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/)

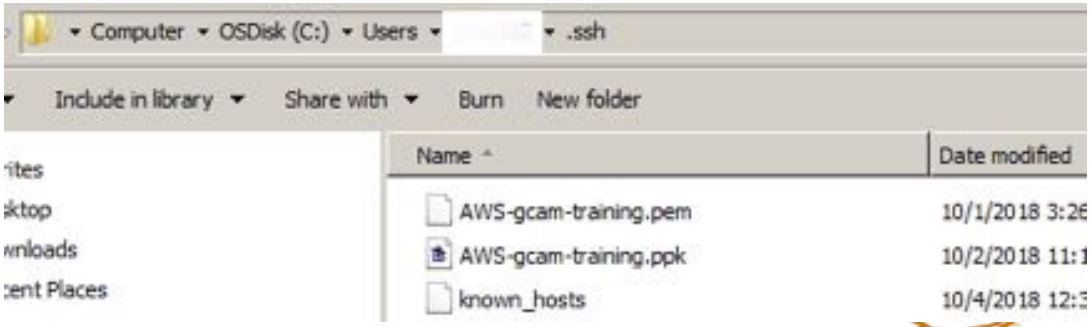
- Optional but helpful
  - XML files will open in a text editor, but better options exist
    - Windows: XML Marker:http://symbolclick.com/xmlmarker_1_1_setup.exe
    - Mac: BBEdit: http://www.barebones.com/products/bbedit/
    - Mac: XML Author: http://www.oxygenxml.com/
  - A program to diff files
    - 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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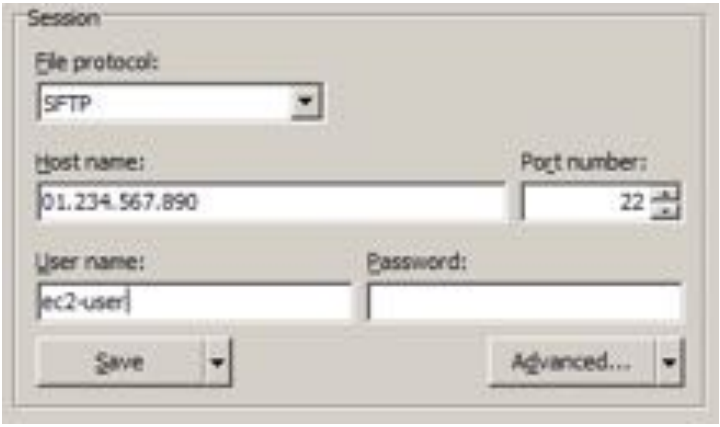
1: Configuring and Using WinSCP (Windows)

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



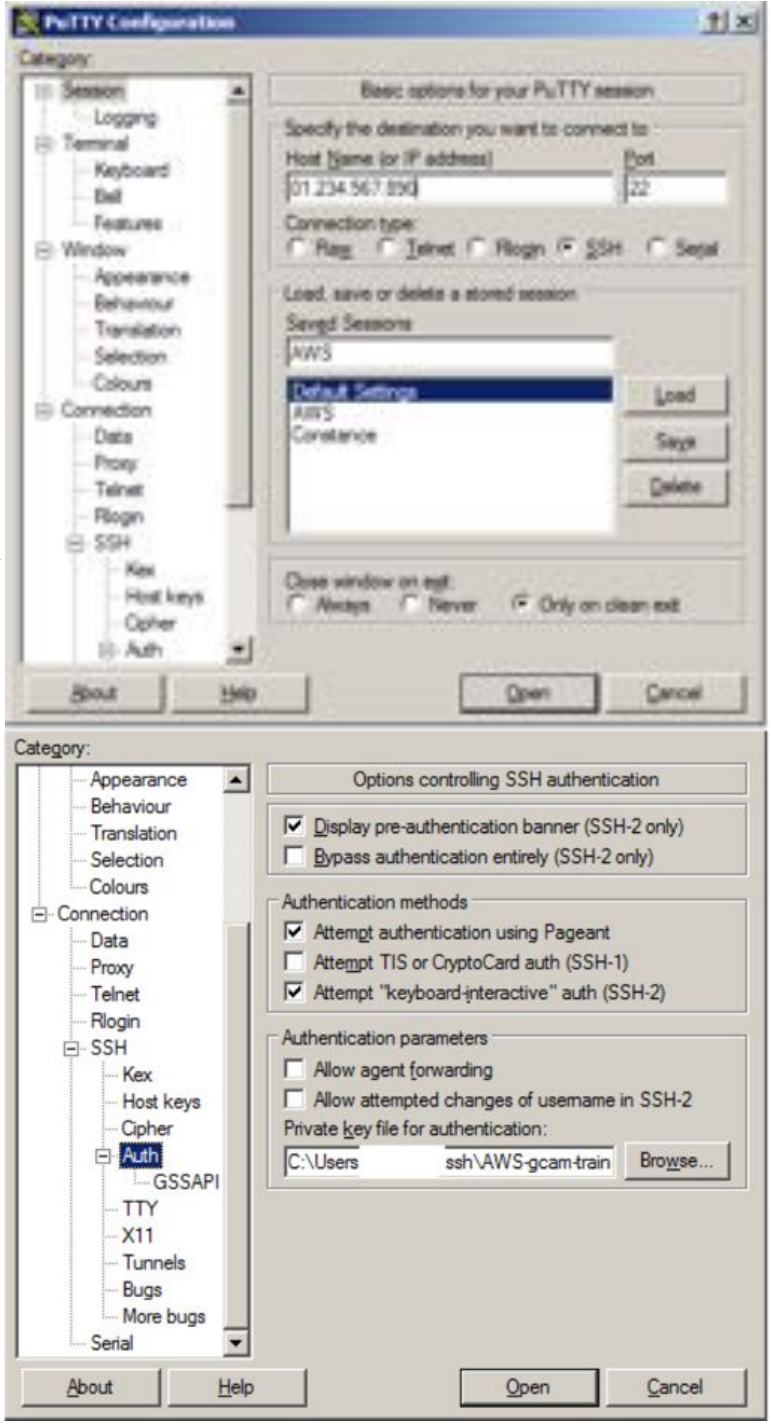
- In advanced settings, open SSH -> Authentication. Use the browser "…" to find your private key file at "C:/Users/[username]/.ssh/". When saved, WinSCP will automatically convert the .pem file to a .ppk file, readable by both WinSCP and PuTTY.
- Once logged in you will be able to interact with files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

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

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2: Configuration: the “Files” section

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

```
<Files>
    <Value name="xmlInputFileName">
    <Value name="BatchFileName
    <Value name="policy-target-file">
    <Value name="GHGInputFileName">../
                                                    name="xmldb-location">../output/database_basexdb</Value>
                                                    name="xmlOutputFileName">../output/output.xml</Value>
    <Value write-output="1" append-scenario-name="1" 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>
```

