

Global Change Assessment Model (GCAM) Tutorial

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General Outline

- ▶ Preliminary: Software to Download
- ▶ Part 1: Connecting to AWS
- ▶ Part 2: Running the GCAM Reference Scenario
 - Location of key files
 - How to run the model
 - Looking at, interpreting, and exporting the output
- ▶ Part 3: Running alternative scenarios
 - Including additional “add-on” XML files
 - Policies
 - Running multiple scenarios in batch mode
- ▶ Part 4: Debugging
- ▶ Part 5: Theory and meaning of parameters
- ▶ Appendix: Additional resources

Preliminary: software to download

► AWS Downloads

■ X11 Forwarding Software

- Windows: Xming (<https://sourceforge.net/projects/xming/>)
- Mac: Xquartz (<https://www.xquartz.org>)

■ Command Line Interface

- Windows: PuTTY (<https://www.chiark.greenend.org.uk/~sgtatham/putty/latest.html>)
- Mac: Terminal (Included)

■ Remote Server GUI

- Windows: WinSCP (<https://winscp.net/eng/download.php>)
- Mac: FileZilla (<https://filezilla-project.org/>)

► 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: BBEdit: <http://www.barebones.com/products/bbedit/>
- Mac: XML Author: <http://www.oxygenxml.com/>

■ A program to diff files

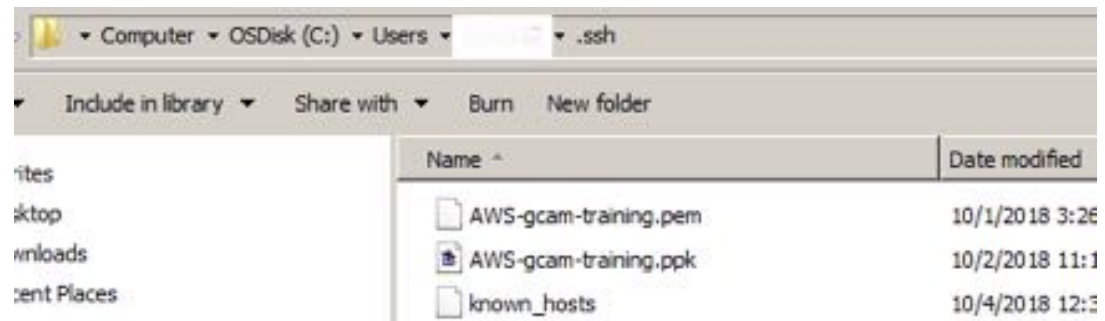
- Windows: Tortoise Git: <https://tortoisegit.org/download/>
- Mac or Windows: DiffMerge: <https://sourcegear.com/diffmerge/downloads.php>

Preliminary: more useful links

- ▶ GCAM documentation: <http://jgcri.github.io/gcam-doc/>

1: Setting up AWS

- ▶ Amazon Web Services creates a copy of an existing server with a pre-compiled version of GCAM.
- ▶ Download and place your private key file, “AWS-gcam-training.pem” in the folder “.ssh” within your user directory. If it does not exist, create it by naming it “.ssh.”
 - On Mac, save it wherever you like, ideally with a simple path
- ▶ Connect to the remote server
 - Windows: WinSCP, PuTTY, Xming
 - Mac: Terminal, Xquartz



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1: Configuring and Using WinSCP (Windows)

- ▶ Host name: IP address of AWS server
- ▶ Port: 22
- ▶ User Name: ec2-user



- ▶ In advanced settings, open SSH -> Authentication. Use the browser “...” to find your private key file at “C:/Users/[username]/.ssh/”. When saved, WinSCP will automatically convert the .pem file to a .ppk file, readable by both WinSCP and PuTTY.
- ▶ Once logged in you will be able to interact with files and folders as in a system browser

1: Configuring and Using FileZilla (Mac)

- ▶ Open settings, open Connection -> SFTP. Click “Add keyfile...” to find your private key file. When saved, FileZilla will ask to convert the .pem file to a supported format. Click “yes” and save it with the file extension “.ppk”.
- ▶ Once logged in you will be able to interact with files and folders as in a system browser
- ▶ Click button in top left and add “new site”
 - Host: IP address of AWS server
 - Protocol: SFTP
 - Port: 22
 - Logon type: Normal
 - User Name: ec2-user
 - Password: left blank
- ▶ You will be asked if you trust this host. Click “OK”.

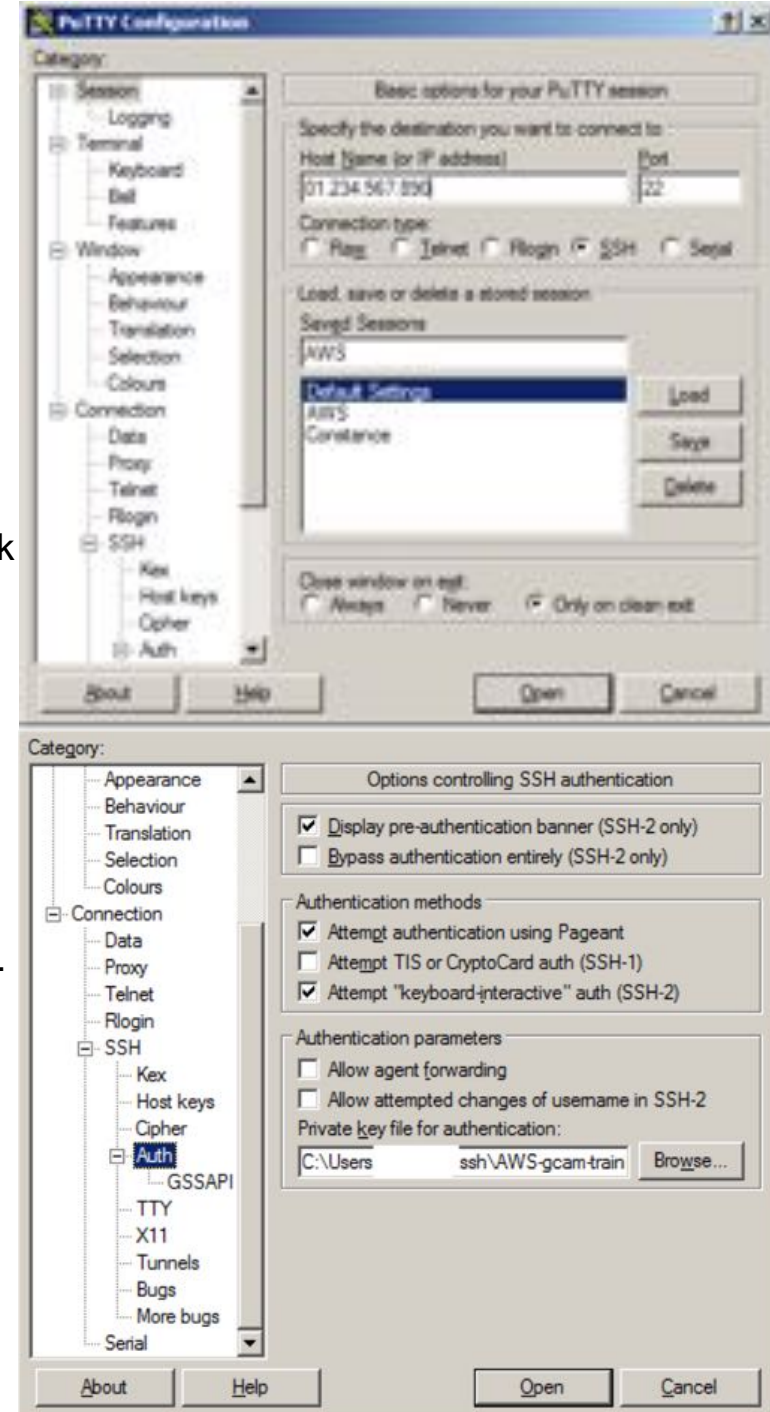


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1: Using PuTTY to Connect (Windows)

- ▶ Open your X11 software (Windows: Xming)
- ▶ Open PuTTY; it will open a configuration window. In the window enter your IP address and the default port, 22.
- ▶ Under connection/SSH/Auth, click browse next to “Private key file for authentication” to find your key file. Use the .ppk file saved by WinSCP.
- ▶ Under connection/SSH/X11, check the box “enable X11 forwarding”
- ▶ Return to “Session” and click “save” to save your preferences in a preset. In later logins, load this preset.
- ▶ Click “Open.” You will now have access to a terminal window requesting login
- ▶ Enter your Username, “ec2-user.”
- ▶ Putty uses standard command line commands to navigate. For a list of a few of these commands, see: <https://www.codecademy.com/articles/command-line-commands>

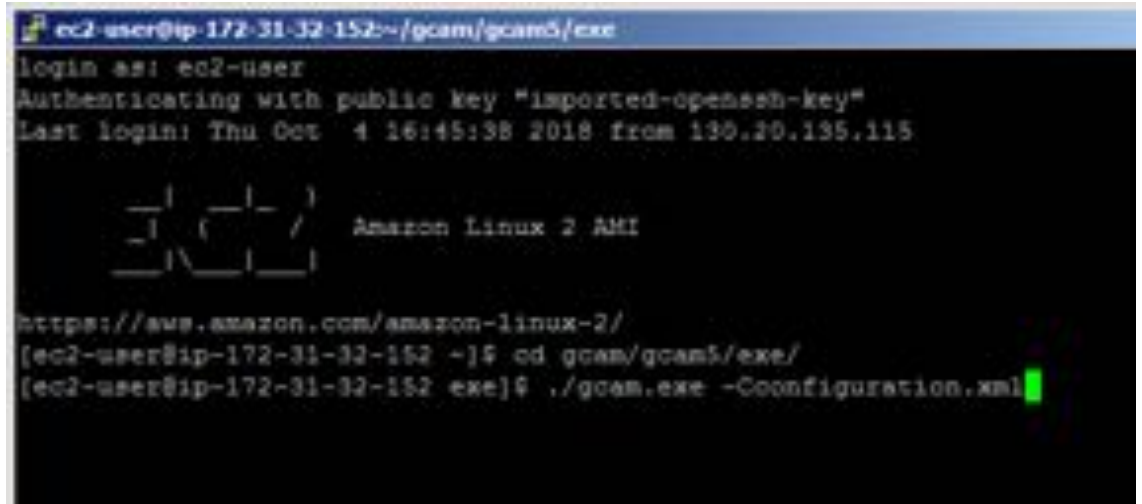


1: Using Terminal to Connect (Mac)

- ▶ Open you X11 software (Xquartz)
- ▶ Open a terminal window
- ▶ cd to the file location of your private key
 - (you can drag and drop the path into the terminal)
 - Type “chmod 400 AWS-gcam-training.pem”. This sets your permissions so only you can see your private key. Only do this once.
- ▶ Type in “ssh -Y -i AWS-gcam-training.pem [ec2-user@xx.xxx.xxx.xxx](#)”
 - xx.xxx is the provided IP address of the AWS server

2: Running the Reference Scenario

- 1) In your folder browser (WinSCP or FileZilla), 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) In your command line (Windows:PuTTY, Mac:Terminal), navigate to exe/ and run gcam.exe
 - 1) Cd gcam/gcam5/exe/
 - 2) ./gcam.exe -Cconfiguration.xml



2: Configuration: the “Files” section

```
<Files>
  <Value name="xmlInputFileName">...</Value>
  <Value name="BatchFileName">...</Value>
  <Value name="policy-target-file">...</Value>
  <Value name="GHGInputFileName">...</Value>
  <Value write-output="1" append-scenario-name="1" name="xmlDb-location">../output/database_base.mdb</Value>
  <Value write-output="1" append-scenario-name="0" name="xmlOutputFileName">../output/output.xml</Value>
  <Value write-output="1" append-scenario-name="0" name="xmlDebugFileName">debug.xml</Value>
  <Value write-output="1" append-scenario-name="0" name="climatFileName">gas.emk</Value>
  <Value write-output="1" append-scenario-name="0" name="outFileName">outFile.csv</Value>
  <Value write-output="1" append-scenario-name="1" name="costCurvesOutputFileName">cost_curves.xml</Value>
  <Value write-output="1" append-scenario-name="0" name="batchCSVOutputFile">batch-csv-out.csv</Value>
  <Value write-output="0" append-scenario-name="0" name="supplyDemandOutputFileName">SDCurves.csv</Value>
  <Value write-output="0" append-scenario-name="0" name="dependencyGraphName">DependencyGraph.dot</Value>
  <Value write-output="0" append-scenario-name="0" name="landAllocatorGraphName">LandAllocatorGraph.dot</Value>
  <Value write-output="0" append-scenario-name="0" name="ObjectSGMFileName">ObjectSGMout.csv</Value>
  <Value write-output="0" append-scenario-name="0" name="ObjectSGMGenFileName">ObjectSGMGen.csv</Value>
  <Value write-output="0" append-scenario-name="0" name="dbFileName">../output/output.mdb</Value>
</Files>
```

Base input file. ScenarioComponents append to this.

