Japan, value: nan
Error adding to supply in marketplace for: OtherMeat_Fish, region: Russia, value: nan
ERROR:Model did not solve within set iteration 2513
ERROR:Currently Unsolved Markets:
ERROR:Unsolved Part 1: Solvable Markets
ERROR:Market,      X,      XL,      XR,      ED,      EDL,      EDR,      RED,      brk, Supply, Demand, Mrk Type,
ERROR:Unsolved Part 2: Unsolvble Markets Not Cleaned
ERROR:Market,      X,      XL,      XR,      ED,      EDL,      EDR,      RED,      brk, Supply, Demand, Mrk Type,
ERROR:EU-12district heat      , 244.893 , 4.78357 , 4.78357 , -0.0119646, 0 , 0 , 1 , 0 , 0 , -0.0119646, Normal ,
ERROR:Europe_Easterndistrict heat      , 228.355 , 4.79679 , 4.79679 , -0.0035781, -2.22045e-16, -2.22045e-16, 1 , 0 , 0 , -0.0035781, Normal ,
ERROR:Europe_Non-EUdistrict heat      , 251.278 , 4.87022 , 4.87022 , -0.00014465, 0 , 0 , 1 , 0 , 0 , -0.00014465, Normal ,
ERROR:Russiadistrict heat      , 245.597 , 4.80869 , 4.80869 , -0.00589677, 8.88178e-16, 8.88178e-16, 1 , 0 , 0 , -0.00589677, Normal ,
ERROR:
Period 6: 2025
^C
logout
[Process completed]
```

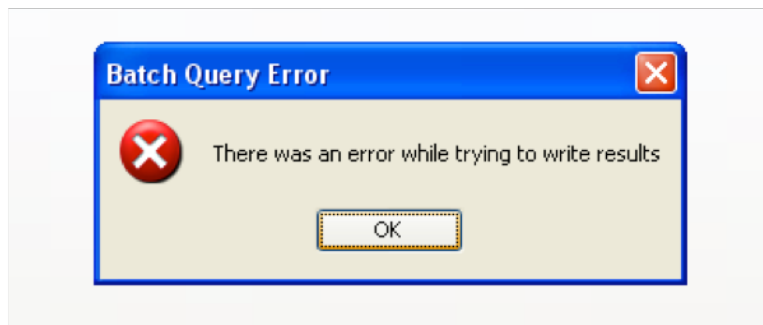
- The problem: An extremely high carbon tax (\$25,000/tC) was implemented in 2020. Solution failure is more likely with carbon emissions constraints than taxes, particularly if land use change emissions are included in the cap.



Pacific Northwest
NATIONAL LABORATORY

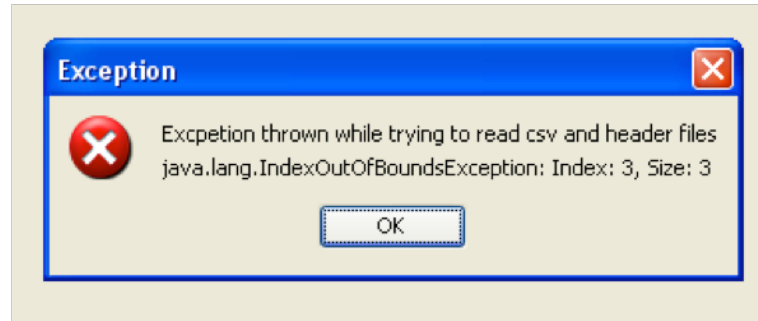
4: Queries – general

- ▶ **Message: “The query returned no results”**
 - The market may not exist (e.g. C price in a non-policy run)
 - The syntax of the XPATH may be wrong (e.g. not enough slashes)
- ▶ **Nothing at all prints out (not even a warning message)**
 - The syntax of the XPATH is incorrect. Check that all parentheses are closed.