* 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">Referen
    <Value name="debug-region">USA</Value>
    <Value name=
    <Value name=
</Strings>
<Bools>
    <Value name="CalibrationAc
    <Value name="BatchMode">0<
    <Value name="find-path">0<
    <Value name="createCostCurv
    <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>
```

No spaces or special characters allowed

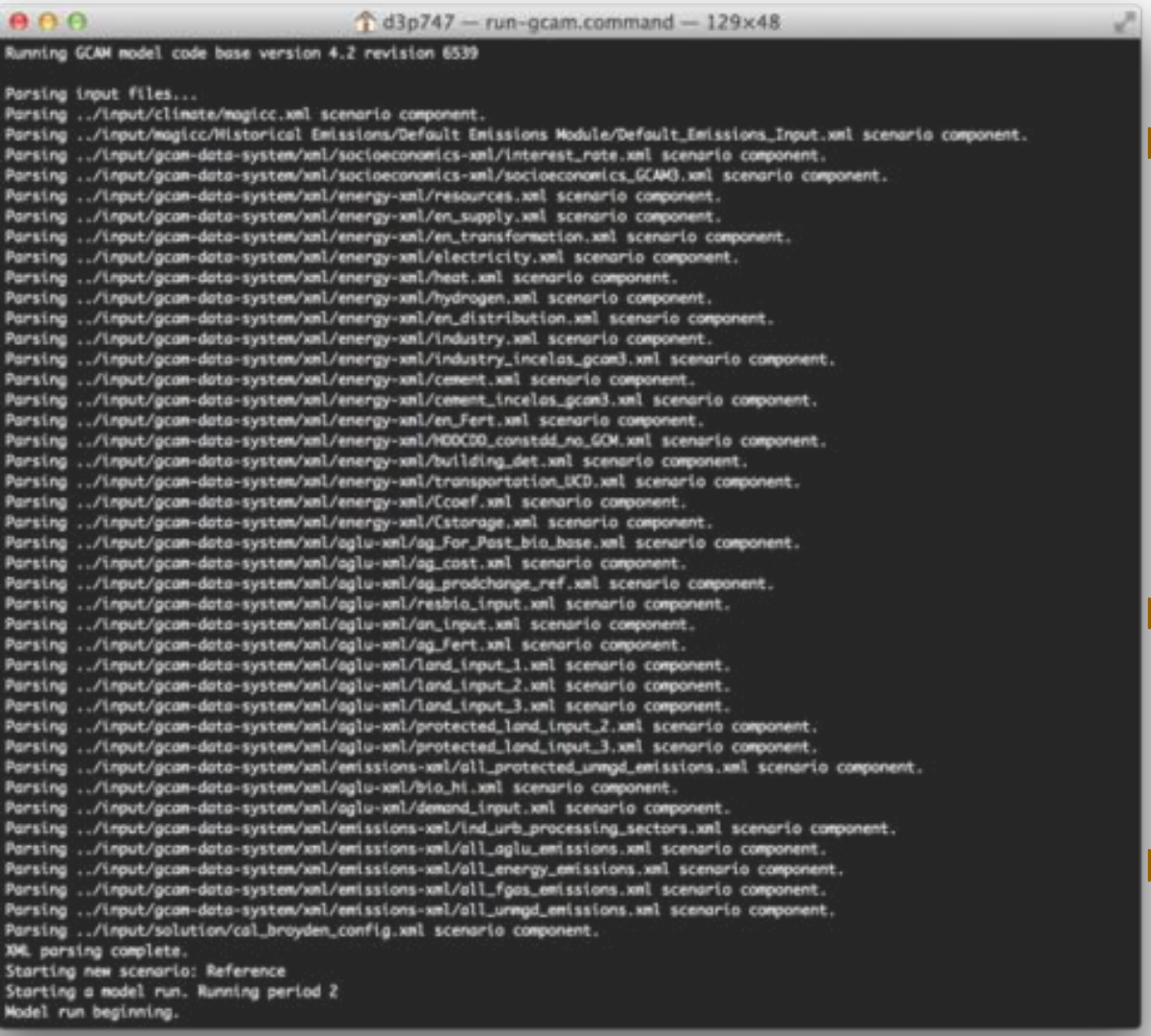
The debug file has a lot of detail but is only written for one region

Always keep calibration on

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

If true, uses policy-target-file

2: Running GCAM

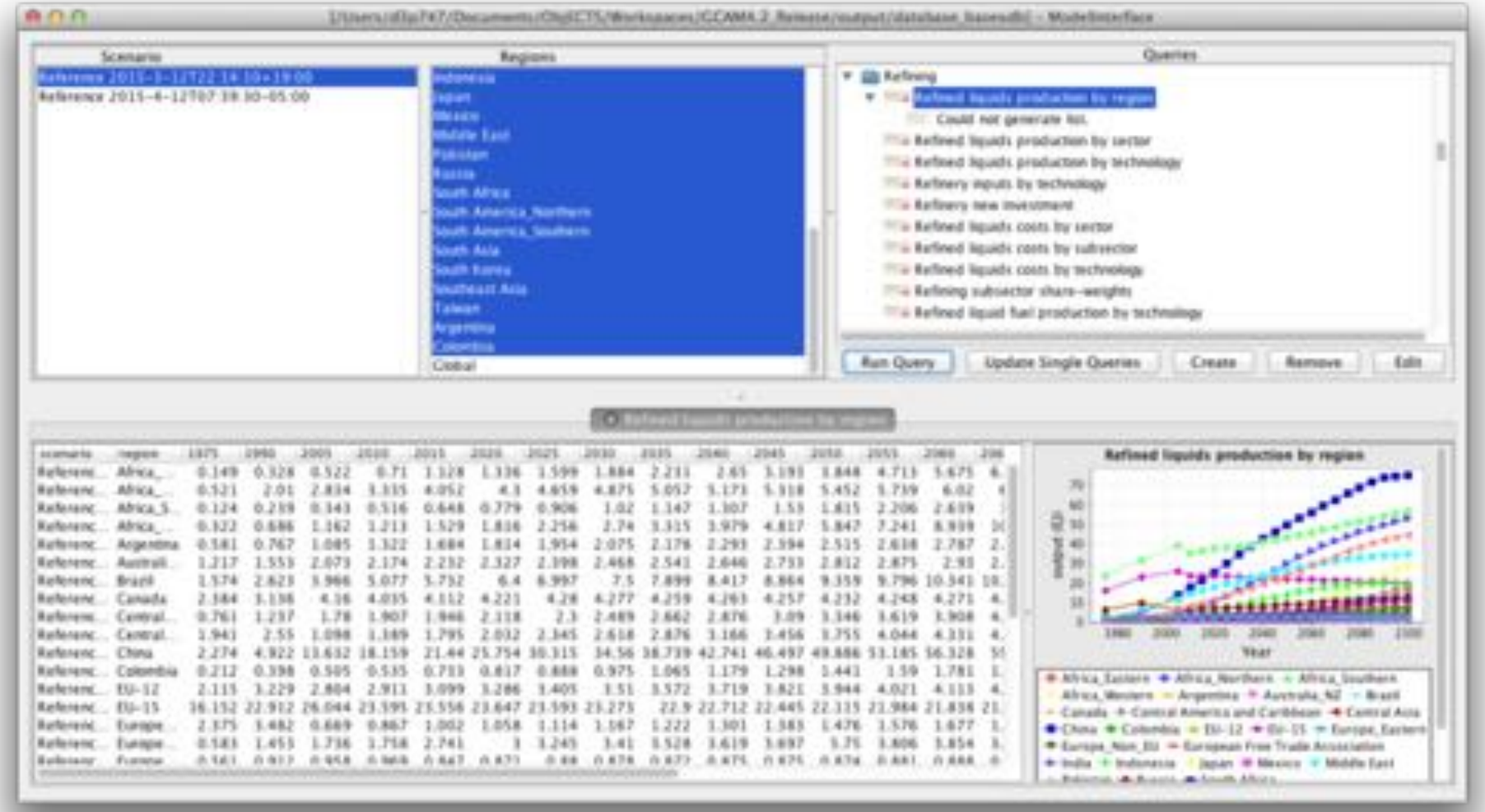


- Command prompt/terminal window contains log messages
  - These are also written out to exe/logs/main_log.txt
- Input files are read in the order that they appear in the configuration.exe file.
  - Where multiple files refer to the same parameter, the last one read in is the one whose value is used.
- 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

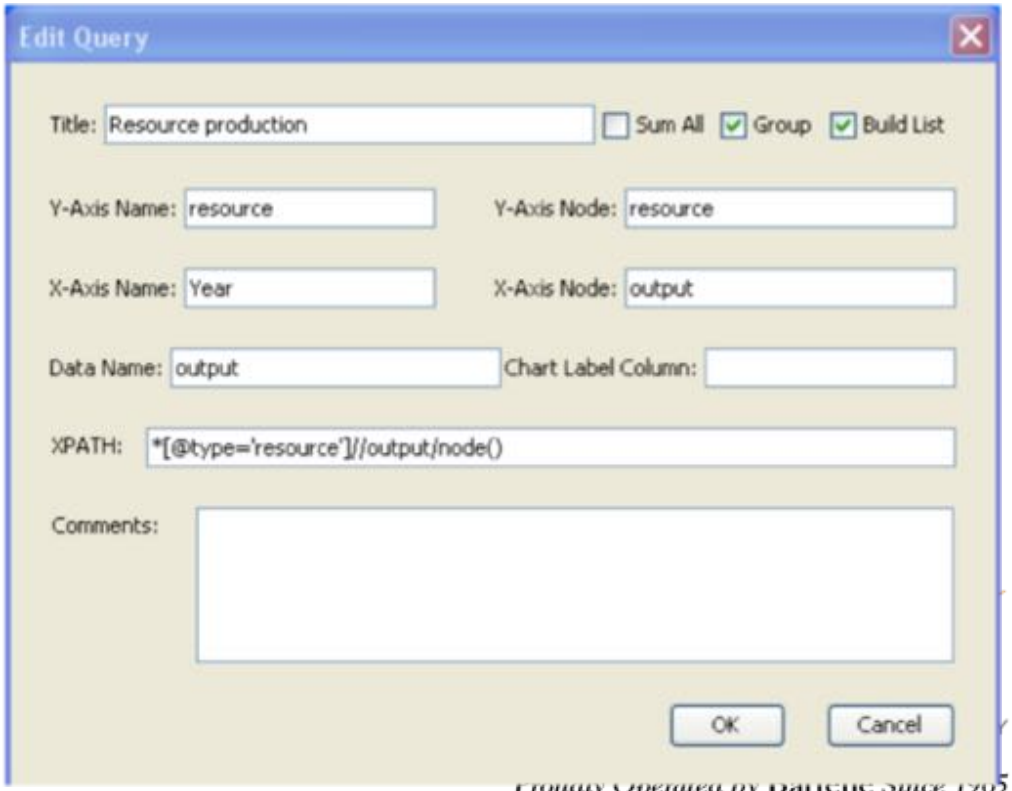


- In PuTTY or Terminal, navigate to gcam/gcam5/output/modelinterface
- Type “java -jar ModelInterface.jar”.
- File -> Open -> DB Open
- output/database_basexdb

2: Queries

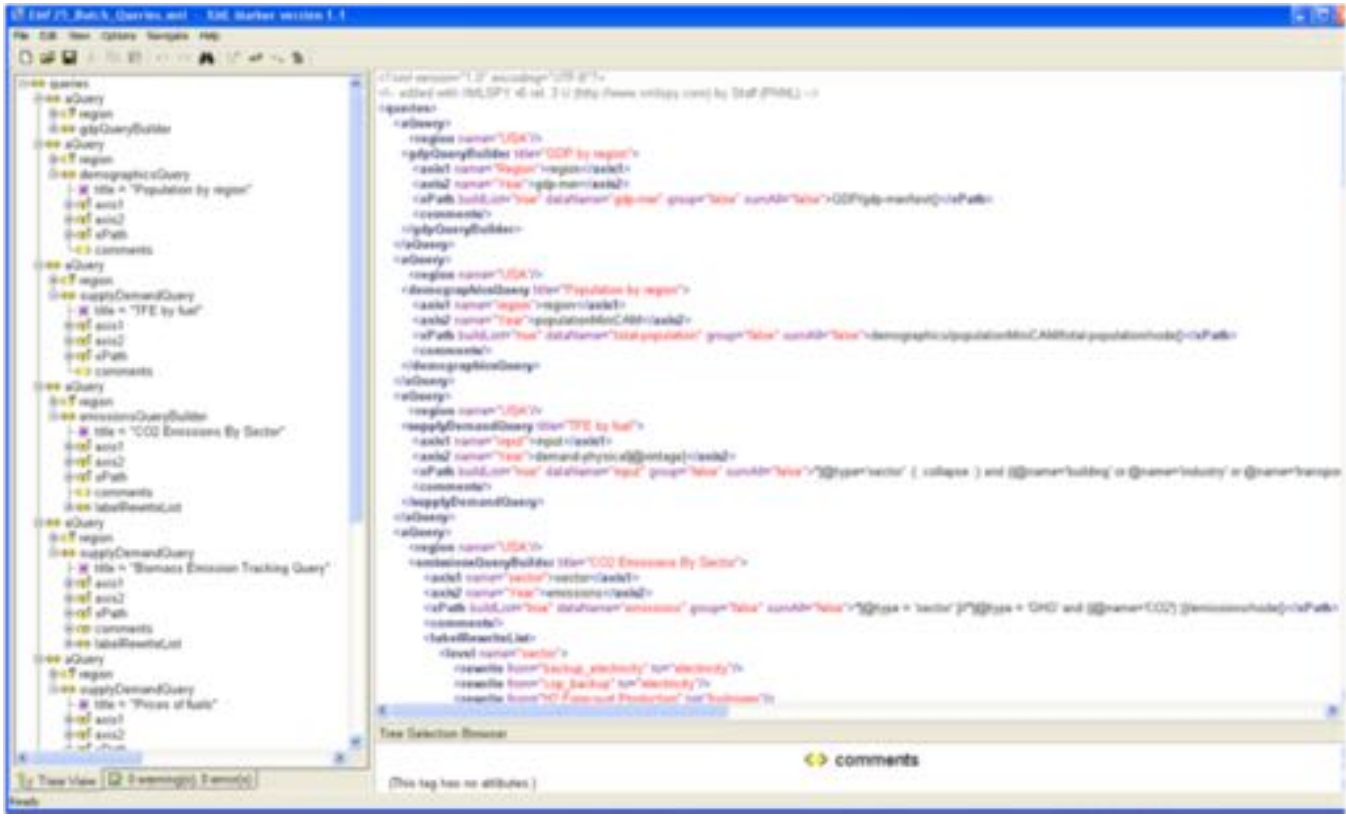
- Update single queries: allows a query to focus on an individual element

- 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.



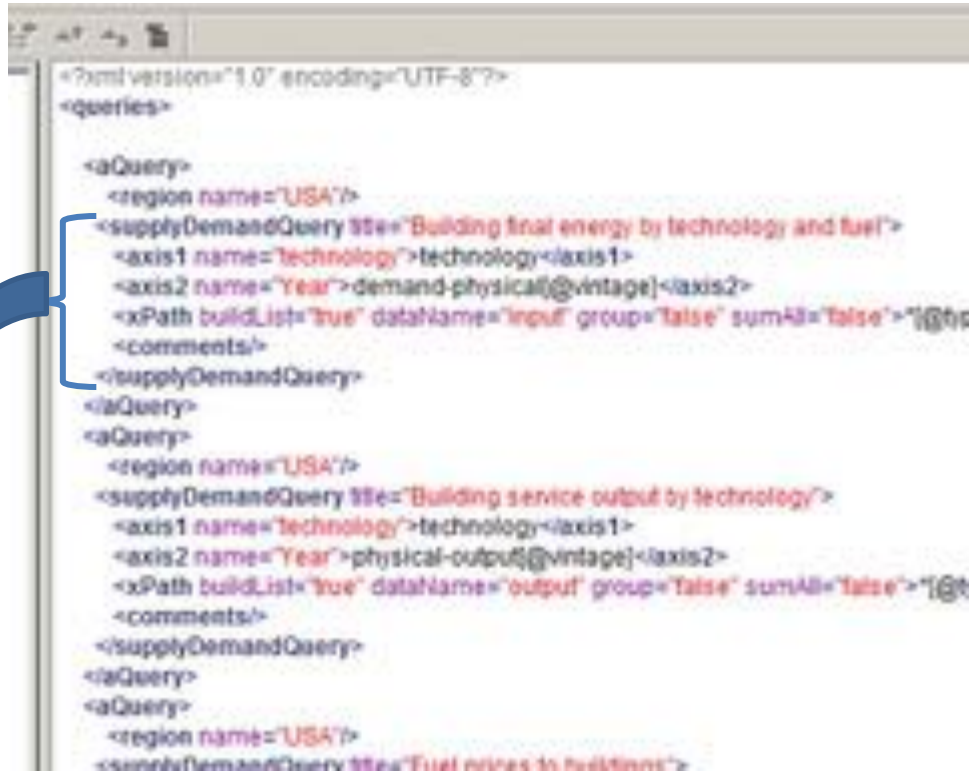
2: Exporting data

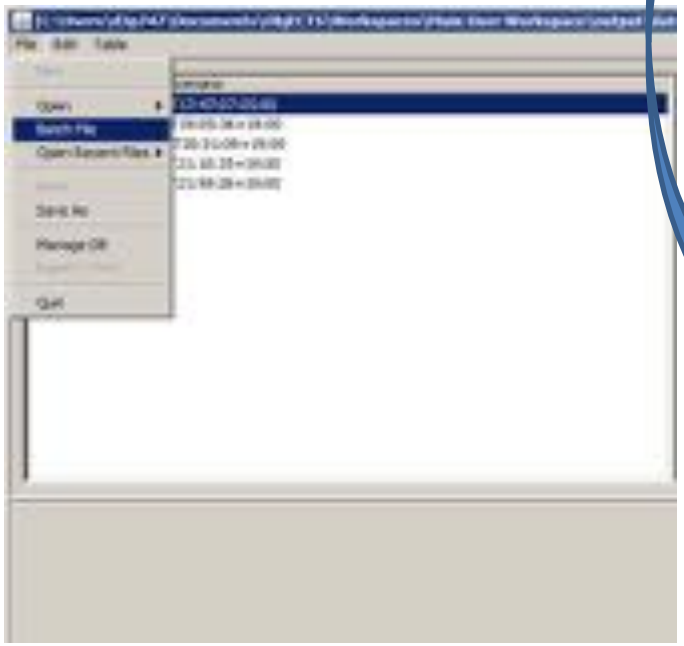
- Highlight cells, copy and paste
- Use a batch query to export a large number of queries directly into an Excel spreadsheet
  - The dbxml file needs to be open for this to work
  - File -> Batch File. Select batch query file and output workbook.
  - This won't work if the Excel workbook selected is 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