For running multiple scenarios in sequence. Requires setting BatchMode bool to 1

For running climate target finder. Requires setting find-path bool to 1

xmlDb is where the output will be saved

- * Write-output: indicate whether to create the file
- * Append-scenario-name: indicate whether to append the scenario name to the name of the file being created

2: Configuration: Other sections

```
<Strings>
```

```
<Value name="scenarioName">Referenc
```

No spaces or special characters allowed

```
<Value name="debug-region">USA</Value>
```

```
<Value name=
```

The debug file has a lot of detail but is only written for one region

```
<Value name=
```

```
</Strings>
```

```
<Bools>
```

Always keep calibration on

```
<Value name="CalibrationAc
```

If true, appends XML files listed in BatchFileName to ScenarioComponents here

```
<Value name="BatchMode">0<
```

```
<Value name="find-path">0<
```

```
<Value name="createCostCurve
```

If true, uses policy-target-file

```
<Value name="debugChecking">0</Value>
```

```
<Value name="simulActive">1</Value>
```

```
<Value name="PrintValuesOnGraphs">1</Value>
```

```
<Value name="ShowNullPaths">0</Value>
```

```
<Value name="PrintPrices">1</Value>
```

```
</Bools>
```

```
<Ints>
```

```
<Value name="numMarketsToFindSD">10</Value>
```

```
<Value name="numPointsForSD">21</Value>
```

```
<Value name="numPointsForCO2CostCurve">5</Value>
```

```
<Value name="carbon-output-start-year">1705</Value>
```

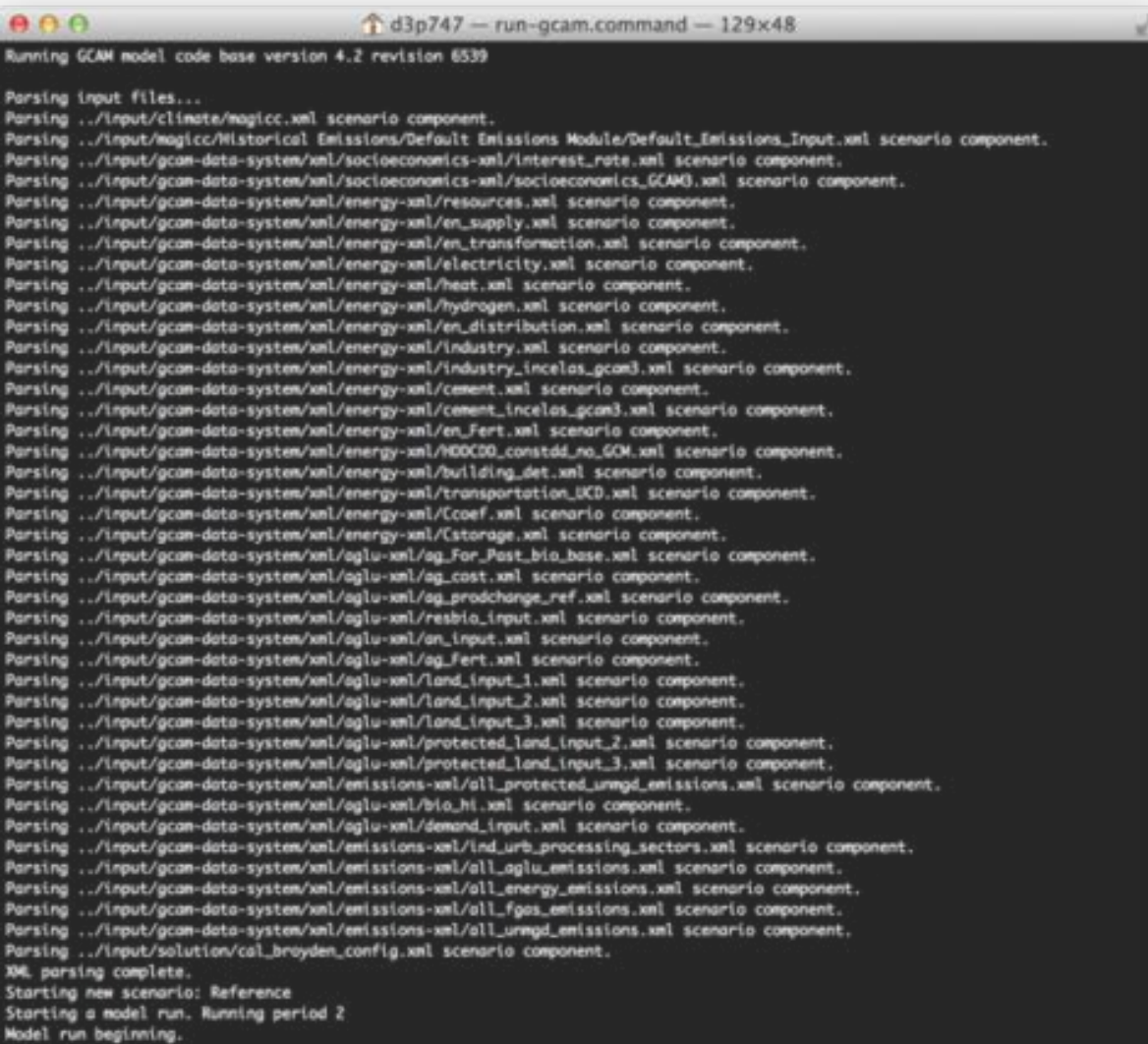
```
<Value name="climateOutputInterval">5</Value>
```

```
<Value name="parallel-grain-size">50</Value>
```

```
<Value name="stop-period">-1</Value>
```

```
</Ints>
```


2: Running GCAM



```
Running GCAM model code base version 4.2 revision 6539

Parsing input files...
Parsing ../input/climate/magicc.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_incelas_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_incelas_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/HOCCO_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_Far_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/ag_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/emissions-xml/all_protected_umgd_emissions.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/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_umgd_emissions.xml scenario component.
Parsing ../input/solution/cal_broyden_config.xml scenario component.
XML parsing complete.
Starting new scenario: Reference
Starting a model run. Running period 2
Model run beginning.
```

- ▶ 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

2: Output

▶ Two forms of output

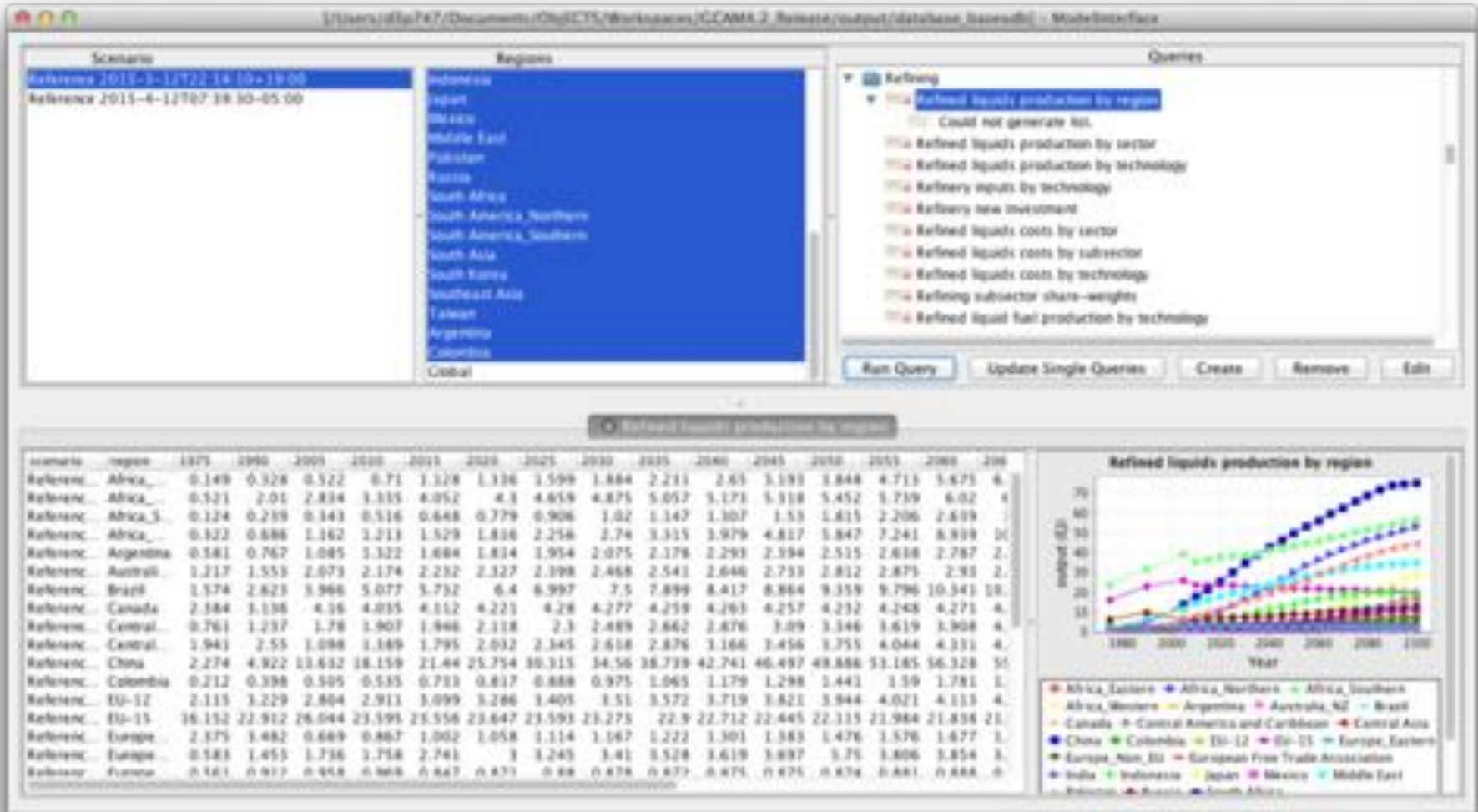
■ The output database

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

■ The debug file

- 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

2: basexdb and ModelInterface



- ▶ In PuTTY or Terminal, navigate to gcam/gcam5/output/modelinterface
- ▶ Type "java -jar ModelInterface.jar".
- ▶ File -> Open -> DB Open
- ▶ output/database_basexdb