- ▶ **Batch query error:**



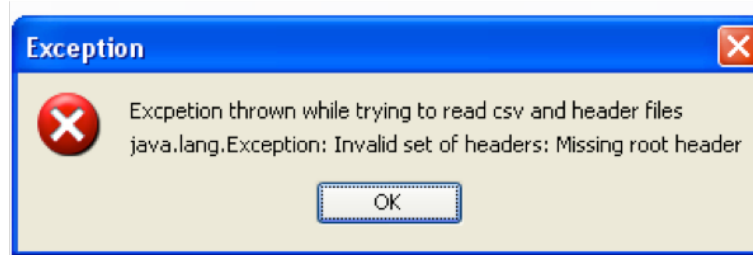
- The Excel workbook being written to was open during the export

4: Building XML files - general



- ▶ The model interface was expecting data where there was a missing value. The missing value/column was in the third column. Either:
 - The header file has too many entries with “+” symbols. The table only has two columns, so one entry needs to be deleted from the header, or a column has to be added to the table.
 - The data table has a missing value in the third column
- ▶ Note that this warning message does not indicate which table/header caused the problem.
- ▶ Note that there is no corresponding problem for a table where not all of the data is read (i.e. a header with too few entries). This will produce a valid XML file, but may not have all of the data that was intended.

4: Building XML files - general



- ▶ There is a header in the headers file that doesn't have the following entry:
 ,scenario,

What does it all mean?

- ▶ This section focuses on the meaning of several key input parameters found throughout the input XML file set
 - Elasticities
 - Logit exponents
 - Share-weights and interpolation rules