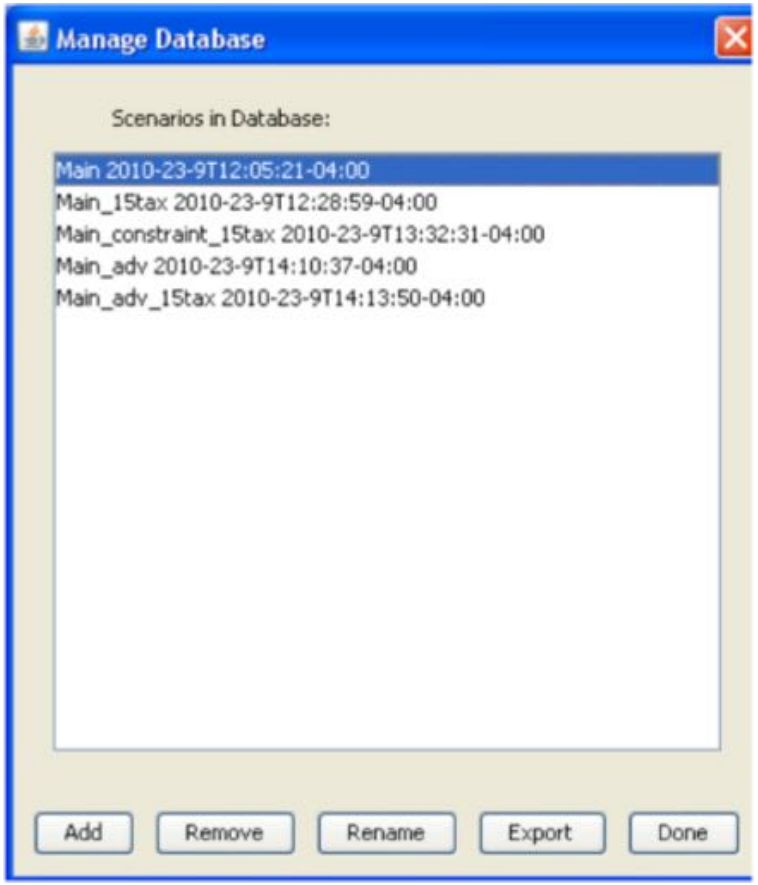




This portion is pasted from model interface queries, or Main_queries.xml file. Only need to add region and aQuery tags to make the batch query file.

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



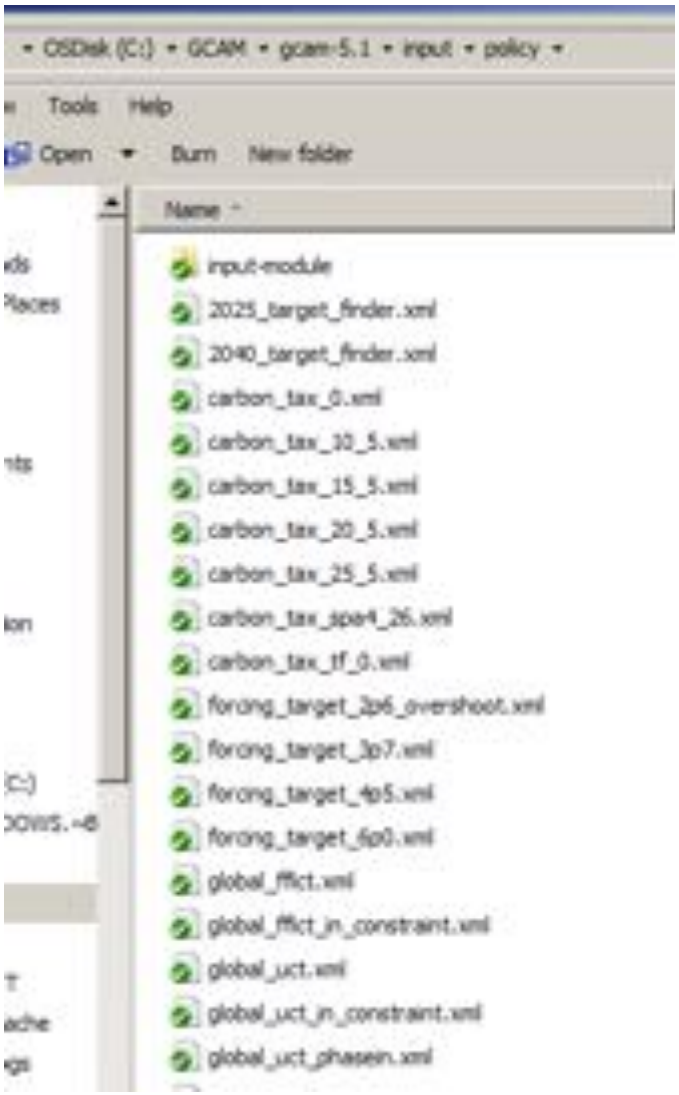
2: Useful Miscellaneous Info

- 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
  - CO_2 is in Mt C. Multiply by 44/12 to convert to CO_2
  - Non-CO_2 gases are generally in Tg (same as Mt). Exceptions are the hi-GWP gases (e.g. HFCs, PFCs, SF_6), 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$/tC. Multiply by 12/44 to convert to 1990$/t$CO_2$.
  - 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:
    - C price ($/tC) * 1t / 1000kg * Fuel C content (kgC/GJ) * (1 – 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)
  - CO_2 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

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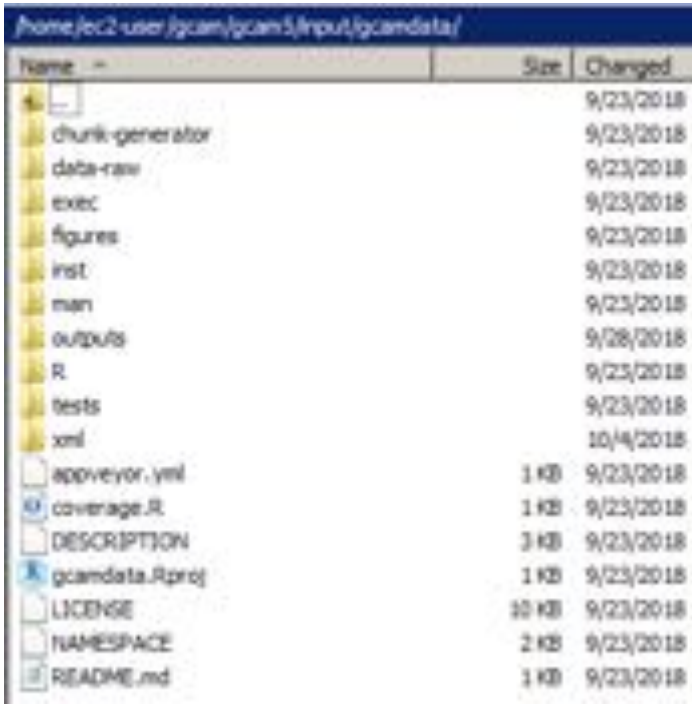
3: Configuration

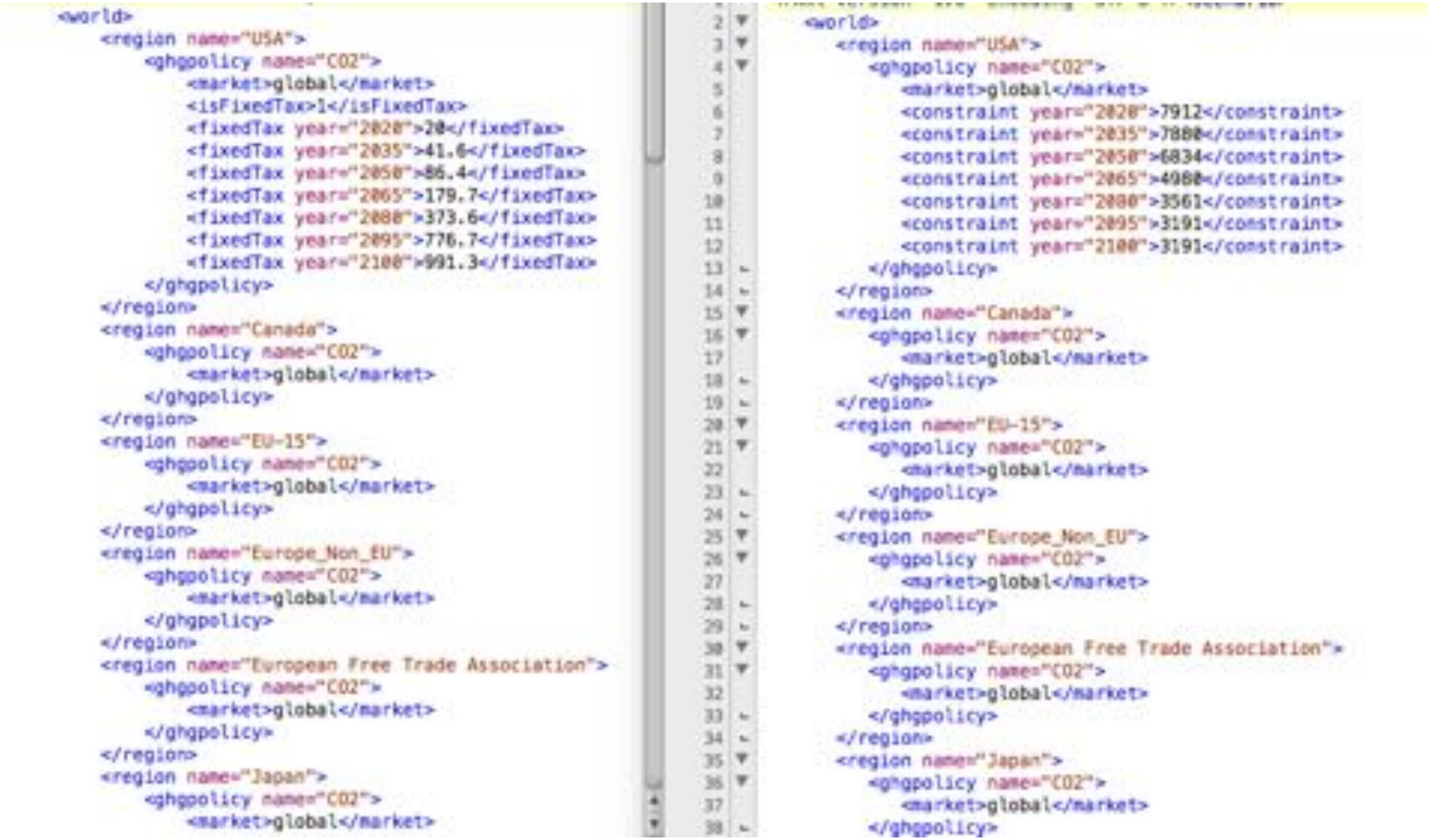
- Alternative scenarios may be run as follows:
  - add additional XML files at the end of the existing ScenarioComponents
  - Change the scenarioName
  - Indicate whether to use target-finder (if running an end-of-century climate target)
  - Indicate whether to calculate abatement cost curves

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
  - 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>
```

```
<world>
    <region name="USA">
        <ghgpolicy name="CO2">
            <market>global</market>
            <constraint year="2020">7912</constraint>
            <constraint year="2035">7888</constraint>
            <constraint year="2050">6834</constraint>
            <constraint year="2065">4988</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>
```