2: Queries

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

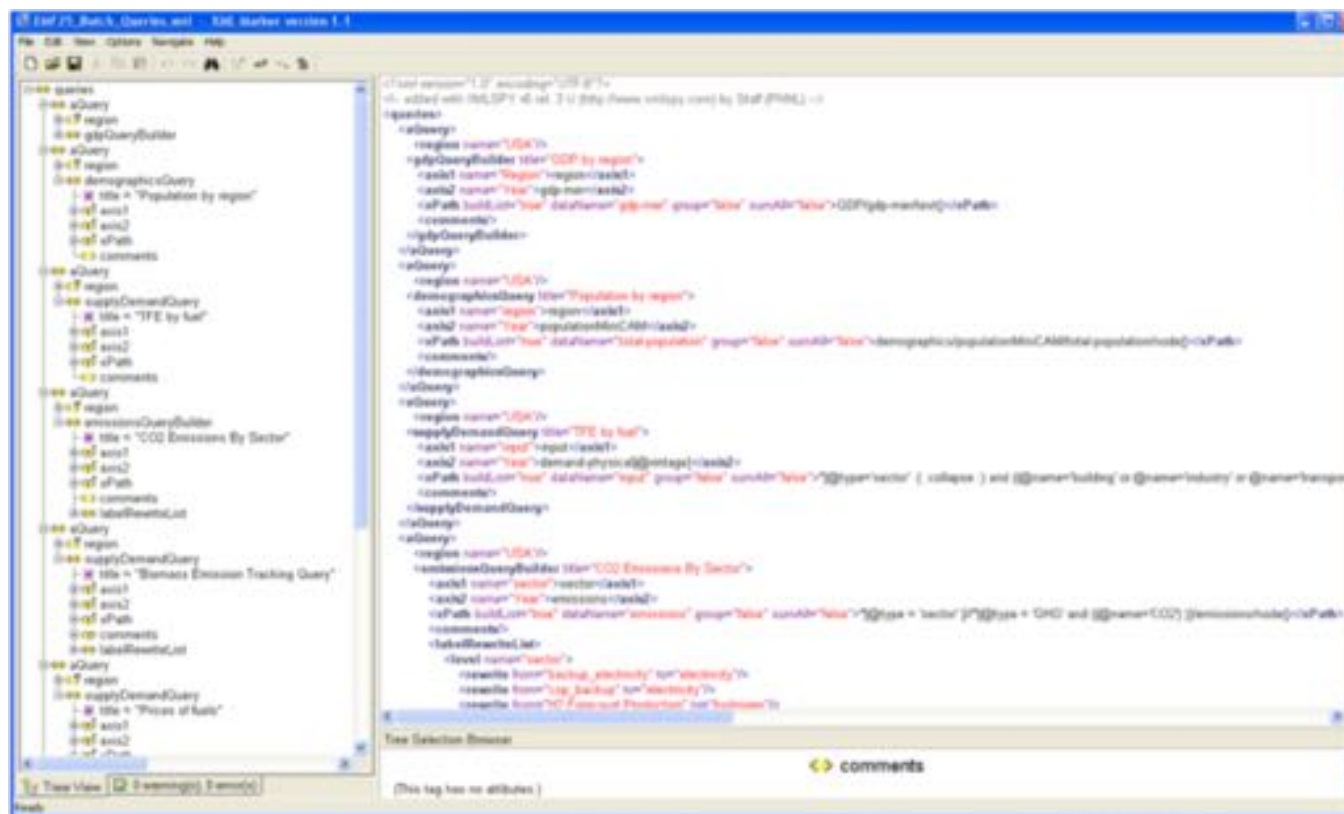
► Edit query window

- 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 main area contains several input fields and checkboxes. The 'Title' field is set to 'Resource production'. There are checkboxes for 'Sum All' (unchecked), 'Group' (checked), and 'Build List' (checked). The 'Y-Axis Name' field is 'resource' and the 'Y-Axis Node' field is 'resource'. The 'X-Axis Name' field is 'Year' and the 'X-Axis Node' field is 'output'. The 'Data Name' field is 'output' and the 'Chart Label Column' field is empty. The 'XPATH' field contains the expression '*[@type='resource']/output/node()'. There is a 'Comments' text area at the bottom. At the bottom right, there are 'OK' and 'Cancel' buttons.

2: Exporting data

- ▶ Highlight cells, copy 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
- ▶ Drag and drop, e.g. into Excel (disabled in X11)



2: Exporting data with a batch query

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



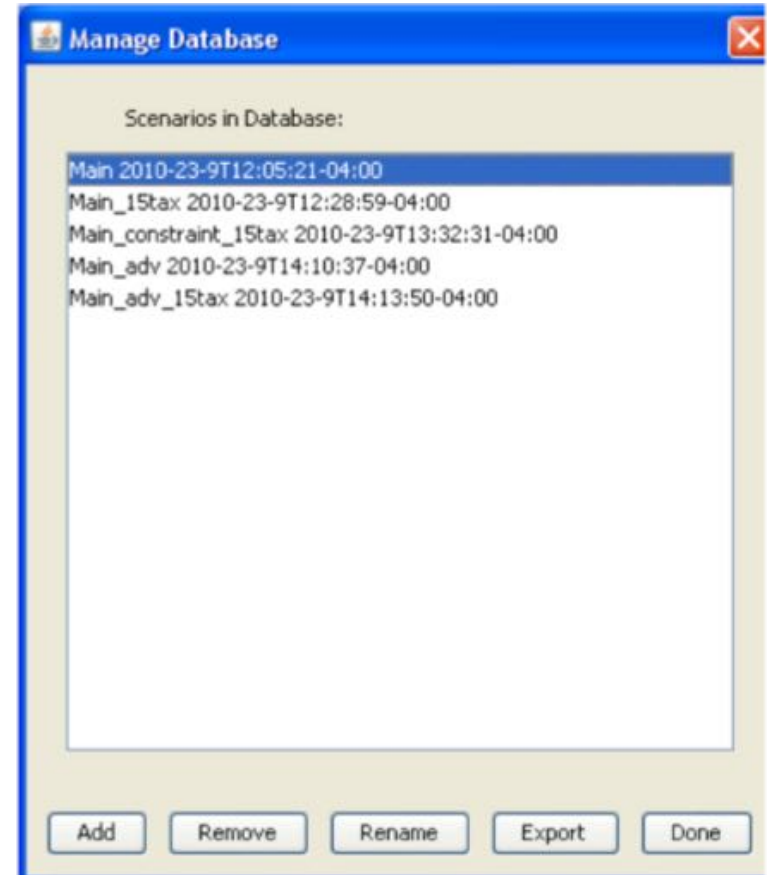
```
<?xml version="1.0" encoding="UTF-8"?>
<queries>
  <aQuery>
    <region name="USA"/>
    <supplyDemandQuery title="Building final energy by technology and fuel">
      <axis1 name="technology">technology</axis1>
      <axis2 name="Year">demand-physical[@vintage]</axis2>
      <xPath buildList="true" dataName="input" group="false" sumAll="false">["@fuel"]</xPath>
      <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">["@fuel"]</xPath>
      <comments/>
    </supplyDemandQuery>
  </aQuery>
  <aQuery>
    <region name="USA"/>
    <supplyDemandQuery title="Fuel prices by technology">
      <axis1 name="technology">technology</axis1>
      <axis2 name="Year">fuel-price[@vintage]</axis2>
      <xPath buildList="true" dataName="fuel-price" group="false" sumAll="false">["@fuel"]</xPath>
      <comments/>
    </supplyDemandQuery>
  </aQuery>

```

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.

2: 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



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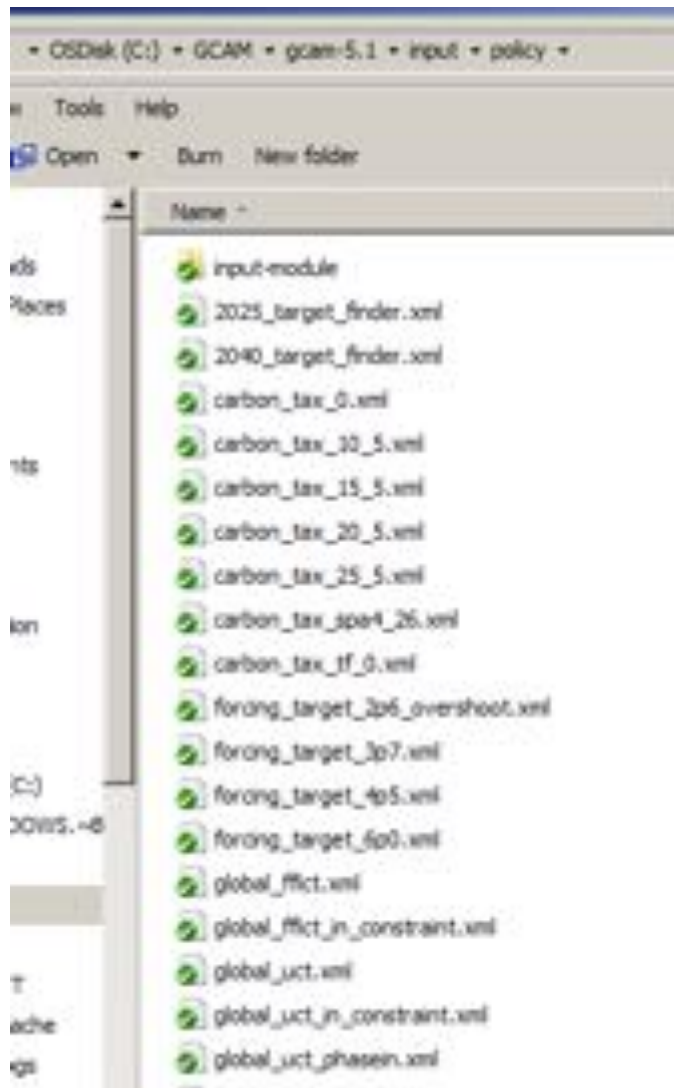
2: Useful Miscellaneous Info

- ▶ 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:
 - $\text{C price (\$/tC)} * 1\text{t} / 1000\text{kg} * \text{Fuel C content (kgC/GJ)} * (1 - \text{sequestration fraction})$

3: 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 the provided policy files in the input/policy folder

3: Provided policy files



Carbon tax: exogenous CO₂ price in each time period (1990\$/t C)

Forcing target: radiative forcing (W/m²).
Overshoot allows end-of-century target to be exceeded in prior years

FFICT: fossil fuel and industrial emissions only

UCT: universal (includes land use change emissions)

Input module: allows users to build XML files from excel

3: 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 = "solver">../input/solution/cal_broyden_config.xml</Value>
<Value name = "policy">../input/policy/carbon_tax_15_5.xml</Value>
</ScenarioComponents>
<Strings>
  <Value name="scenarioName">Ctax_15</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="debugChecking">0</Value>
  <Value name="simulActive">1</Value>
  <Value name="PrintValuesOnGraphs">1</Value>
  <Value name="ShowNullPaths">0</Value>
  <Value name="PrintPrices">1</Value>
</Bools>
<Ints>
```



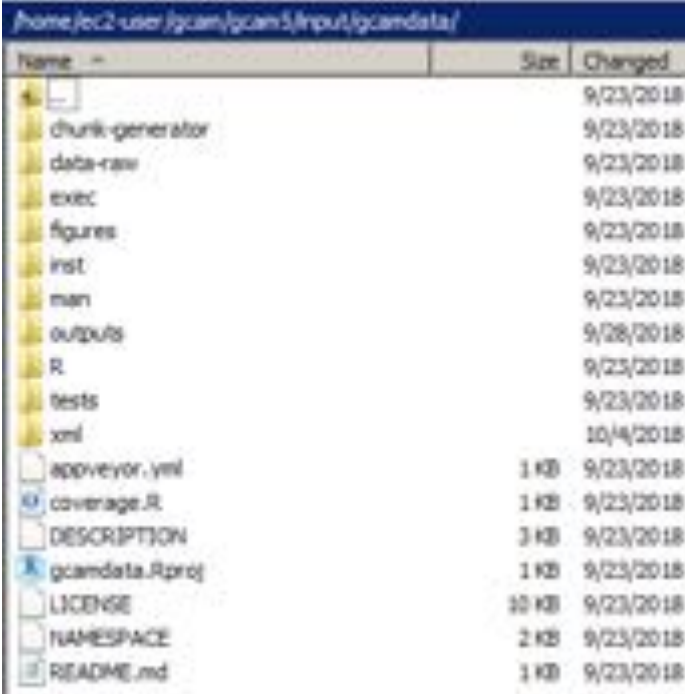
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3: The input folder

- ▶ 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



Name	Size	Changed
chunk-generator		9/23/2018
data-raw		9/23/2018
exetc		9/23/2018
figures		9/23/2018
inst		9/23/2018
man		9/23/2018
outputs		9/28/2018
R		9/23/2018
tests		9/23/2018
xml		10/4/2018
approveor.xml	1 KB	9/23/2018
coverage.R	1 KB	9/23/2018
DESCRIPTION	3 KB	9/23/2018
gcamdata.Rproj	1 KB	9/23/2018
LICENSE	10 KB	9/23/2018
NAMESPACE	2 KB	9/23/2018
README.md	1 KB	9/23/2018

- gcamdata generates the XML files from CSV files in the inst/extdata folders, a header file in inst/extdata/mi_headers, and batch XML files located in the R folder
- policy: selected policies that can be run


```

<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*

3: Running in batch mode

```
<Configuration>
  <Files>
    <Value name="xmlInputFileName">../input/gcam-data-system/xml/modeltime-xml/modeltime.xml
    <Value name="BatchFileName">batch_example.xml</Value>
  ...
  </Files>
  <ScenarioComponents>
    <Value name = "climate">../input/climate/magicc.xml</Value>
  ...
  </ScenarioComponents>
  <Strings>
    <Value name="scenarioName">Base</Value>
  ...
  </Strings>
  <Bools>
    <Value name="CalibrationActive">1</Value>
    <Value name="BatchMode">1</Value>
  ...
  </Bools>
```