 - Efficiencies and coefficients

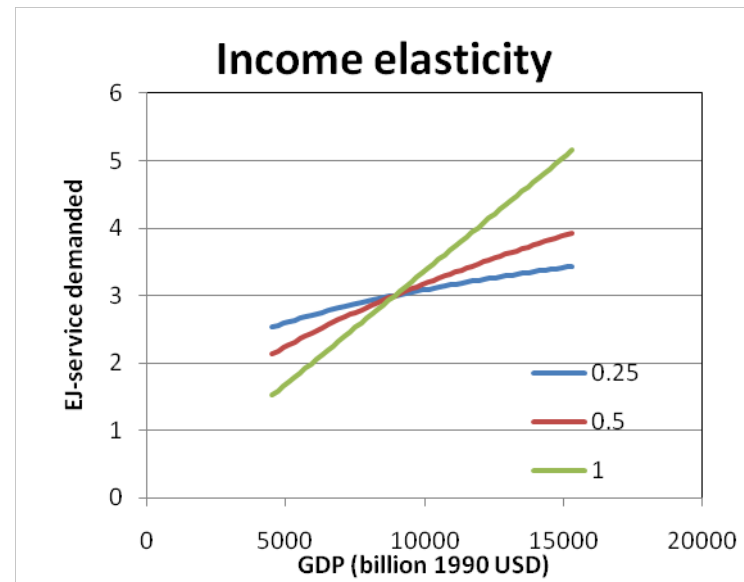
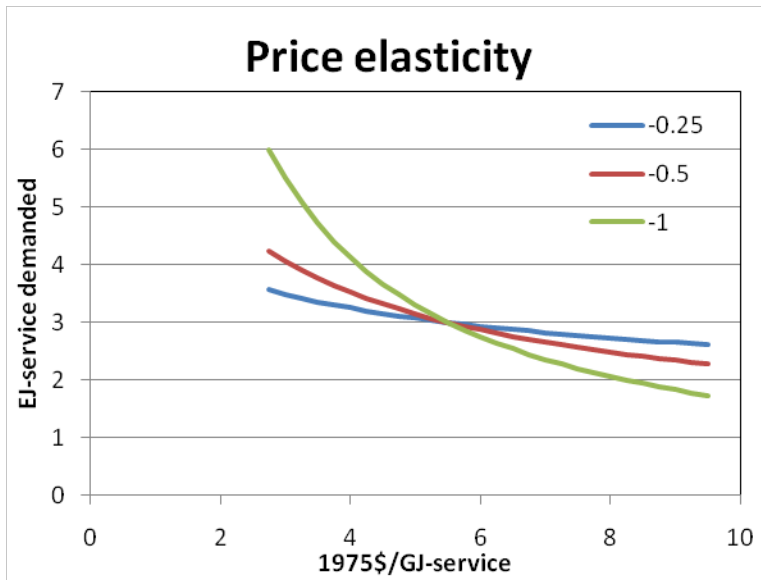


Pacific Northwest
NATIONAL LABORATORY

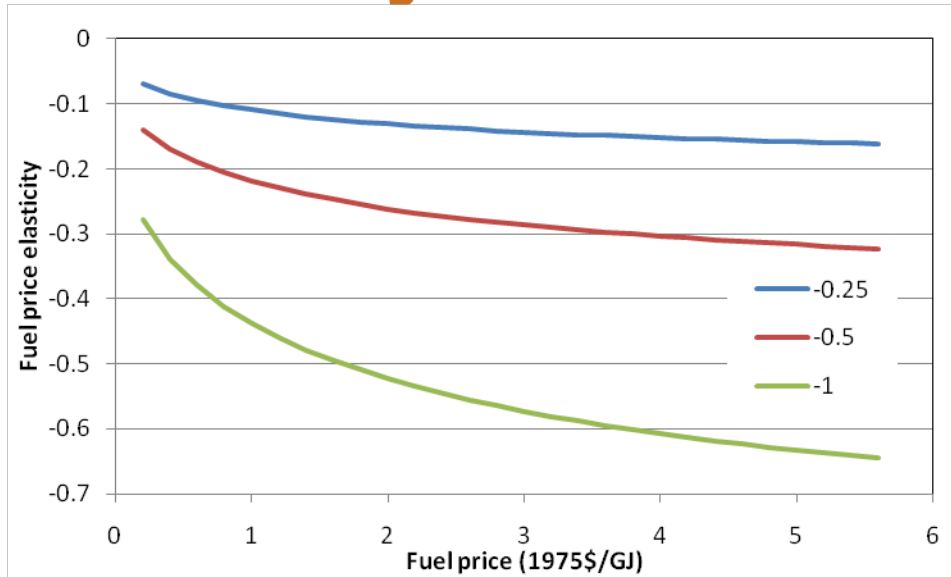
Elasticity

- ▶ Price elasticity: The percent change in demand of a good divided by the percent change in the price
- ▶ Income elasticity: The percent change in demand of a good divided by the percent change in GDP

$$D_{i,t} = D_{i,2005} \cdot \left(\frac{GDP_t}{GDP_{2005}} \right)^{inc-elas} \cdot \left(\frac{P_t}{P_{2005}} \right)^{p-elas}$$



Service price elasticity \neq fuel price elasticity

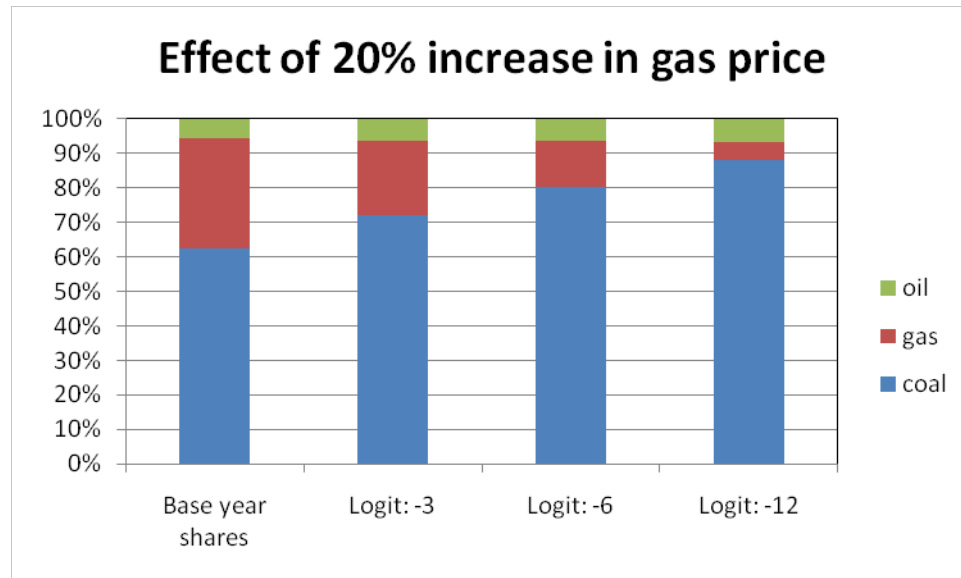


- ▶ Service price elasticities include ALL costs of providing the energy service
 - Levelized capital costs, fixed O&M, variable O&M
 - In passenger transportation, service costs may include time value costs

Logit-exponents and fuel-switching

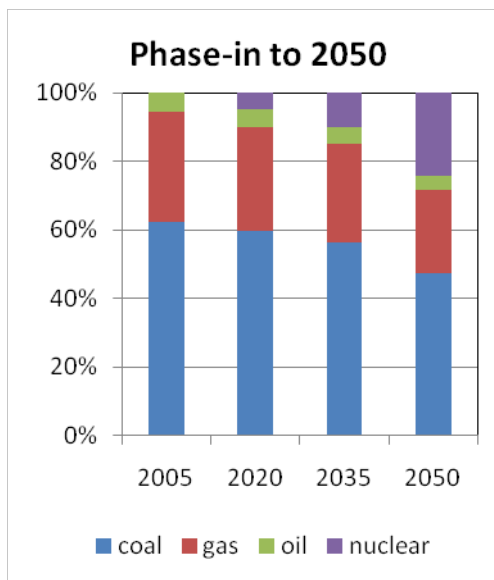
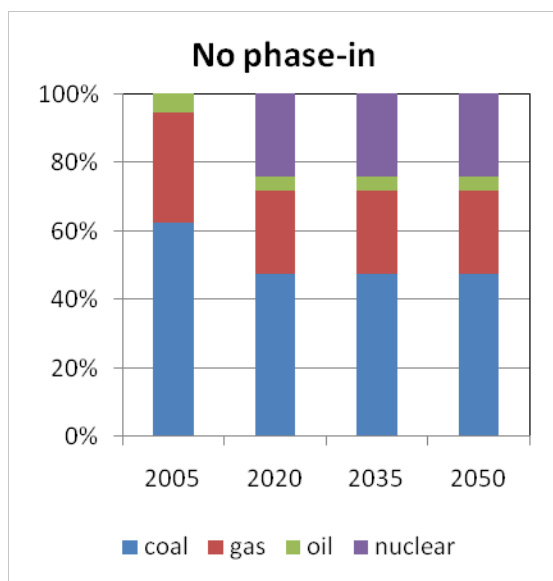
- ▶ The logit exponents control the degree of switching between technologies or fuels in response to price changes
 - Low values = low fuel-switching = strong influence of base year shares even far into the future
 - High values tend towards winner-take-all responses in response to changes in costs

$$Share_i = \frac{sw_i \cdot P_i^\beta}{\sum_i sw_i \cdot P_i^\beta}$$



Share-weights

- ▶ The roles of the share-weight
 - Calibration parameter
 - Phasing in new technologies
 - Allows gradual movement away from the base year's calibrated share weight values



- ▶ Without any phase-in, markets rapidly transition in response to introductions of new technologies

Efficiencies and coefficients

- ▶ Efficiency = output / input
- ▶ Coefficient = input / output
 - Coefficients make more sense where there are multiple inputs; a shared denominator is more intuitive than a shared numerator
- ▶ Where the input-unit and output-unit are the same, these parameters are unitless. Several exceptions include:
 - Transportation coef: BTUs fuel per vehicle kilometer
 - Cement coef: GJ of energy per kg of cement
 - Fertilizer coef: GJ of energy per kg of N fertilizer
 - Nuclear fuel efficiency: GJ of energy per kg of uranium



Pacific Northwest
NATIONAL LABORATORY

Interpolation

- ▶ Interpolation is primarily used for defining share-weight pathways into the future
 - Fixed: carry the shareweight in the “from-year” to the “to-year” with no changes. Requires a from-value.