- 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:noNa
    <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

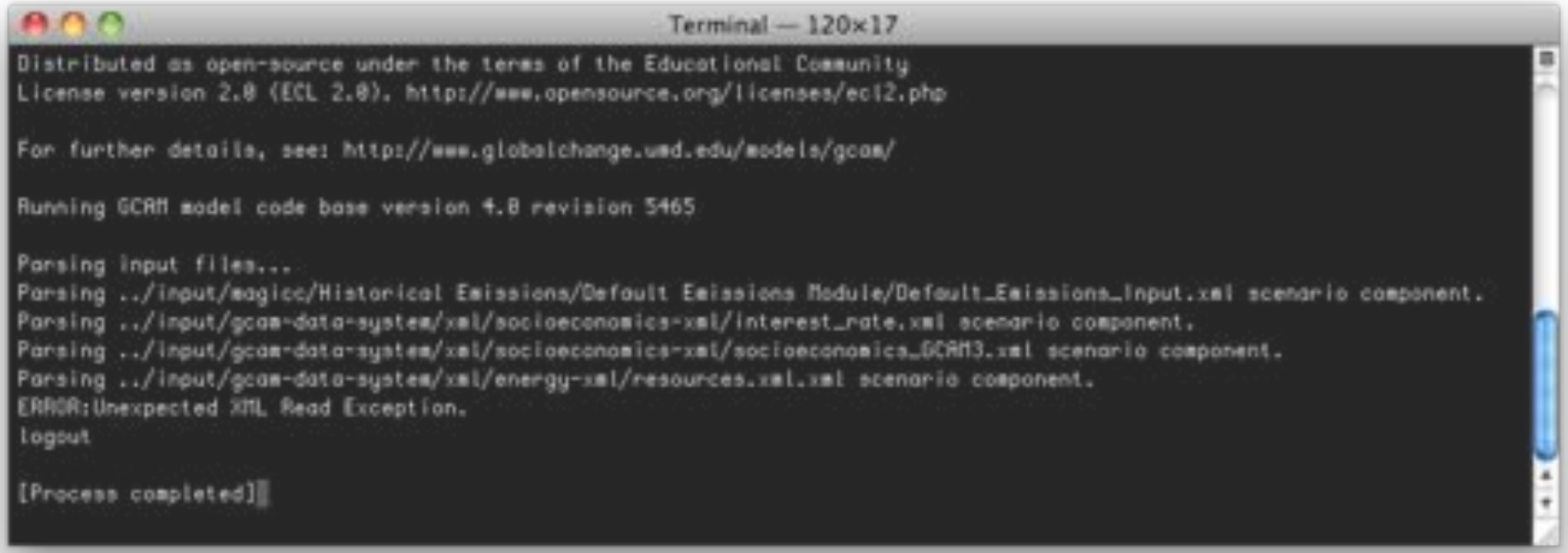
4: Configuration/input errors

- Problem: Immediate crash

- 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

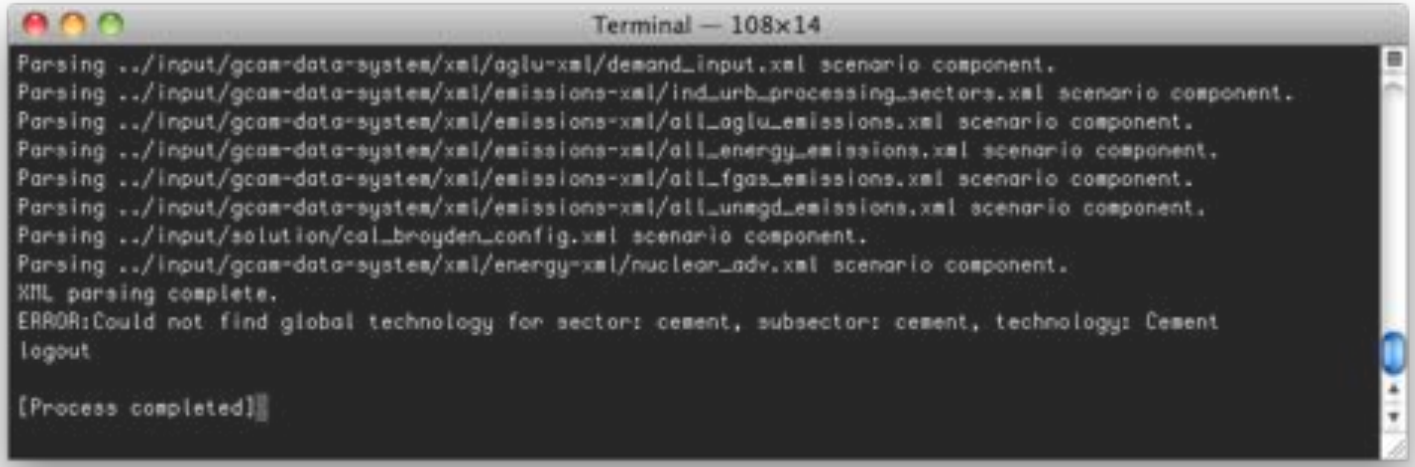
- Problem: crash while reading in the ScenarioComponents XML files