Set the bool and batch file name

scenarioName and FileSet name append (e.g., Base_tax)

```
<BatchRunner xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNameSpace="http://www.w3.org/2001/XMLSchema-instance">
  <ComponentSet name="Policy scenarios">
    <FileSet name="">
      </FileSet>
    <FileSet name="_tax">
      <Value name="ctax">../input/policy/carbon_tax_15_5.xml</Value>
    </FileSet>
  </ComponentSet>
</BatchRunner>
```

Files in FileSet will be added to the scenarioComponents in the config file

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

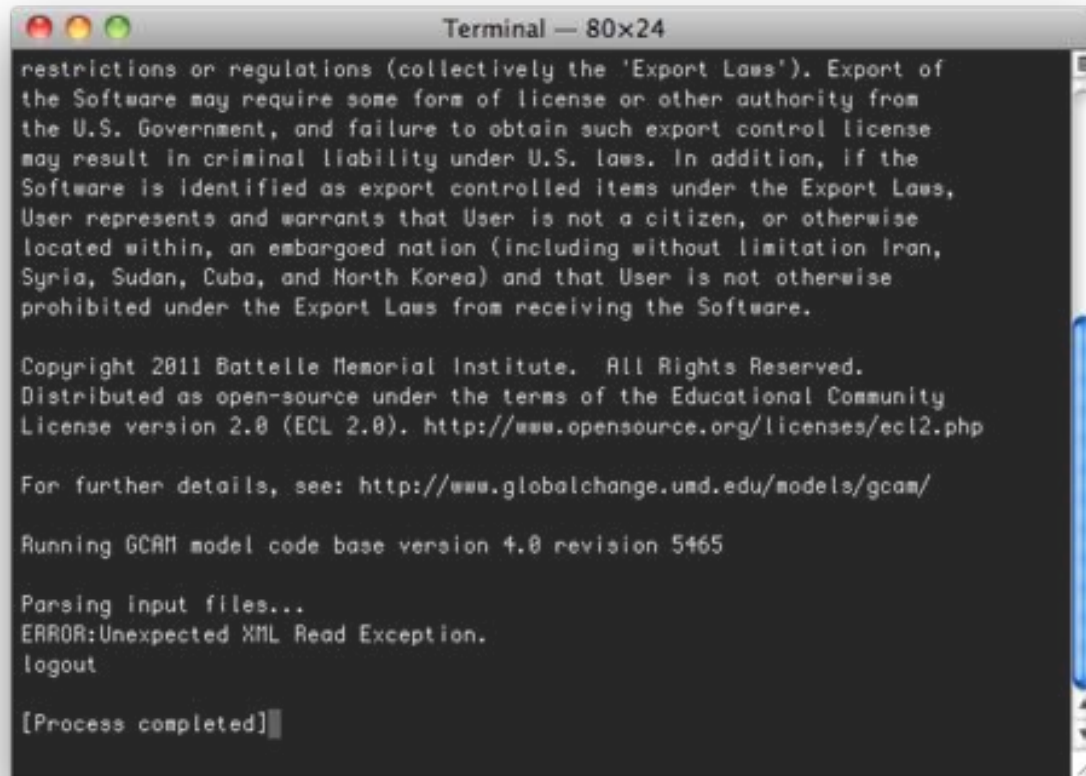


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4: Configuration/input errors

► 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 base, and then the process of parsing input files. Finally, it displays an error message: "ERROR:Unexpected XML Read Exception." followed by "logout" and "[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

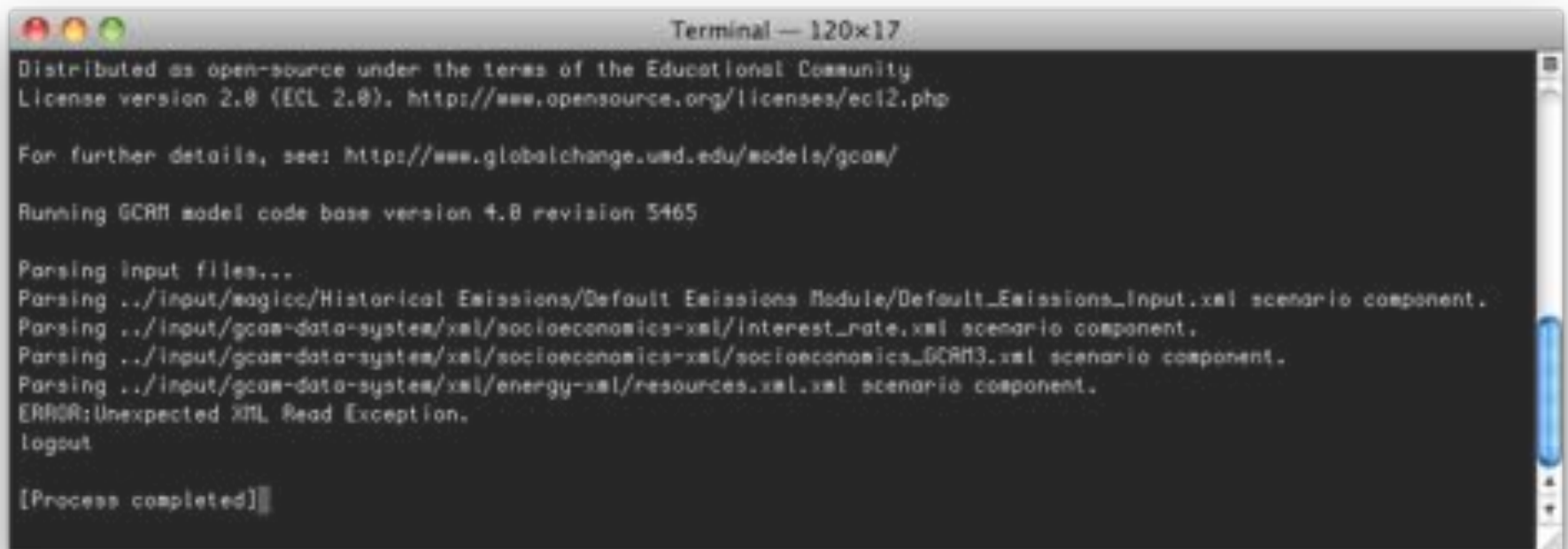
[Process completed]
```

► Possible causes

- The XMLInputFileName or BatchFileName (or their pathways) are incorrect
- If running from code editor, 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/ec12.php

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

Running GCRM model code base version 4.8 revision 5465

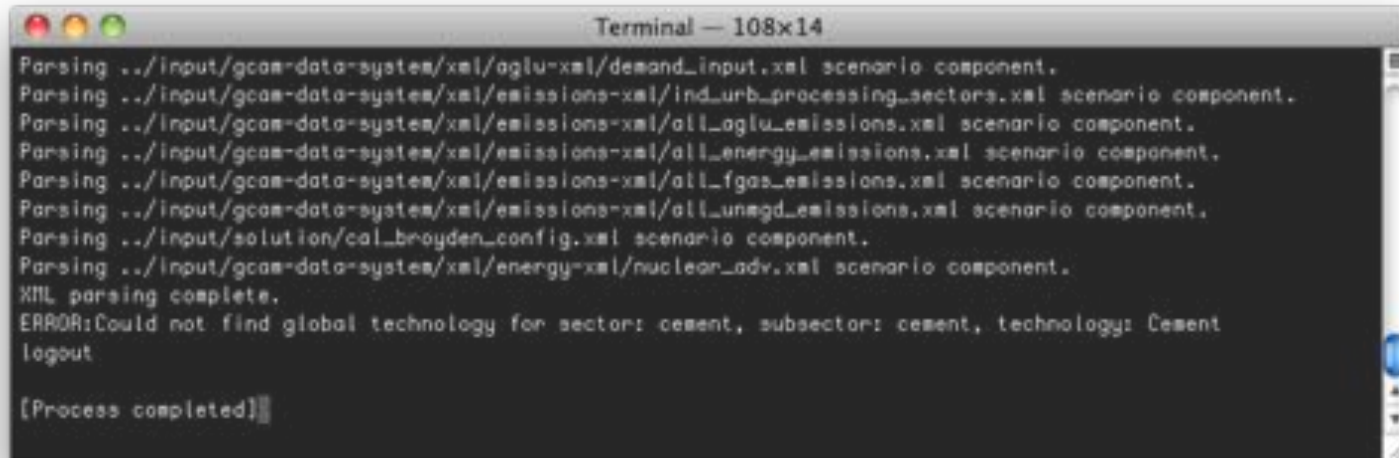
Parsing input files...
Parsing ../input/eagice/Historical Emissions/Default Emissions Module/Default_Emissions_Input.xml scenario component.
Parsing ../input/gcam-data-system/xml/socioeconomics-xml/Interest_rate.xml scenario component.
Parsing ../input/gcam-data-system/xml/socioeconomics-xml/socioeconomics_GCRM3.xml 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/oglu-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_oglu_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_unsgd_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: 1998
Calibration failed by 2.4 % Technology: crude oil Regions: USA Sectors: regional oil Subsectors: crude oil Outputs: 34.26 Calibrations: 33.47 relativeDiff: 0.02361 Seen
enOutputs: 34.26 SectorShares: 0.9629
Calibration failed by 1.5 % Technology: Canada unconventional oil Regions: USA Sectors: traded unconventional oil Subsectors: Canada unconventional oil Outputs: 0.7938 Calibrations: 0.7
622 relativeDiff: 0.01462 SectorOutputs: 0.7938 SectorShares: 0.9554
Calibration failed by 38 % Technology: natural gas Regions: USA Sectors: gas processing Subsectors: natural gas Outputs: 28.89 Calibrations: 38.2 relativeDiff: 0.3314 Se
enOutputs: 28.39 SectorShares: 0.9604
Calibration failed by 2.4 % Technology: oil refining Regions: USA Sectors: refining Subsectors: oil refining Outputs: 32.44 Calibrations: 31.65 relativeDiff: 0.02361 Seen
enOutputs: 32.44 SectorShares: 0.9789
Calibration failed by 66 % Technology: coal (csm pull Regions: USA Sectors: electricity Subsectors: coal Outputs: 9.947 Calibrations: 6.824 relativeDiff: 0.0551 Seen
enOutputs: 15.88 SectorShares: 0.3797
Calibration failed by 66 % Technology: gas (csmw/CT) Regions: USA Sectors: electricity Subsectors: gas Outputs: 9.7229 Calibrations: 9.426 relativeDiff: 0.0551 Seen
enOutputs: 15.88 SectorShares: 0.6274
Calibration failed by 66 % Technology: gas (CT) Regions: USA Sectors: electricity Subsectors: gas Outputs: 9.9758 Calibrations: 8.5963 relativeDiff: 0.0551 Seen
enOutputs: 15.88 SectorShares: 0.62717
Calibration failed by 66 % Technology: refined liquids (csmw/CT) Regions: USA Sectors: electricity Subsectors: refined liquids Outputs: 8.7474 Calibrations: 8.4581 relativeDiff: 0.
0331 SectorOutputs: 15.88 SectorShares: 0.62829
Model did not calibrate successfully in period 1
ERROR:Model did not solve within set iteration 587.
ERROR:Currently Unsolved Markets:
ERROR:Unsolved Part 1: Solvable Markets
ERROR:Market, Y, R, IR, IS, EDL, OSE, RES, Int, Supp, Demand, Brk Type,
ERROR:Unsolved Part 2: Unsolvable Markets Not Elimined
ERROR:Market, Y, R, IR, IS, EDL, OSE, RES, Int, Supp, Demand, Brk Type,
ERROR:globalcrudeoil, 0.450, 0.435, 0.435, 18.799, -19.6771, -19.6771, 8.184262, 0, 92.7363, 183.575, Normal,
ERROR:globalcrudeoil, 1.37, 1.37, 1.37, 0.795968, 0.89966, 0.89966, 8.88574971, 0, 135.825, 136.51, Normal,
ERROR:globalnatural gas, 0.612, 0.612, 0.612, 1.09473, 4.29427, 4.29427, 8.8262365, 0, 26.3201, 22.2319, 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 -- 187x21
Error adding to supply in marketplace for: Etherbeat_Fish, region: Russia, values nan
Error adding to supply in marketplace for: Etherbeat_Fish, region: ID-12, values nan
Error adding to supply in marketplace for: Etherbeat_Fish, region: Europe/Eastern, values nan
Error adding to supply in marketplace for: Etherbeat_Fish, region: Japan, values nan
Error adding to supply in marketplace for: Etherbeat_Fish, region: Russia, values nan
ERROR:Model did not solve within set Iteration 2533
ERROR:Currently Unsolved Markets:
ERROR:Unsolved Part 1: Salvable Markets
ERROR:Market,      X,      X0,      X1,      ES,      ES0,      ES1,      AES,      Brk, Supply, Demand, Brk Type,
ERROR:Unsolved Part 2: Unsolvble Markets Not Cleared
ERROR:Market,      X,      X0,      X1,      ES,      ES0,      ES1,      AES,      Brk, Supply, Demand, Brk Type,
ERROR:ID-12district heat      244.882      4.76257      4.76257      -8.81194e-06      0      0      0      0      0      0      0      -8.81194e-06, Noneall
ERROR:Europe_Easterndistrict heat      226.355      4.79679      4.79679      -8.88257e-01      -2.22845e-06      -2.22845e-16      1      0      0      0      -8.88257e-01, Noneall
ERROR:Europe_Rus_district heat      251.278      4.87822      4.87822      -8.88814e-05      0      0      0      0      0      0      0      -8.88814e-05, Noneall
ERROR:Russiadistrict heat      245.597      4.88889      4.88889      -8.88556e-07      8.88178e-06      8.88178e-06      1      0      0      0      -8.88556e-07, Noneall
ERROR:
Period to 2025
°C
lognet
[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.

4: Database open while trying to write

- The model can't write to the output database