 - Linear: linearly interpolate. Requires a from-value and a to-value, which can be set within the interpolation rule, or in the share-weight parameter.
 - S-curve: s-curve shaped function. Requires a from-value and a to-value. Note that the to-year doesn’t need to be a model time period, but if it isn’t, need to set the “to-value” within the rule.

```
<subsector name="unconventional oil">  
  <logit-exponent fillout="1" year="1975">-6</logit-exponent>  
  <share-weight fillout="1" year="2050">1</share-weight>  
  <interpolation-rule apply-to="share-weight" from-year="2010" to-year="2185">  
    <to-value>2</to-value>  
    <interpolation-function name="s-curve"/>  
  </interpolation-rule>
```



Pacific Northwest
NATIONAL LABORATORY

3: Adjusting queries

- Changes can be made in the Main_queries.xml file, or by opening up a database in the model GUI
 - Note that label re-write lists for aggregated queries can not be accessed from the model GUI
 - X-Axis name is almost always year; y-axis name is the same as the series name.
 - XPATH has the specific query instructions



3: Adjusting queries in XPATH

- ▶ Generally, copy an existing query first (Ctrl-C, Ctrl-V), similar to the one that is sought
- ▶ Base query XPATH: `*[@type='resource']//output/node()`
 - This queries output of all elements tagged as “resources”
 - To limit the query to coal: **and ()**
 - `*[@type='resource' and (@name='coal')]//output/node()`
 - To limit the query to fossil fuels: **and (...or...)**
 - `*[@type='resource' and (@name='coal' or @name='crude oil' or @name='unconventional oil' or @name='natural gas')]//output/node()`
 - To remove non-energy resources: **and not (...or...)**
 - `*[@type='resource' and not (@name='Scavenging' or @name='limestone' or @name='misc emissions sources')]//output/node()`
 - To aggregate across all of the fossil fuels: **(:collapse:)**
 - `*[@type='resource' (:collapse:) and (@name='coal' or @name='crude oil' or @name='unconventional oil' or @name='natural gas')]//output/node()`



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

3: Adjusting queries in XPATH

- ▶ Where information is low in a hierarchy, one can choose how many levels of the hierarchy to show in the output:
- ▶ Base query XPATH: `*[@type = 'sector' and ((@name='gas processing'))]// *[@type = 'technology']/*[@type='output' (:collapse:)]/physical-output/node()`

Gas production by technology

scenario	region	sector	technology	1990	2005	2020
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	biomass gasification	0.031	0.160	0.159
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	coal gasification	0.136	0.046	0.067
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	natural gas	18.267	21.692	23.517

- The double slash (`//`) indicates to go down by more than one level
- To also write out the subsector: only one `/*`
- `*[@type = 'sector' and ((@name='gas processing'))] /*[@type = 'subsector']/*[@type = 'technology']/*[@type='output' (:collapse:)]/physical-output/node()`

Gas production by technology

scenario	region	sector	subsector	technology	1990	2005	2020
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	biomass gasification	biomass gasification	0.031	0.160	0.159
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	coal gasification	coal gasification	0.136	0.046	0.067
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	natural gas	natural gas	18.267	21.692	23.517



The End