- 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

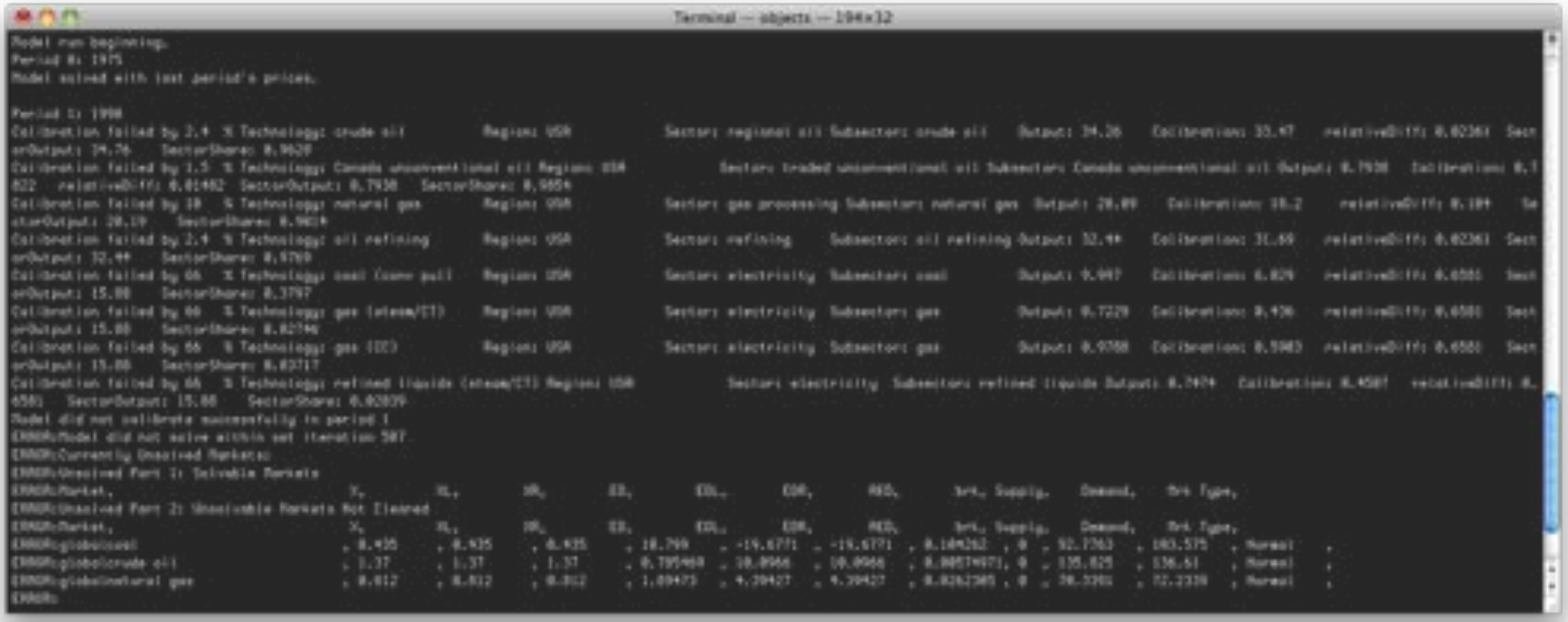


- The problem: mis-spelled a technology name (Cement instead of cement). Strings in GCAM are case-sensitive.

```
<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="19
        <keyword final-energy="industry"/>
        <subsector name="cement">
          <logit-exponent fillout="1" year="
          <share-weight fillout="1" year="19
          <interpolation-rule apply-to="shar
            <interpolation-function name="f
          </interpolation-rule>
          <stub-technology name="Cement">
```

4: Errors from changes to input files

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



- 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

- 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

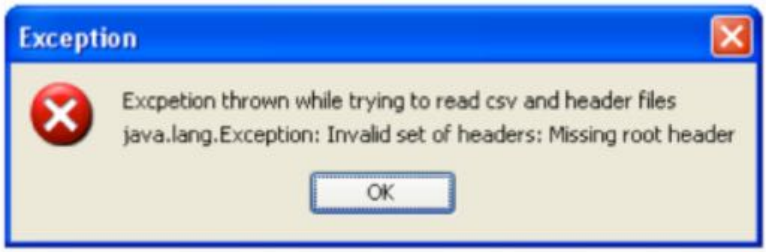
- Message: "The query returned no results"
  - The market may not exist (e.g. C price in a non-policy run)
  - The syntax of the XPATH may be wrong (e.g. not enough slashes)
- Nothing at all prints out (not even a warning message)
  - The syntax of the XPATH is incorrect. Check that all parentheses are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

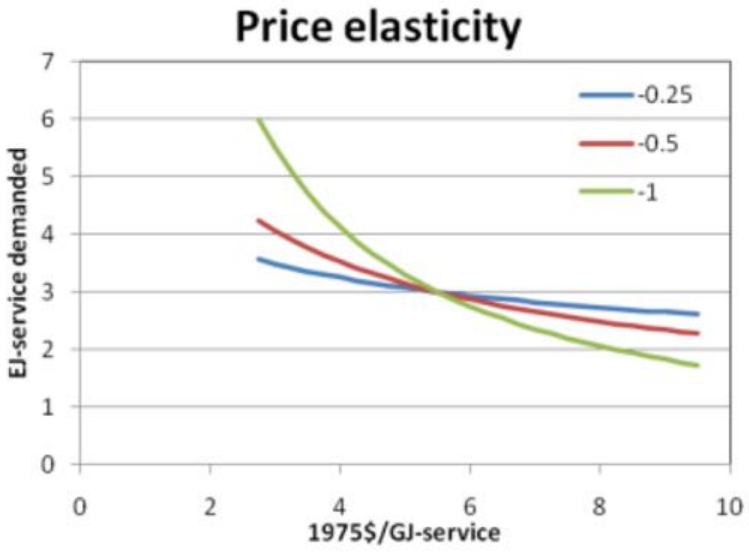
5: What does it all mean?

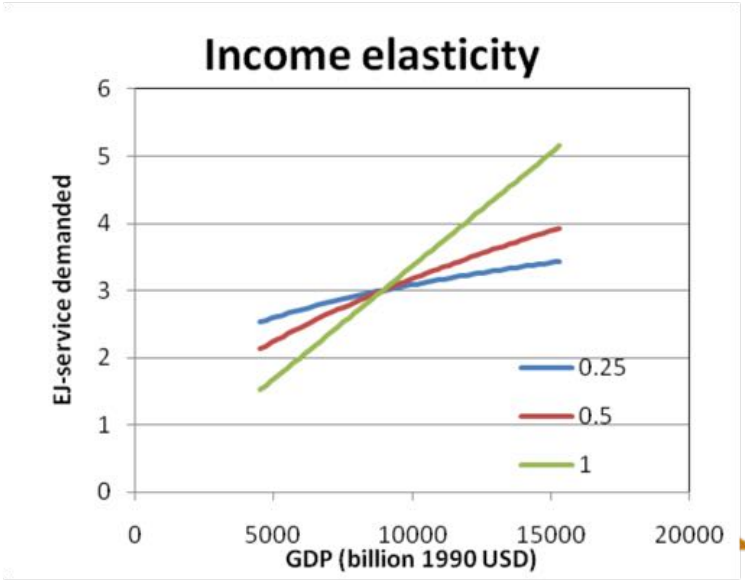
- This section focuses on the meaning of several key input parameters found throughout the input XML file set
  - Elasticities
  - Logit exponents
  - Share-weights and interpolation rules
  - Efficiencies and coefficients

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

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





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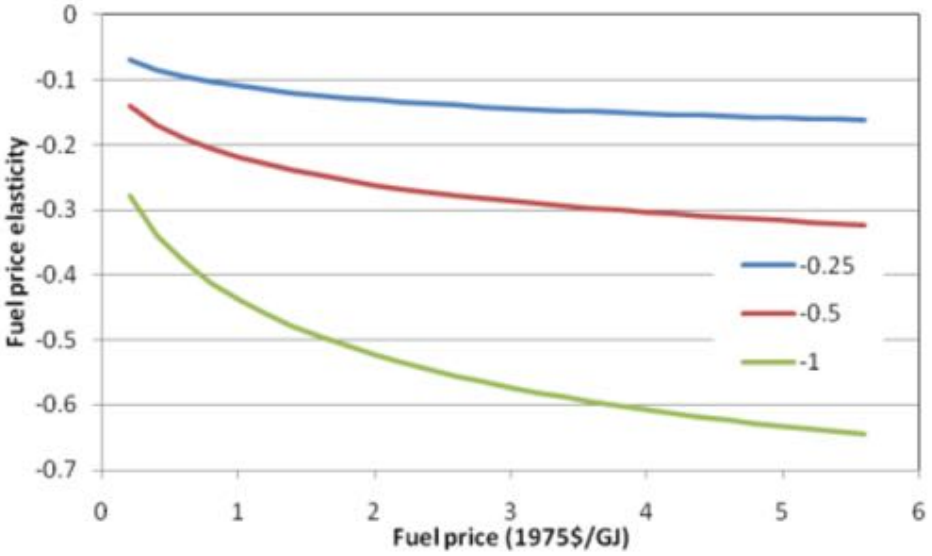
5: Service price elasticity ≠ fuel price elasticity