```
All model periods solved correctly.  
Calling the climate model...  
Model run completed.  
Printing output  
Starting output to XML Database.  
The database database_basexdb appears to be open.  
Please close it and press return to continue..  
█
```

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:**



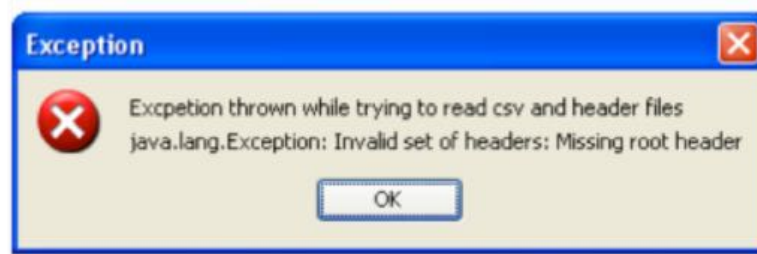
- The Excel workbook being written to was open during the export

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,

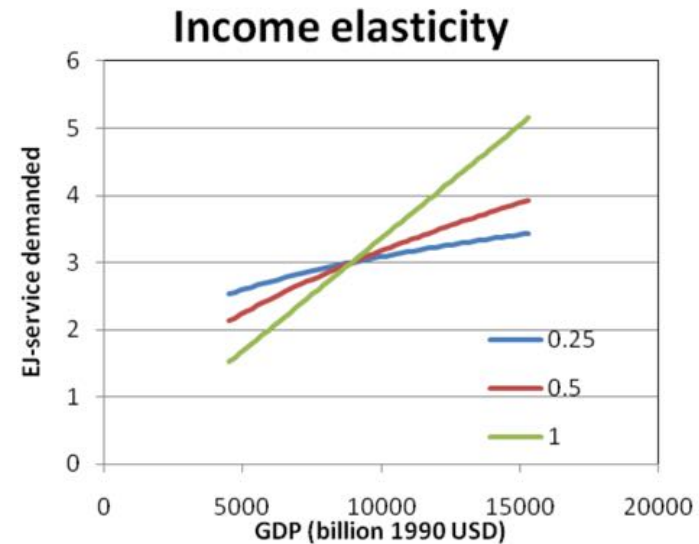
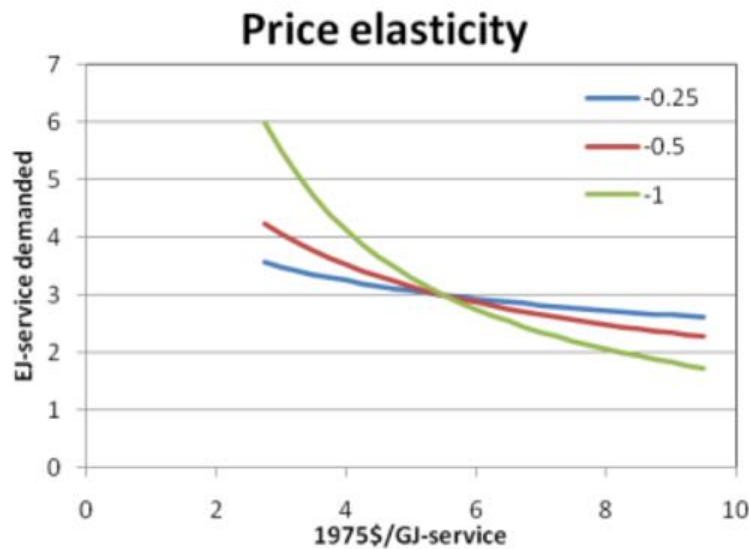
5: What does it all mean?

- ▶ 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

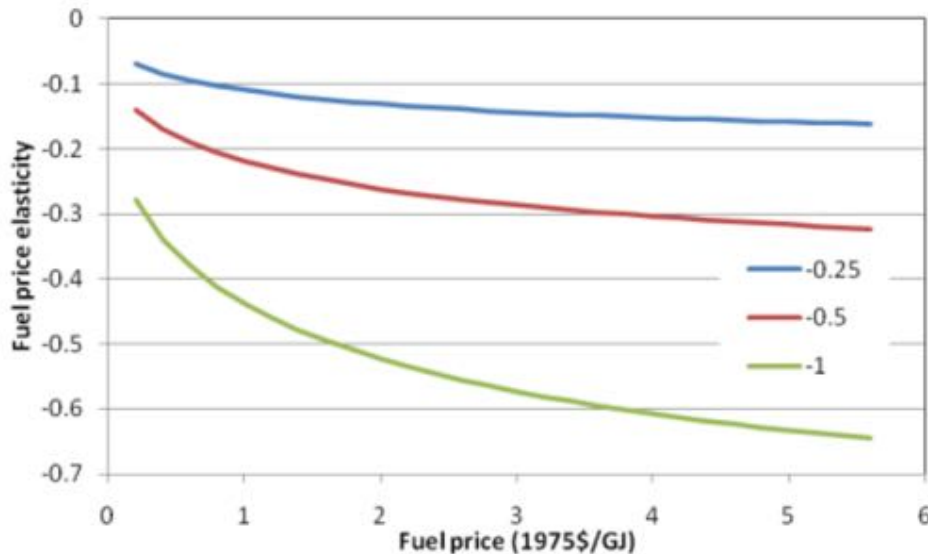
5: Elasticity

- ▶ 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

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



5: Service price elasticity \neq fuel price elasticity

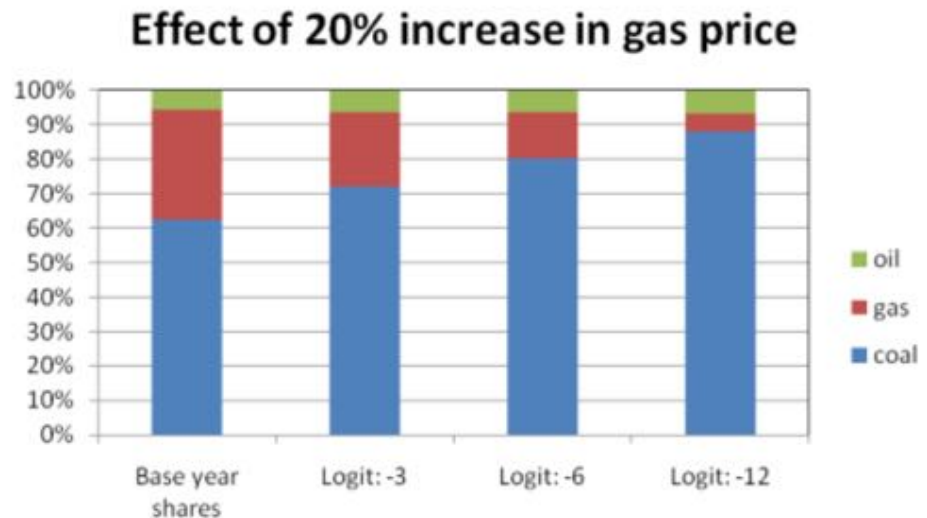


- ▶ Service price elasticities include ALL costs of providing the energy service
 - Levelized capital costs, fixed O&M, variable O&M
 - In passenger transportation, service costs may include time value costs

5: 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

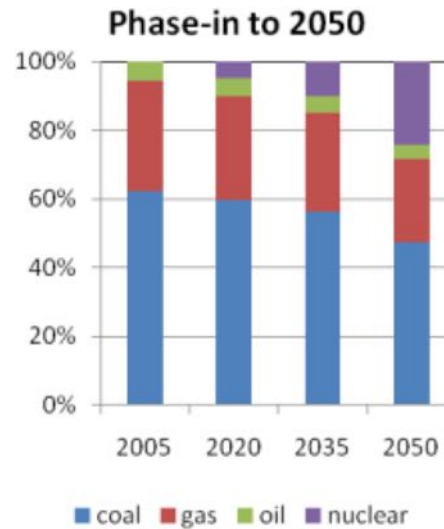
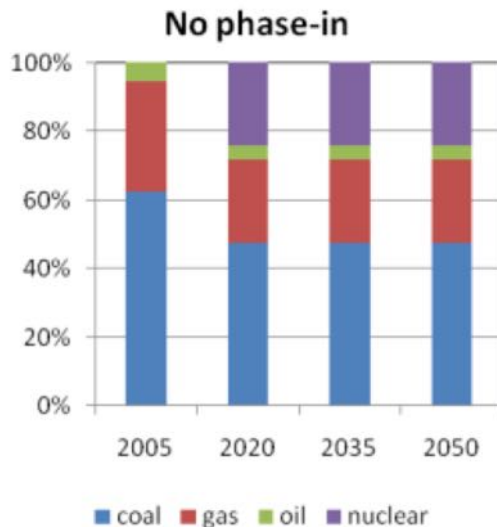
$$Share_i = \frac{sw_i \cdot P_i^\beta}{\sum_i sw_i \cdot P_i^\beta}$$



5: 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

5: 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

5: 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>
```



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Appendix

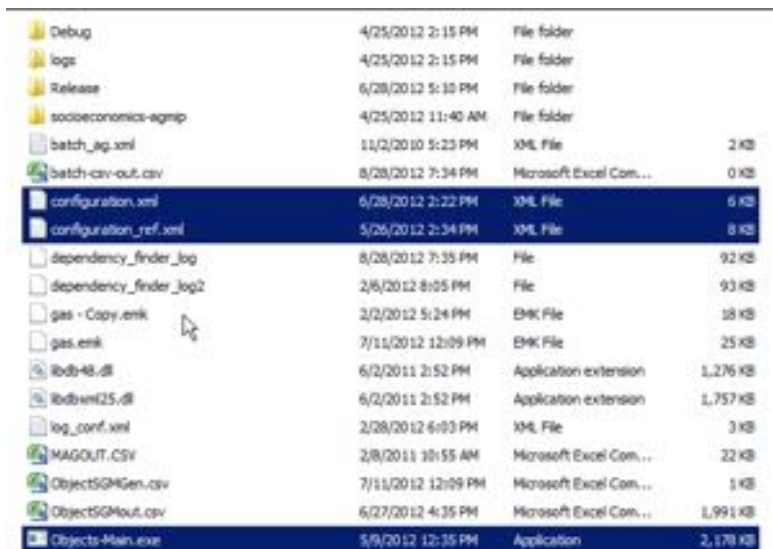
Preliminary: software to download for Desktop

► Desktop Version Downloads:

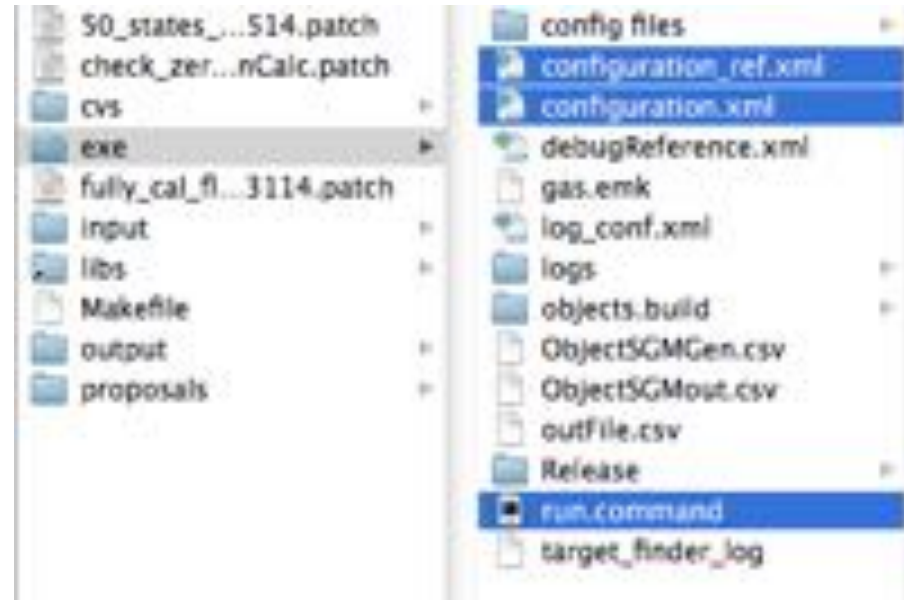
- GCAM: <https://github.com/JGCRI/gcam-core/releases>
- Windows: Java Runtime Environment (64 bit) <http://www.java.com/en/download/manual.jsp>
- Mac: Java Development Kit (recommend version 1.8)
- To compile GCAM code:
 - Windows: Visual C++ Redistributable (x64): <http://www.microsoft.com/download/en/details.aspx?id=14632>
 - Mac: Xcode: <https://developer.apple.com/xcode/downloads/>
- R: <https://cran.r-project.org/> and Rstudio <https://www.rstudio.com>

1: Running the Reference Scenario on Desktop

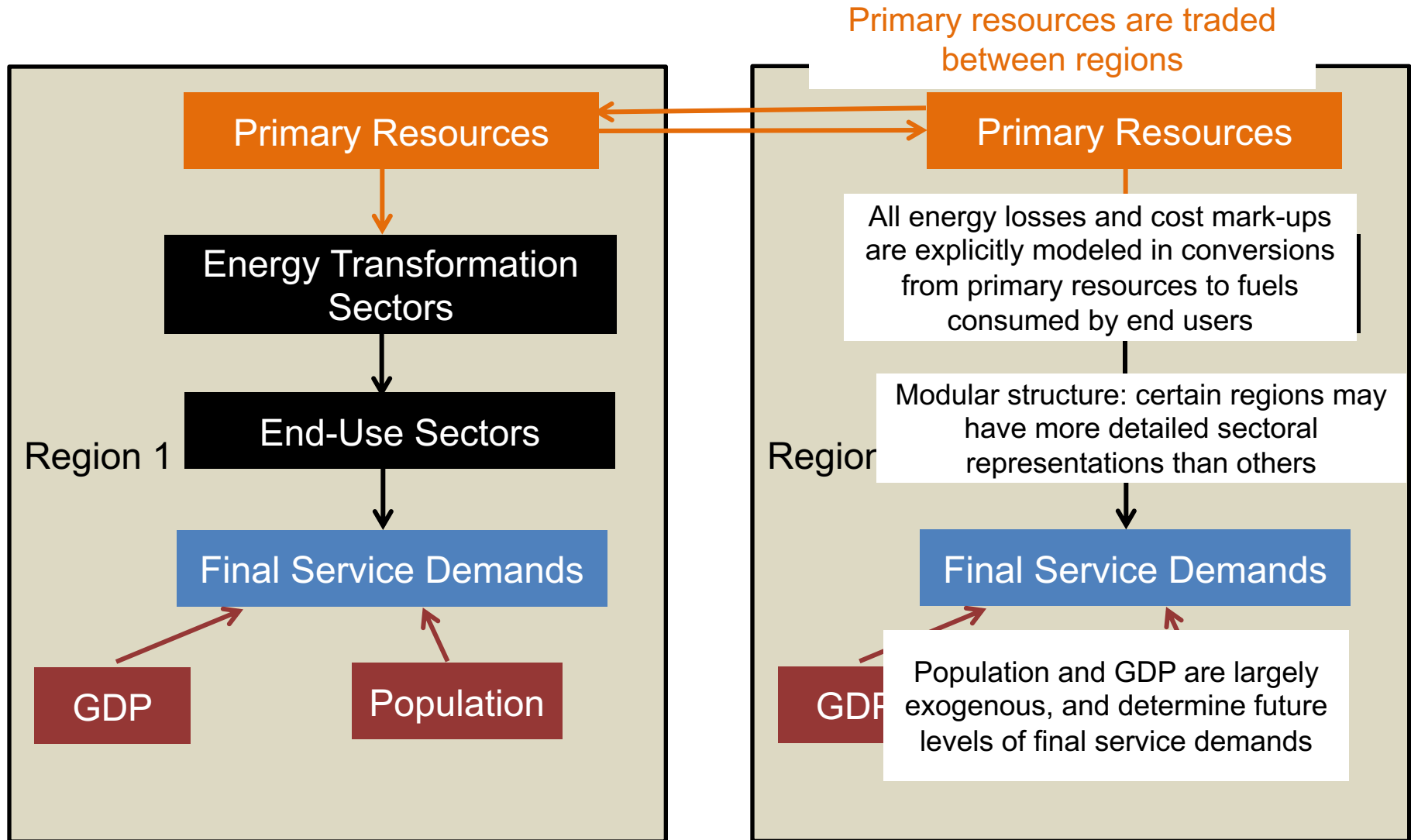
- 1) Navigate to the exe folder
- 2) Open configuration_ref.xml
 - This is a base configuration file that reads in files for the reference, or main, scenario
- 3) Save this as configuration.xml
 - This is the control file that is called when the model is run; the configuration.xml file itself is usually 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 run-gcam.bat
 - 1) This will run Objects-Main.exe
- 4) Mac: Double click run-gcam.command
 - 1) This will run Release/objects, the executable



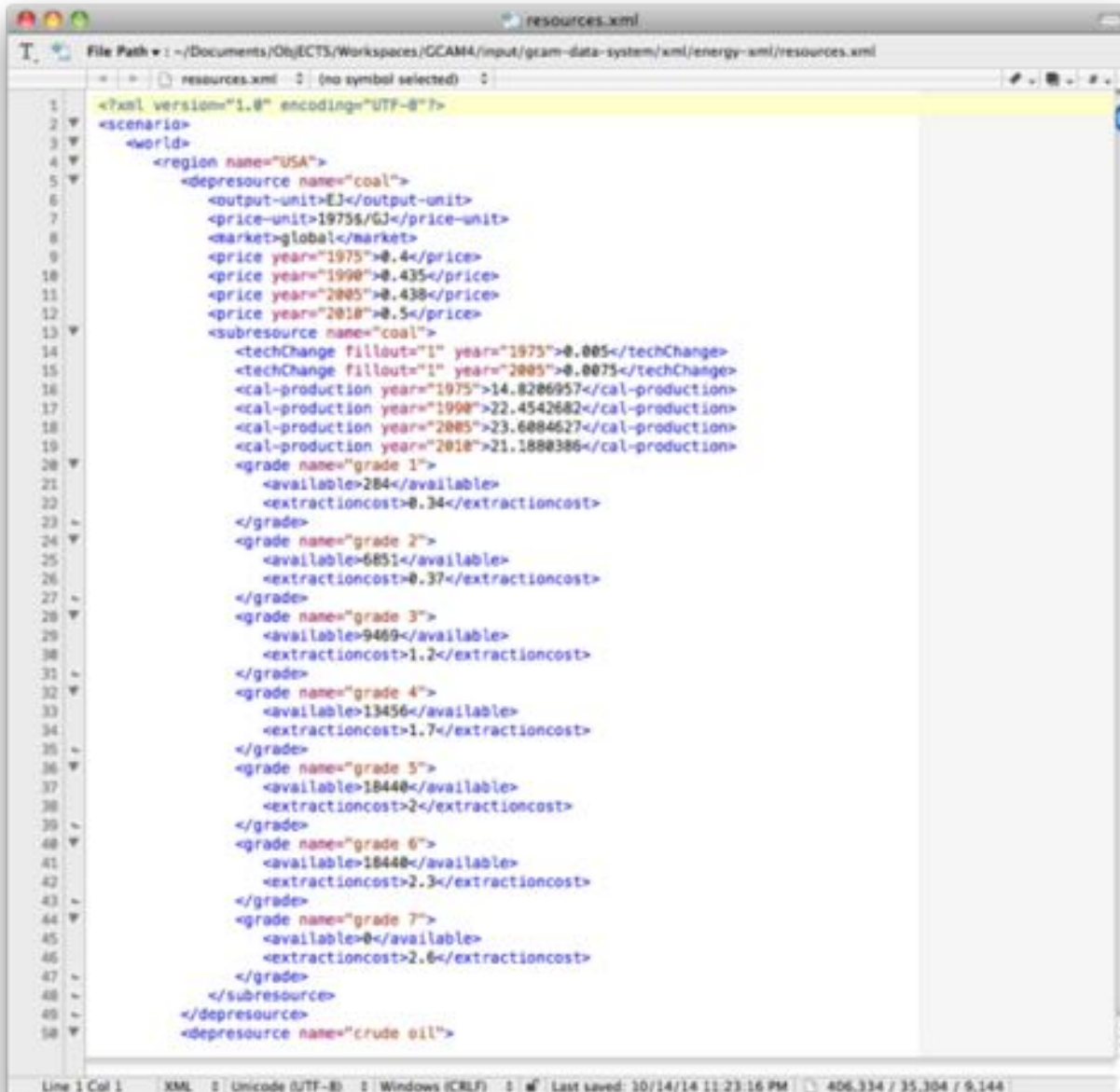
Debug	4/25/2012 2:15 PM	File folder	
logs	4/25/2012 2:15 PM	File folder	
Release	6/28/2012 5:10 PM	File folder	
socioeconomics-agmp	4/25/2012 11:40 AM	File folder	
batch_ag.xml	11/2/2010 5:23 PM	XML File	2 KB
batch-csv-out.csv	8/28/2012 7:34 PM	Microsoft Excel Com...	0 KB
configuration.xml	6/28/2012 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	2/8/2012 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	2,170 KB