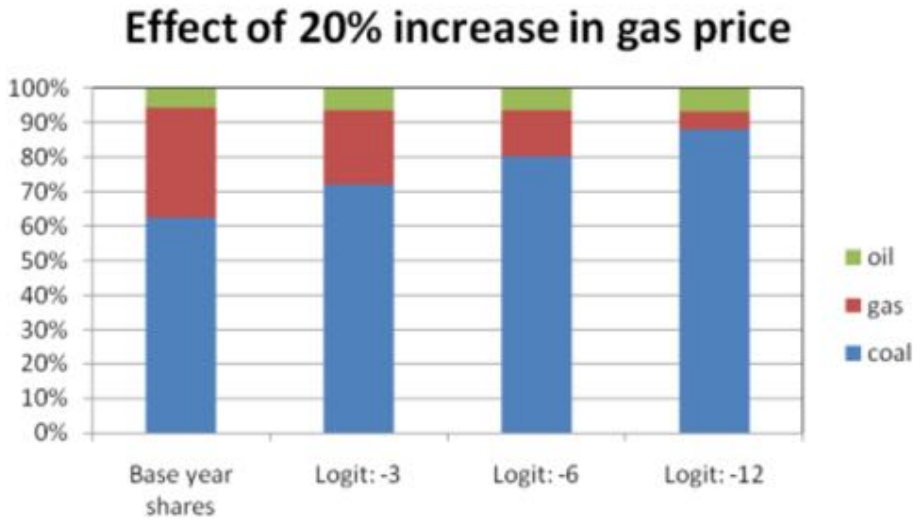


- Service price elasticities include ALL costs of providing the energy service
  - Levelized capital costs, fixed O&M, variable O&M
  - In passenger transportation, service costs may include time value costs

5: Logit-exponents and fuel-switching

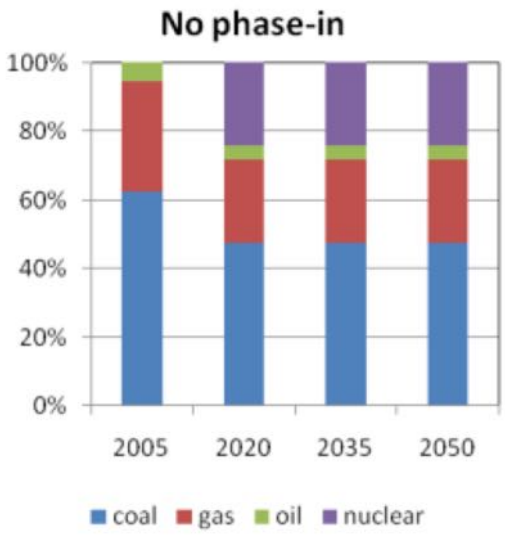
- The logit exponents control the degree of switching between technologies or fuels in response to price changes
  - Low values = low fuel-switching = strong influence of base year shares even far into the future
  - High values tend towards winner-take-all responses in response to changes in costs

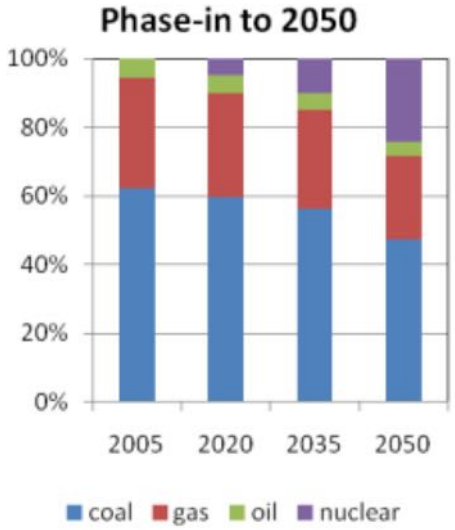
$$Share_i = \frac{sw_i \bullet P_i^{\beta}}{\sum_i sw_i \bullet P_i^{\beta}}$$