1: General energy system structure



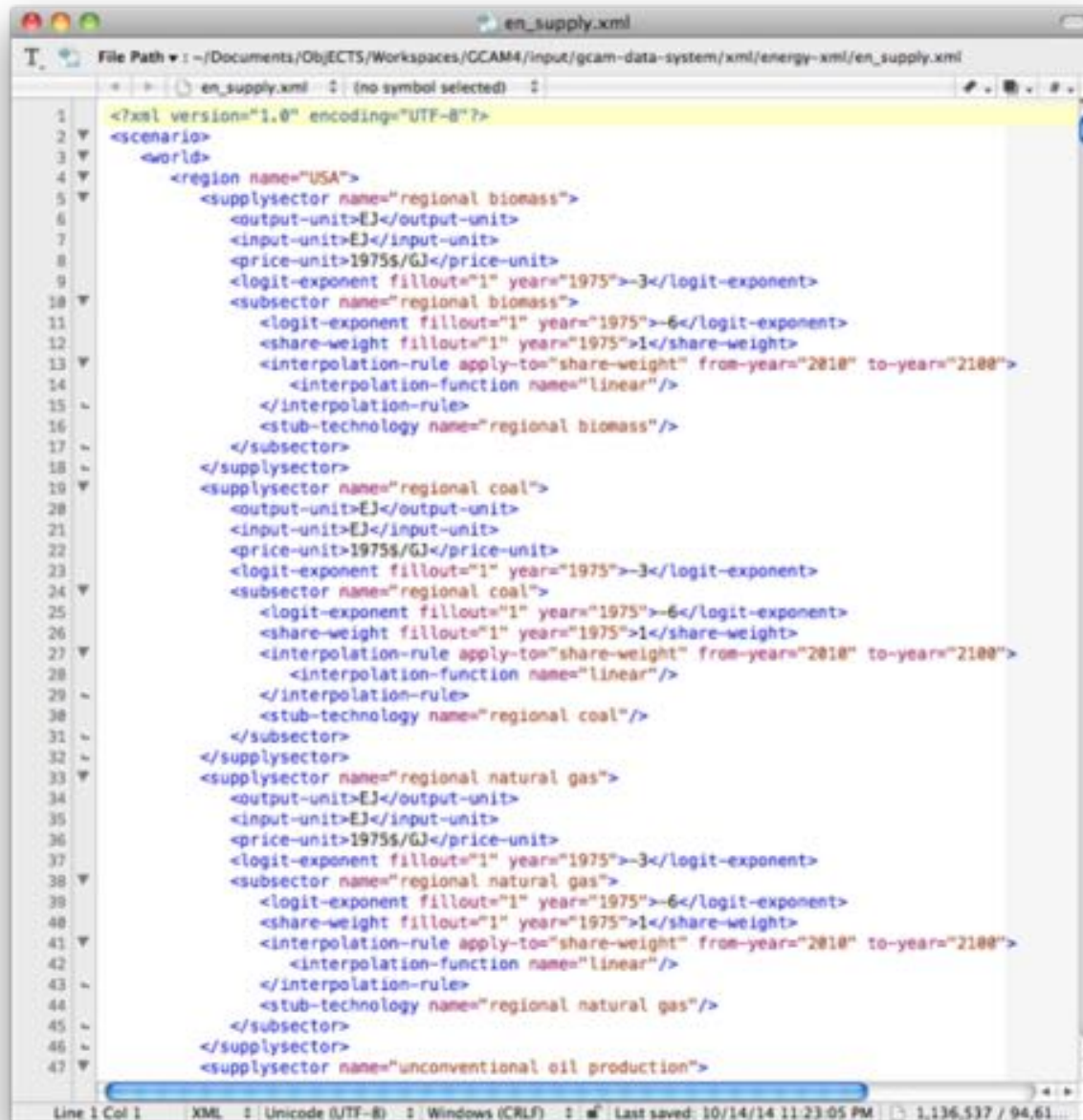
1: Resources



```
<?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">23.6004627</cal-production>
          <cal-production year="2010">21.1888386</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



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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

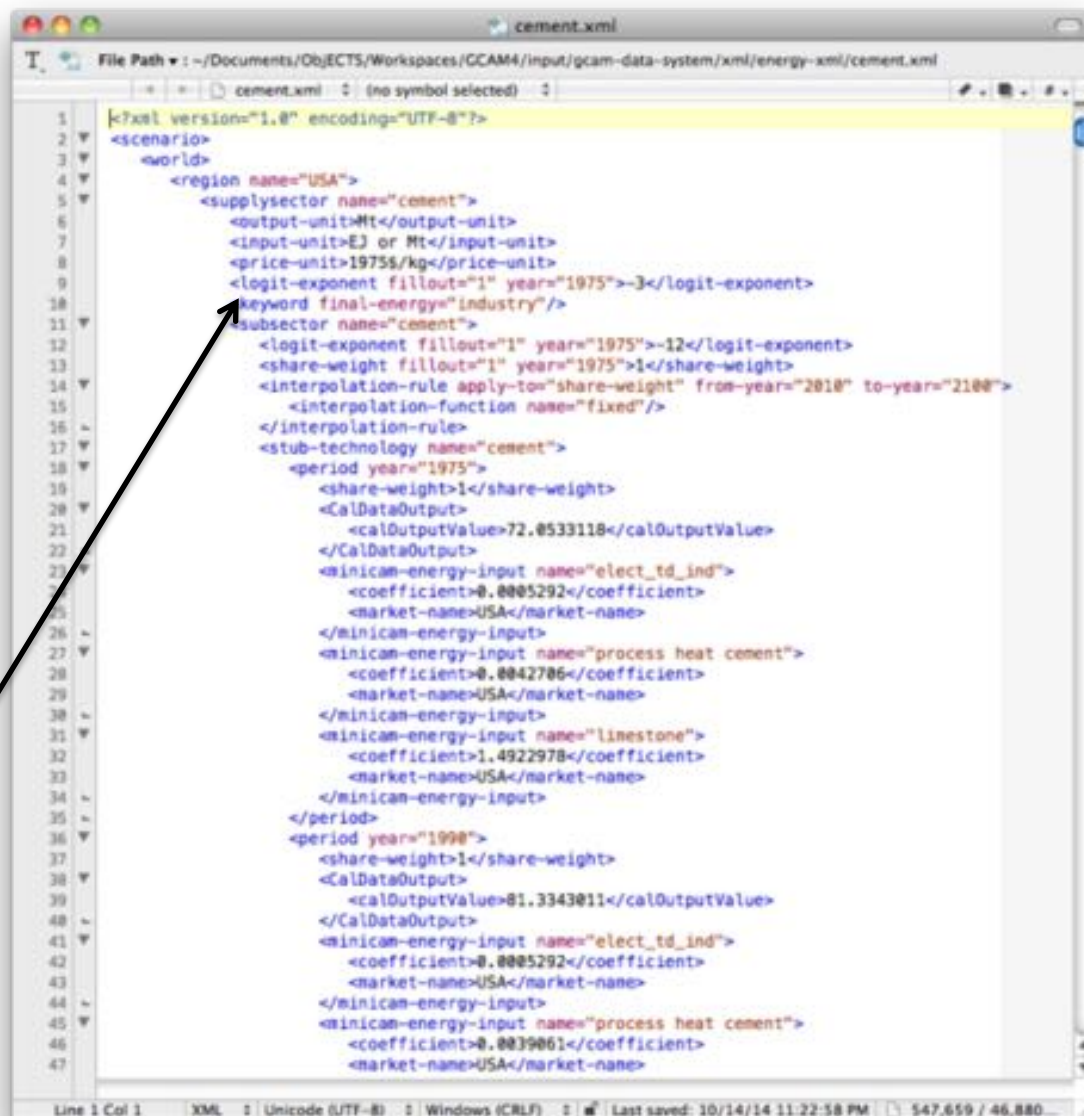
► Sector-specific XML files

- 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

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

- 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

```

1  <?xml version="1.0" encoding="UTF-8"?>
2  <scenario>
3    <region name="USA">
4      <supplysector name="trn_aviation_intl"> </supplysector>
5      <supplysector name="trn_freight"> </supplysector>
6      <supplysector name="trn_freight_road"> </supplysector>
7      <supplysector name="trn_pass"> </supplysector>
8      <supplysector name="trn_pass_road"> </supplysector>
9      <supplysector name="trn_pass_road_LDV"> </supplysector>
10     <supplysector name="trn_pass_road_LDV_2H"> </supplysector>
11     <supplysector name="trn_pass_road_LDV_4H"> </supplysector>
12     <supplysector name="trn_shipping_intl"> </supplysector>
13   </region>
14   <energy-final-demand name="trn_pass">
15     <perCapitaBased>1</perCapitaBased>
16     <final-energy-consumer>
17       <price-elasticity year="2015">-1.25</price-elasticity>
18       <price-elasticity year="2020">-1.25</price-elasticity>
19       <price-elasticity year="2025">-1.25</price-elasticity>
20       <price-elasticity year="2030">-1.25</price-elasticity>
21       <price-elasticity year="2035">-1.25</price-elasticity>
22       <price-elasticity year="2040">-1.25</price-elasticity>
23       <price-elasticity year="2045">-1.25</price-elasticity>
24       <price-elasticity year="2050">-1.25</price-elasticity>
25       <price-elasticity year="2055">-1.25</price-elasticity>
26       <price-elasticity year="2060">-1.25</price-elasticity>
27       <price-elasticity year="2065">-1.25</price-elasticity>
28       <price-elasticity year="2070">-1.25</price-elasticity>
29       <price-elasticity year="2075">-1.25</price-elasticity>
30       <price-elasticity year="2080">-1.25</price-elasticity>
31       <price-elasticity year="2085">-1.25</price-elasticity>
32       <price-elasticity year="2090">-1.25</price-elasticity>
33       <price-elasticity year="2095">-1.25</price-elasticity>
34       <price-elasticity year="2100">-1.25</price-elasticity>
35       <income-elasticity year="2015">1</income-elasticity>
36       <income-elasticity year="2020">1</income-elasticity>
37       <income-elasticity year="2025">1</income-elasticity>
38       <income-elasticity year="2030">1</income-elasticity>
39       <income-elasticity year="2035">1</income-elasticity>
40       <income-elasticity year="2040">1</income-elasticity>
41       <income-elasticity year="2045">1</income-elasticity>
42       <income-elasticity year="2050">1</income-elasticity>
43       <income-elasticity year="2055">1</income-elasticity>
44       <income-elasticity year="2060">1</income-elasticity>
45       <income-elasticity year="2065">1</income-elasticity>
46       <income-elasticity year="2070">1</income-elasticity>
47       <income-elasticity year="2075">1</income-elasticity>
48       <income-elasticity year="2080">1</income-elasticity>
49       <income-elasticity year="2085">1</income-elasticity>
50       <income-elasticity year="2090">1</income-elasticity>
51       <income-elasticity year="2095">1</income-elasticity>
52       <income-elasticity year="2100">1</income-elasticity>
53       <base-service year="1975">5182216.23323945</base-service>
54       <base-service year="1990">6229746.79134171</base-service>
55       <base-service year="2005">8196827.78848867</base-service>
56       <base-service year="2018">7975184.82804234</base-service>
57     </energy-final-demand>
58     <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="1998"></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"></populationMinicAM>
30        <totalPop>554887</totalPop>
31      </demographics>
32      <GDP>
33        <baseGDP>3473910</baseGDP>
34        <laborforce fillout="1" year="1975">0.5</laborforce>
35        <laborproductivity year="1998">0.02354</laborproductivity>
36        <laborproductivity year="2005">0.01982</laborproductivity>
37        <laborproductivity year="2010">0.00351</laborproductivity>
38        <laborproductivity year="2015">0.01398</laborproductivity>
39        <laborproductivity year="2020">0.01273</laborproductivity>
40        <laborproductivity year="2025">0.01152</laborproductivity>
41        <laborproductivity year="2030">0.01119</laborproductivity>
42        <laborproductivity year="2035">0.01076</laborproductivity>
43        <laborproductivity year="2040">0.01274</laborproductivity>
44        <laborproductivity year="2045">0.01164</laborproductivity>
45        <laborproductivity year="2050">0.01364</laborproductivity>
46        <laborproductivity year="2055">0.01151</laborproductivity>
47        <laborproductivity year="2060">0.01311</laborproductivity>
48        <laborproductivity year="2065">0.01258</laborproductivity>
49        <laborproductivity year="2070">0.01377</laborproductivity>
50        <laborproductivity year="2075">0.01388</laborproductivity>
51        <laborproductivity year="2080">0.01372</laborproductivity>
52        <laborproductivity year="2085">0.01315</laborproductivity>
53        <laborproductivity year="2090">0.01459</laborproductivity>
54        <laborproductivity year="2095">0.01454</laborproductivity>
55        <laborproductivity year="2100">0.01449</laborproductivity>
56        <PPPConvert constRatio="1">0.06187</PPPConvert>
57      </GDP>
58    </region>
59  </world>
60 </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



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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.

```

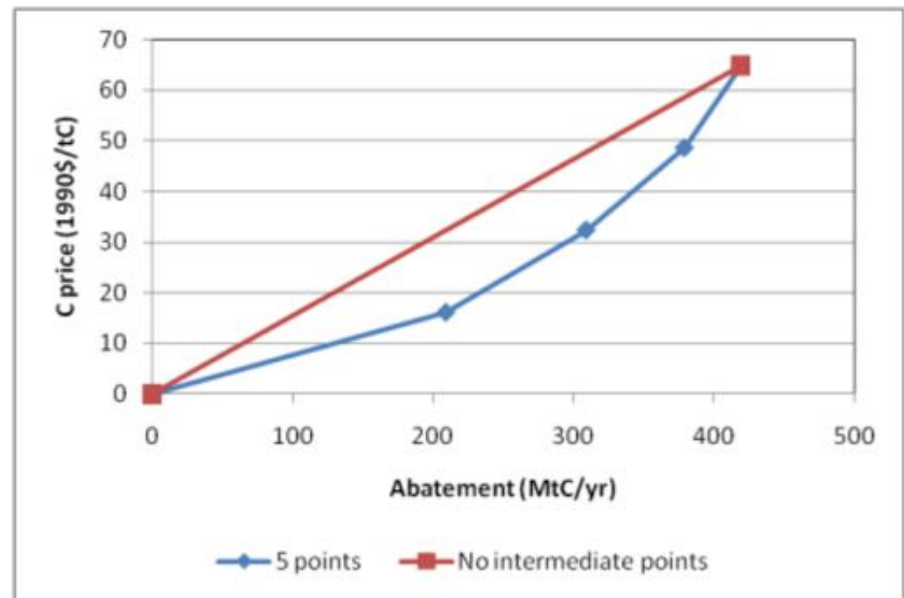
1  <?xml version="1.0" encoding="UTF-8"?>
2  <scenario>
3    <world>
4      <region name="USA">
5        <supplysector name="comm cooling" nocreate="1">
6          <subsector name="gas" nocreate="1">
7            <stub-technology name="gas" nocreate="1">
8              <period year="1975">
9                <Non-CO2 name="SO2_1">
10                  <input-emissions>1.55e-05</input-emissions>
11                  <input-driver/>
12                </Non-CO2>
13                <Non-CO2 name="CO">
14                  <input-emissions>0.011917</input-emissions>
15                  <input-driver/>
16                  <gdp-control name="GDP_control">
17                    <max-reduction>68.5446345299613</max-reduction>
18                    <steepness>3.5</steepness>
19                  </gdp-control>
20                </Non-CO2>
21                <Non-CO2 name="NH3"> </Non-CO2>
22                <Non-CO2 name="N2O"> </Non-CO2>
23                <Non-CO2 name="CH4"> </Non-CO2>
24                <Non-CO2 name="HFC"> </Non-CO2>
25                <Non-CO2 name="PFC"> </Non-CO2>
26                <Non-CO2 name="SF6"> </Non-CO2>
27                <Non-CO2 name="OC">
28                  <emiss-coef>5.08e-05</emiss-coef>
29                  <input-driver/>
30                  <gdp-control name="GDP_control">