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>
```

Appendix

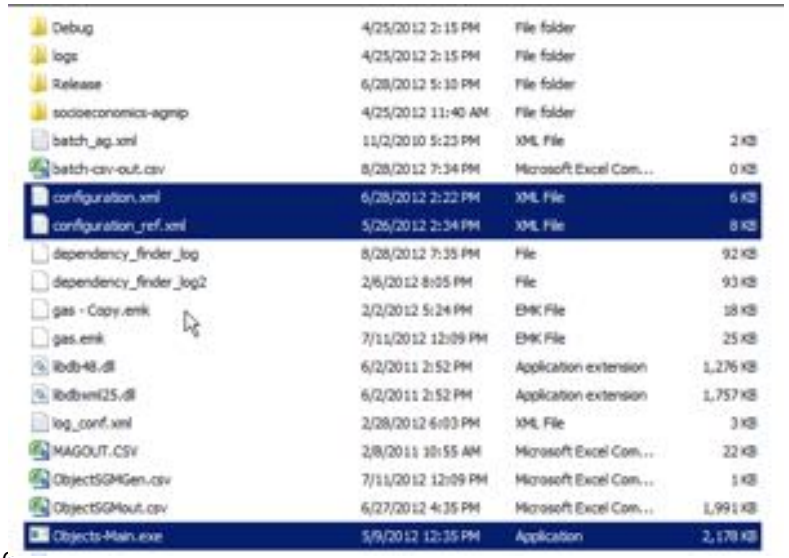
Preliminary: software to download for Desktop

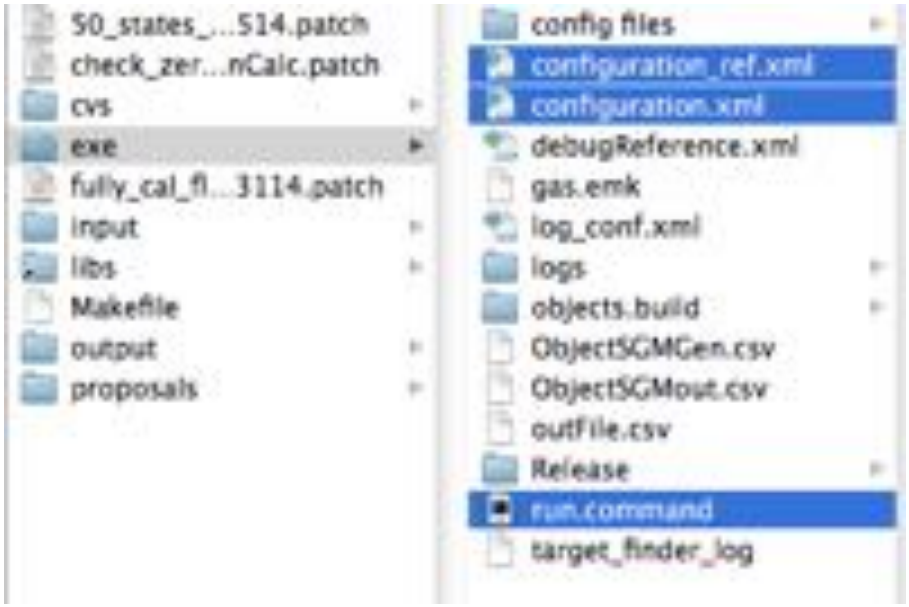
- Desktop Version Downloads:
  - GCAM: https://github.com/JGCRI/gcam-core/releases
  - Windows: Java Runtime Environment (64 bit) http://www.java.com/en/download/manual.jsp
  - Mac: Java Development Kit (recommend version 1.8)
  - To compile GCAM code:
    - Windows: Visual C++ Redistributable (x64): 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

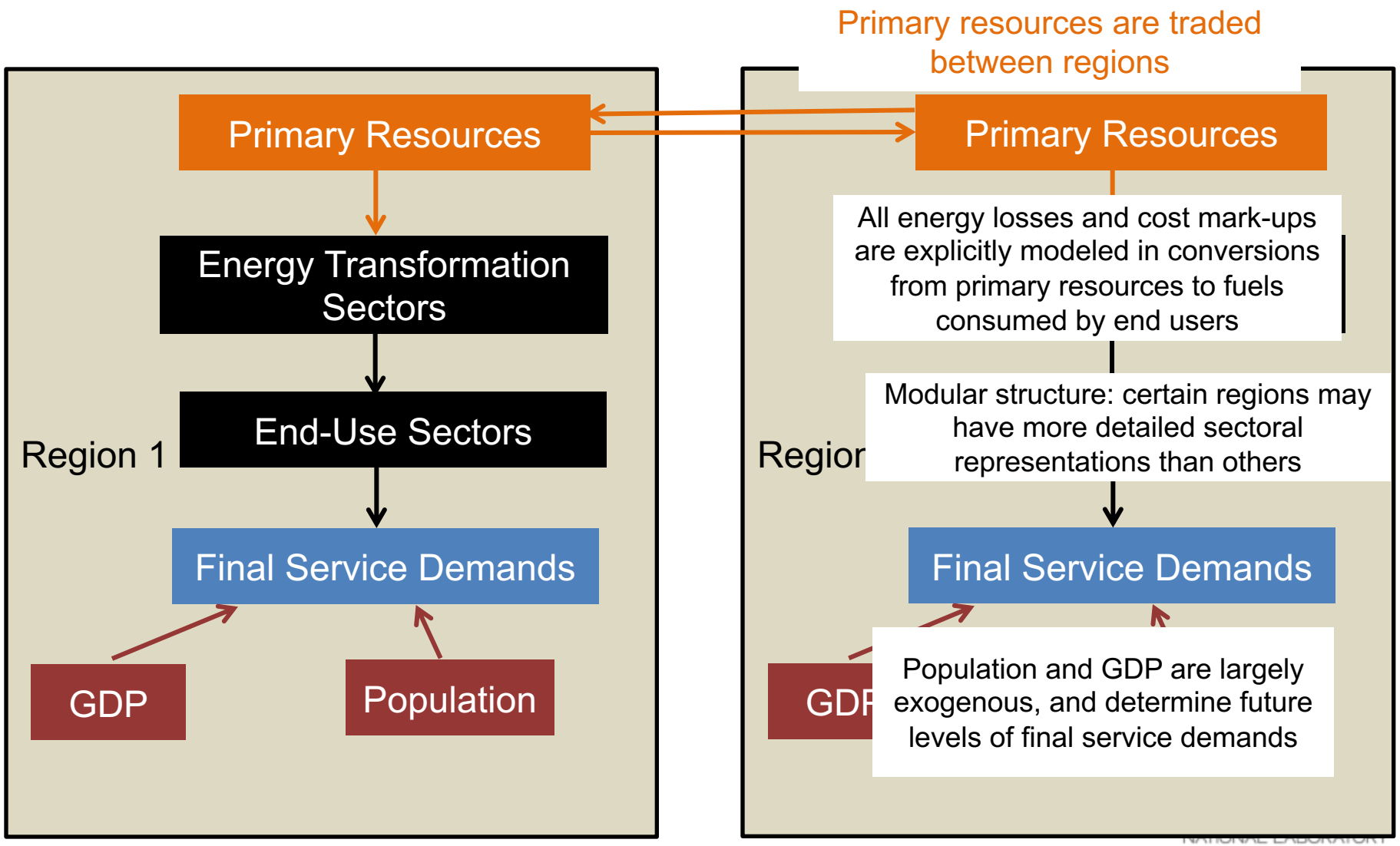
1) Navigate to the exe folder
2) Open configuration_ref.xml
   - This is a base configuration file that reads in files for the reference, or main, scenario
3) Save this as configuration.xml
   - This is the control file that is called when the model is run; the configuration.xml file itself is usually 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