```

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

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



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



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()`

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()`

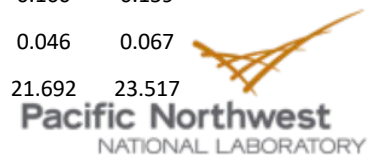
Gas production by technology

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

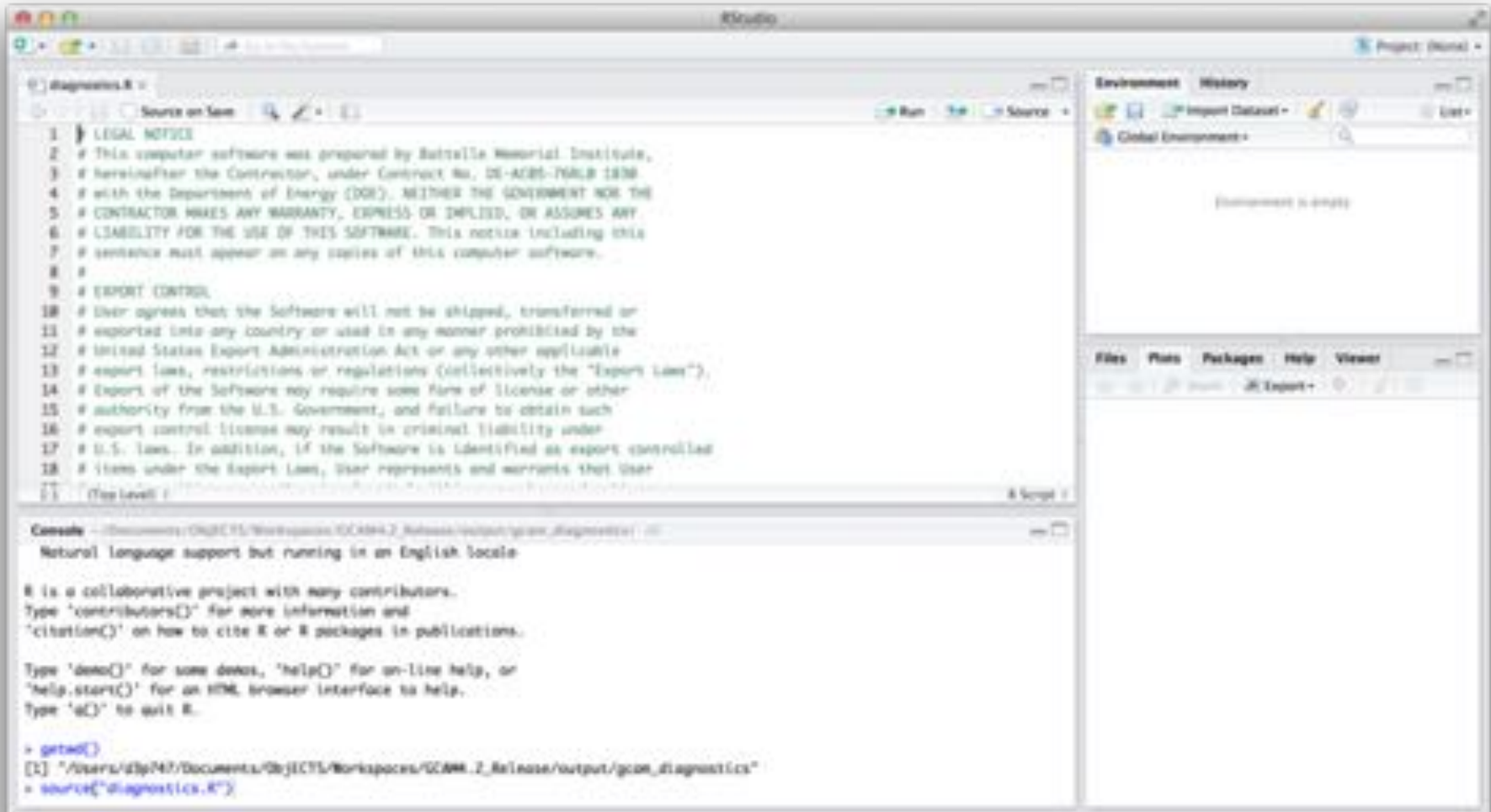
scenario	region	sector	subsector	technology	1990	2005	2020
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	biomass gasification	biomass gasification	0.031	0.160	0.159
Main,date=2010-23-9T12:05:21-04:00	USA	gas processing	coal gasification	coal gasification	0.136	0.046	0.067
Main,date=2010-23-9T12:05:21-04:00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



2: Running the diagnostics package

- ▶ 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

2: Running the diagnostics package



```
diagnostics.R
1 # LEGAL NOTICE
2 # This computer software was prepared by Battelle Memorial Institute,
3 # hereinafter the Contractor, under Contract No. DE-AC05-76MC18180
4 # with the Department of Energy (DOE). NEITHER THE GOVERNMENT NOR THE
5 # CONTRACTOR MAKES ANY WARRANTY, EXPRESS OR IMPLIED, OR ASSUMES ANY
6 # LIABILITY FOR THE USE OF THIS SOFTWARE. This notice including this
7 # sentence must appear on any copies of this computer software.
8 #
9 # EXPORT CONTROL
10 # User agrees that the Software will not be shipped, transferred or
11 # exported into any country or used in any manner prohibited by the
12 # United States Export Administration Act or any other applicable
13 # export laws, restrictions or regulations (collectively the "Export Laws").
14 # Export of the Software may require some form of license or other
15 # authority from the U.S. Government, and failure to obtain such
16 # export control licenses may result in criminal liability under
17 # U.S. laws. In addition, if the Software is identified as export controlled
18 # items under the Export Laws, User represents and warrants that User
19 # will not export the Software to any country to which the Software is
20 # restricted by U.S. laws without the prior written permission of the
21 # Contractor.
22
23 (File level)
```

```
Console -- (Documents\OBJECTS\Workspaces\OCAM4.2_Release\output\gam_diagnostics) --
Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

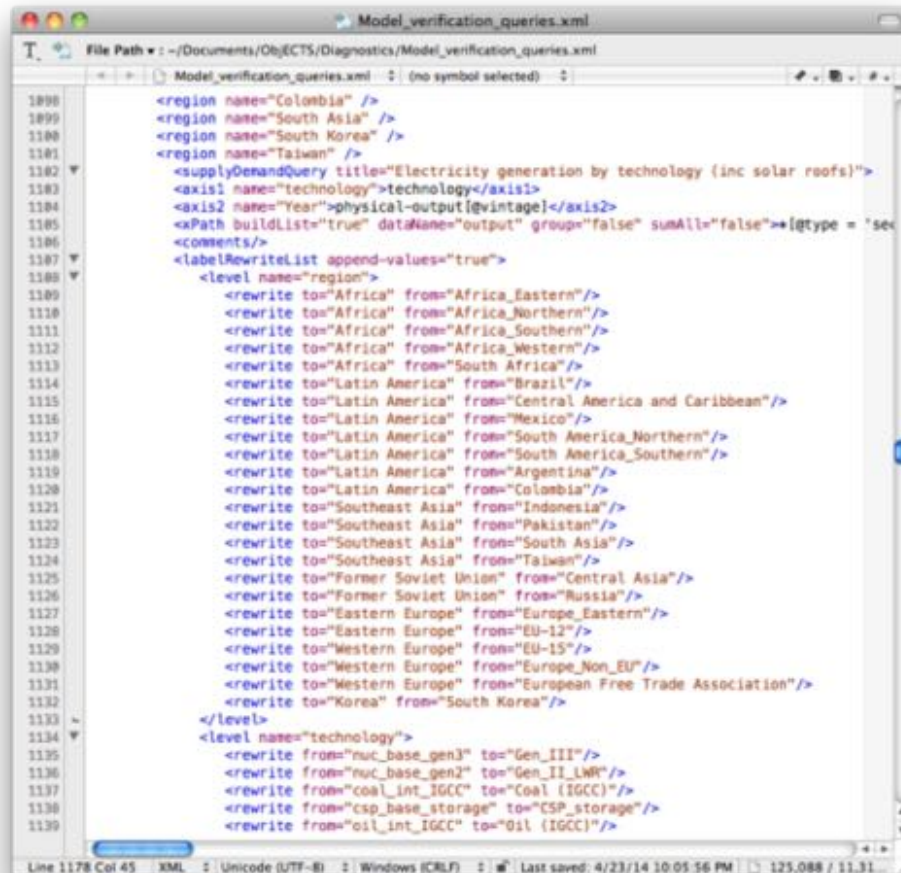
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> getwd()
[1] "C:/Users/djp747/Documents/OBJECTS/Workspaces/OCAM4.2_Release/output/gam_diagnostics"
> source("diagnostics.R")
```

- ▶ Check that the working directory is correct, and run the R script

2: 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.xml file



```
1090 <region name="Colombia" />
1091 <region name="South Asia" />
1092 <region name="South Korea" />
1093 <region name="Taiwan" />
1094 <supplyDemandQuery title="Electricity generation by technology (inc solar roofs)"
1095 <axis1 name="technology">technology</axis1>
1096 <axis2 name="Year">physical-output@vintage</axis2>
1097 <xPath buildList="true" dataName="output" group="false" sumAll="false">@type = 'sec
1098 <comments/>
1099 <labelRewriteList append-values="true">
1100 <level name="region">
1101 <rewrite to="Africa" from="Africa_Eastern"/>
1102 <rewrite to="Africa" from="Africa_Northern"/>
1103 <rewrite to="Africa" from="Africa_Southern"/>
1104 <rewrite to="Africa" from="Africa_Western"/>
1105 <rewrite to="Africa" from="South Africa"/>
1106 <rewrite to="Latin America" from="Brazil"/>
1107 <rewrite to="Latin America" from="Central America and Caribbean"/>
1108 <rewrite to="Latin America" from="Mexico"/>
1109 <rewrite to="Latin America" from="South America_Northern"/>
1110 <rewrite to="Latin America" from="South America_Southern"/>
1111 <rewrite to="Latin America" from="Argentina"/>
1112 <rewrite to="Latin America" from="Colombia"/>
1113 <rewrite to="Southeast Asia" from="Indonesia"/>
1114 <rewrite to="Southeast Asia" from="Pakistan"/>
1115 <rewrite to="Southeast Asia" from="South Asia"/>
1116 <rewrite to="Southeast Asia" from="Taiwan"/>
1117 <rewrite to="Former Soviet Union" from="Central Asia"/>
1118 <rewrite to="Former Soviet Union" from="Russia"/>
1119 <rewrite to="Eastern Europe" from="Europe_Eastern"/>
1120 <rewrite to="Eastern Europe" from="EU-12"/>
1121 <rewrite to="Western Europe" from="EU-15"/>
1122 <rewrite to="Western Europe" from="Europe_Non_EU"/>
1123 <rewrite to="Western Europe" from="European Free Trade Association"/>
1124 <rewrite to="Korea" from="South Korea"/>
1125 </level>
1126 <level name="technology">
1127 <rewrite from="nuc_base_gen3" to="Gen_III"/>
1128 <rewrite from="nuc_base_gen2" to="Gen_II_LWR"/>
1129 <rewrite from="coal_int_IGCC" to="Coal (IGCC)"/>
1130 <rewrite from="csp_base_storage" to="CSP storage"/>
1131 <rewrite from="oil_int_IGCC" to="Oil (IGCC)"/>
1132 </level>
```

2: Running the diagnostics package

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