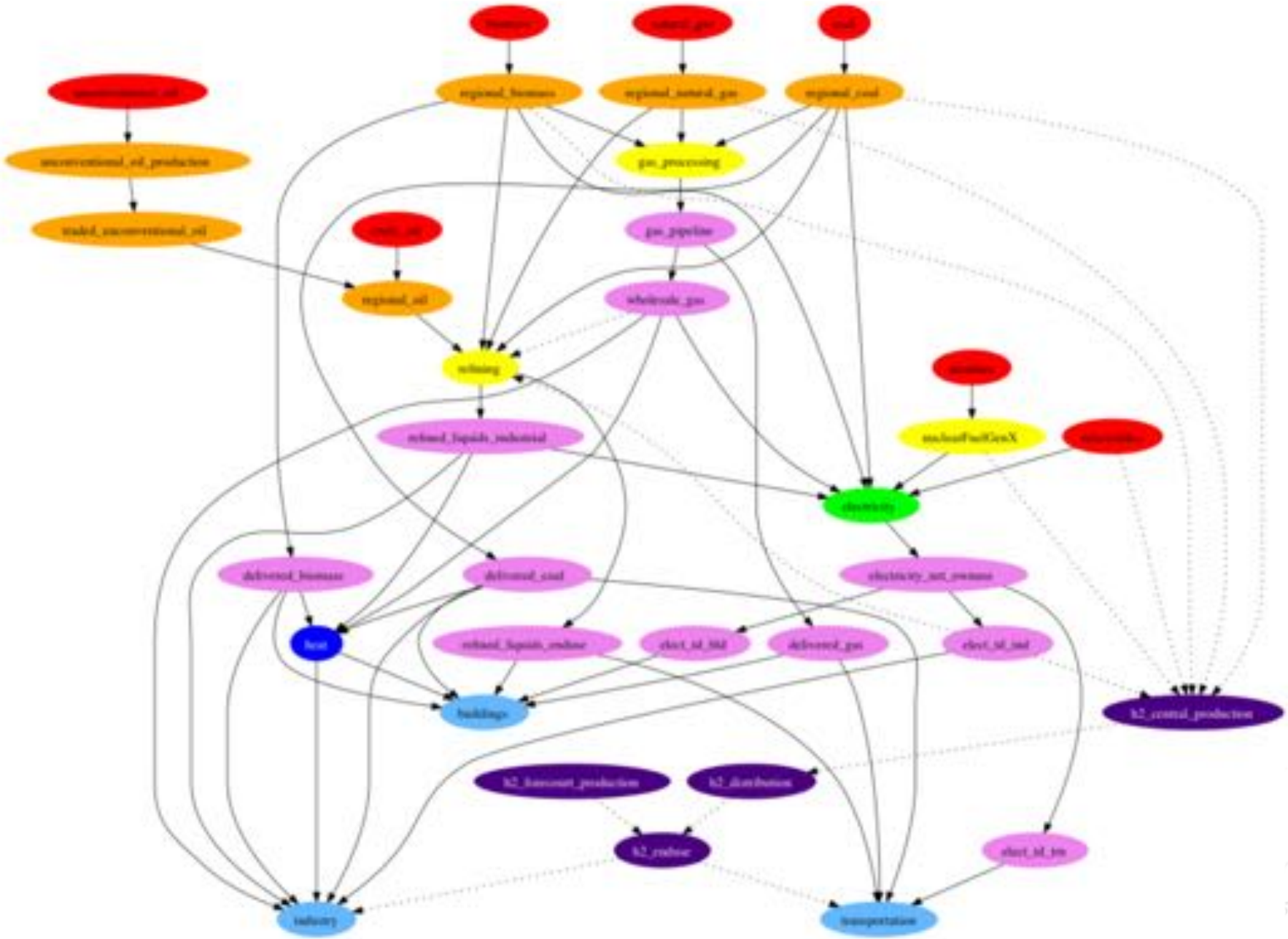




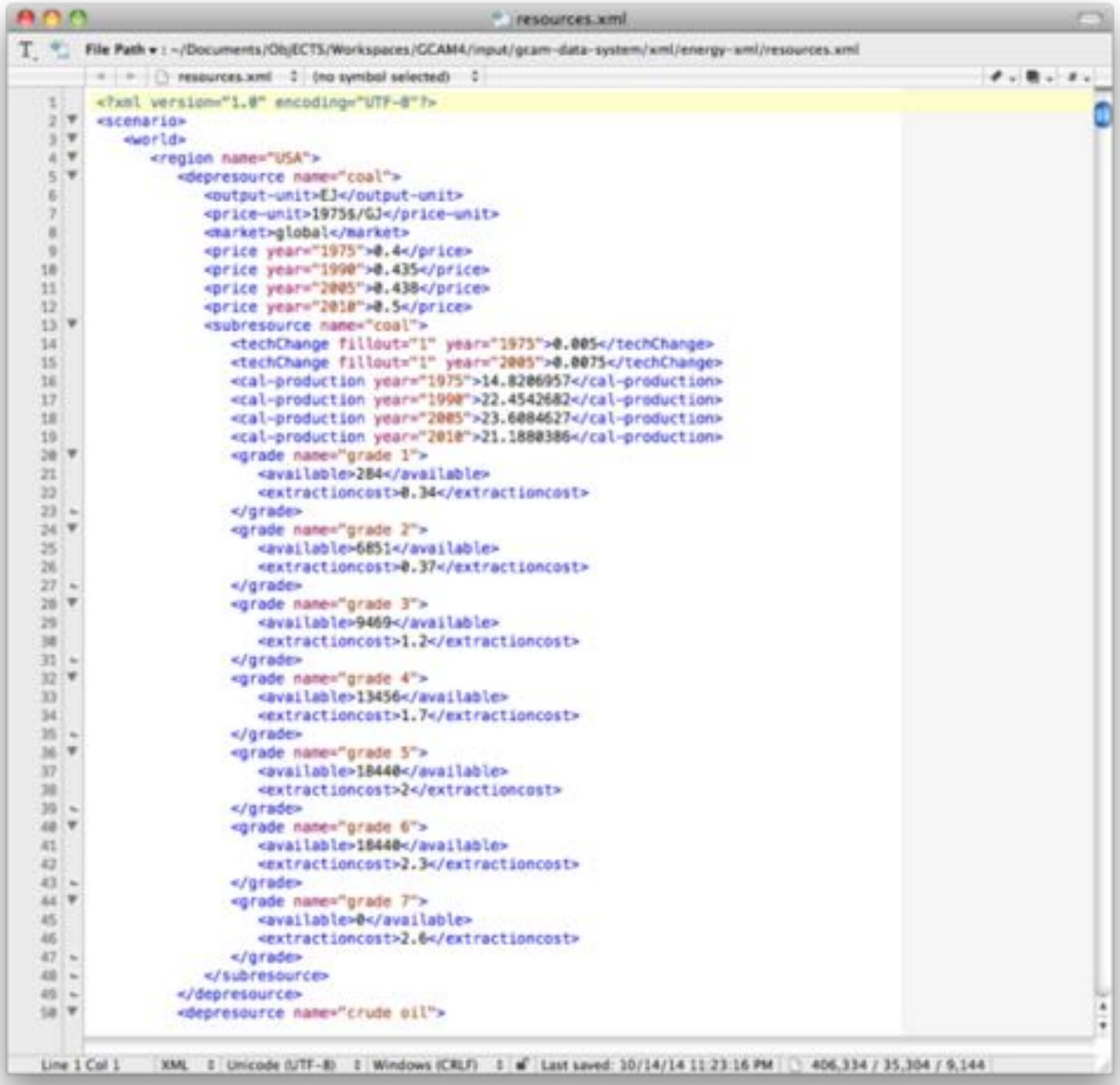
1: General energy system structure



1: General energy system structure

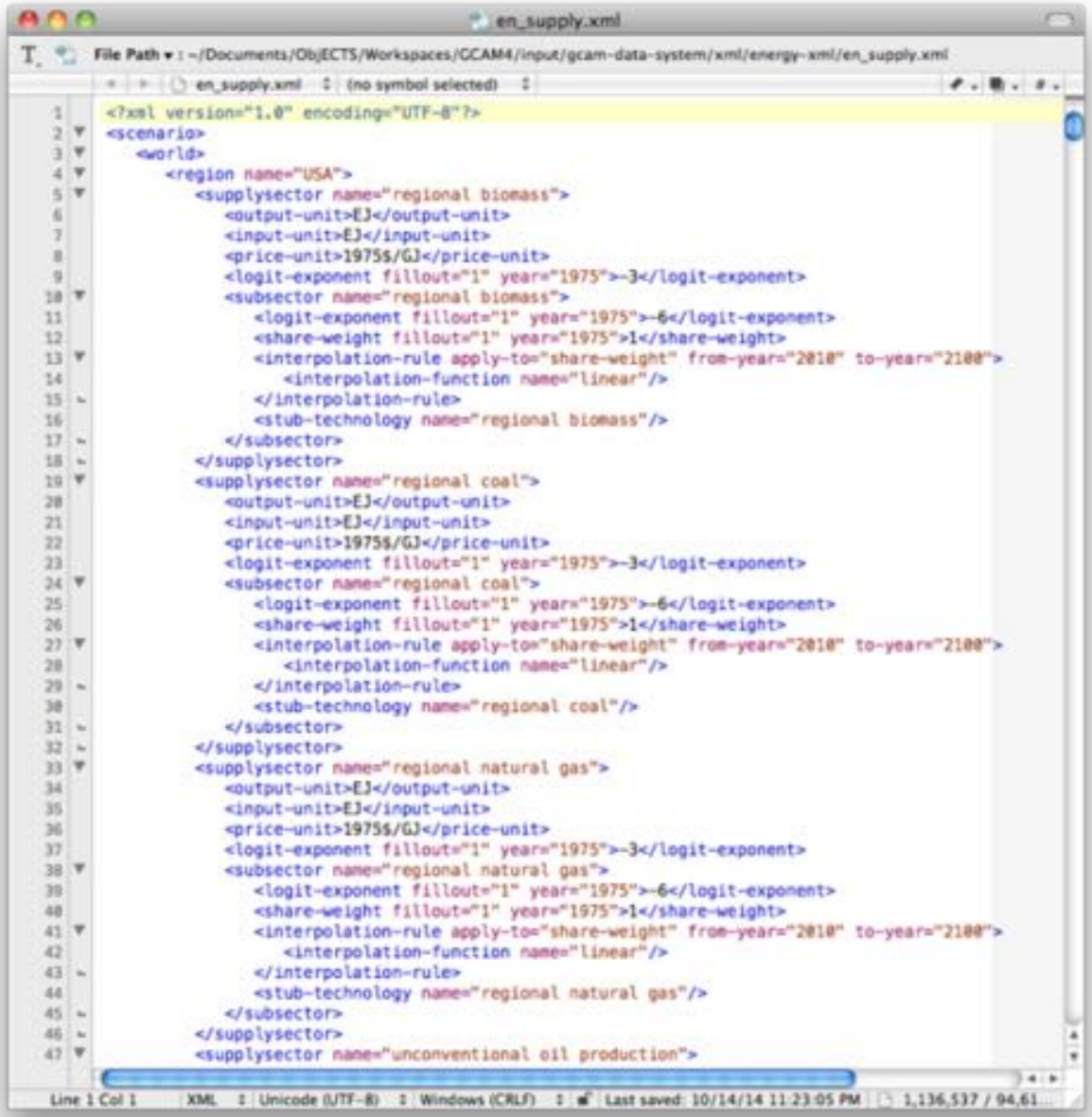


1: Resources



- 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.

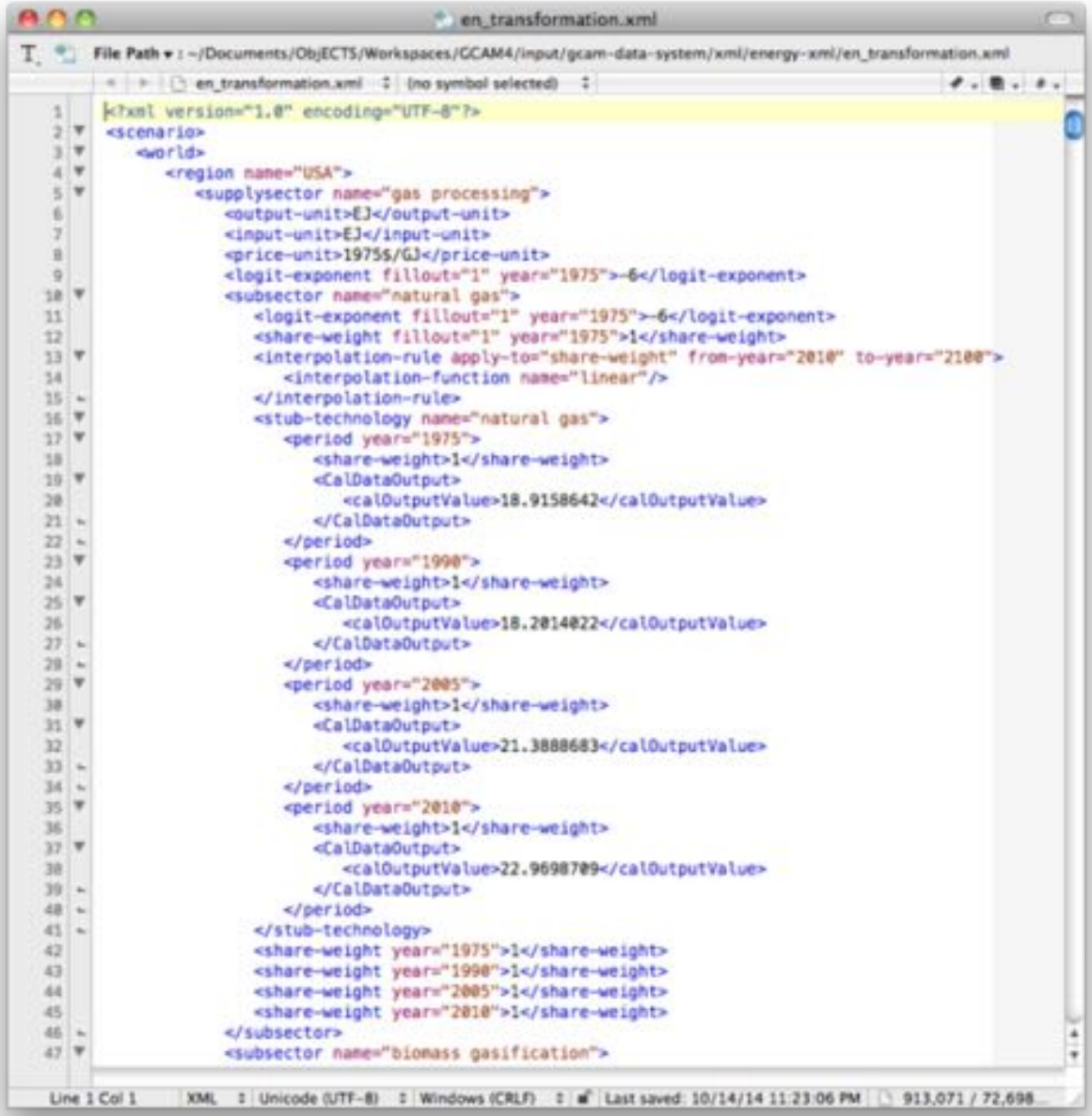
1: Domestic energy supply



- 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

1: Energy transformation sectors

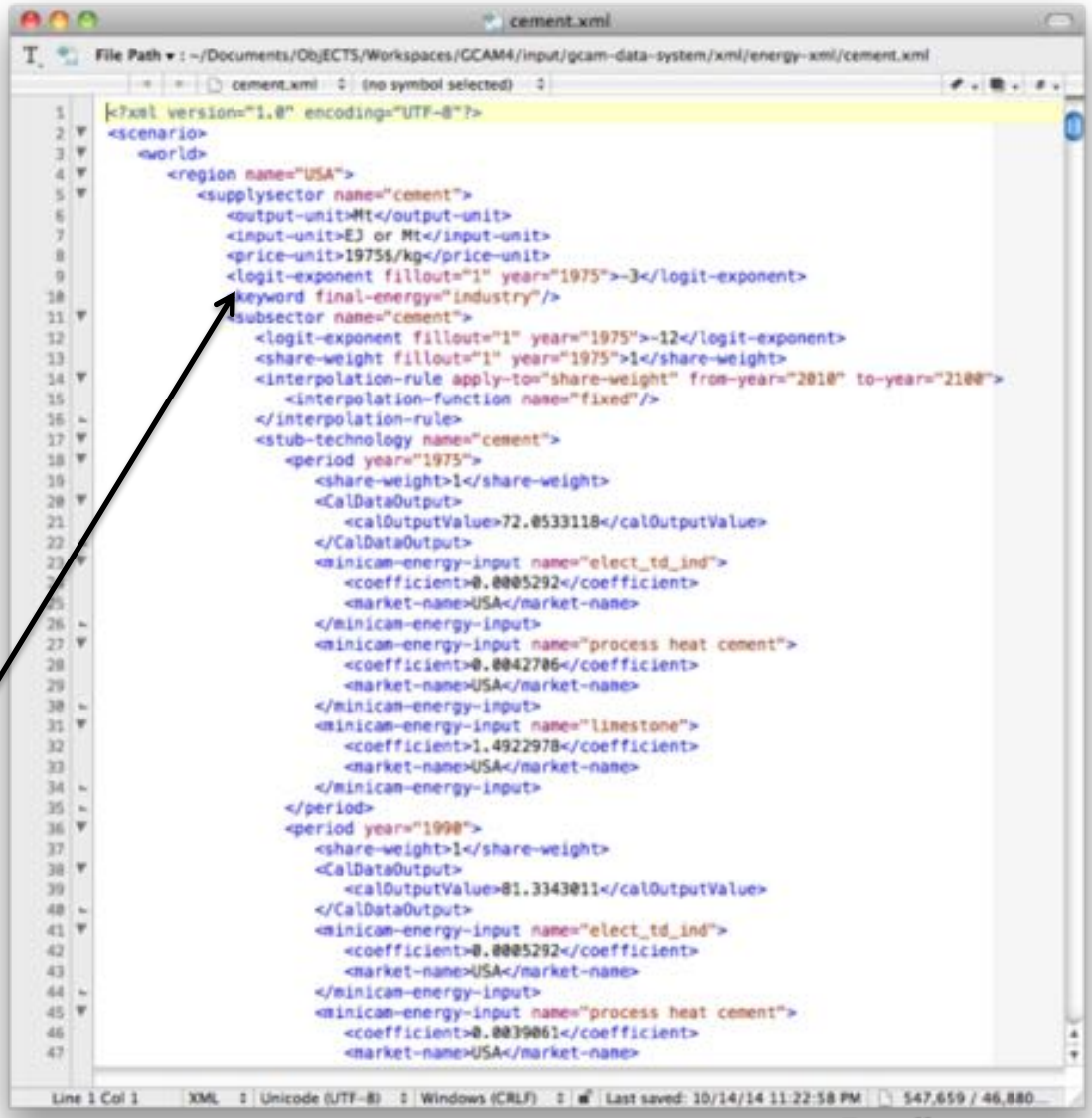
- Four XML files
  - electricity.xml
  - hydrogen.xml
  - heat.xml
  - en_transformation.xml: refining, gas processing, and nuclear fuel enrichment
- Structure: supplysector / subsector / technology
  - Subsector and technology market shares determined by two-level nested logit choice competition
- Technology 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)



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)

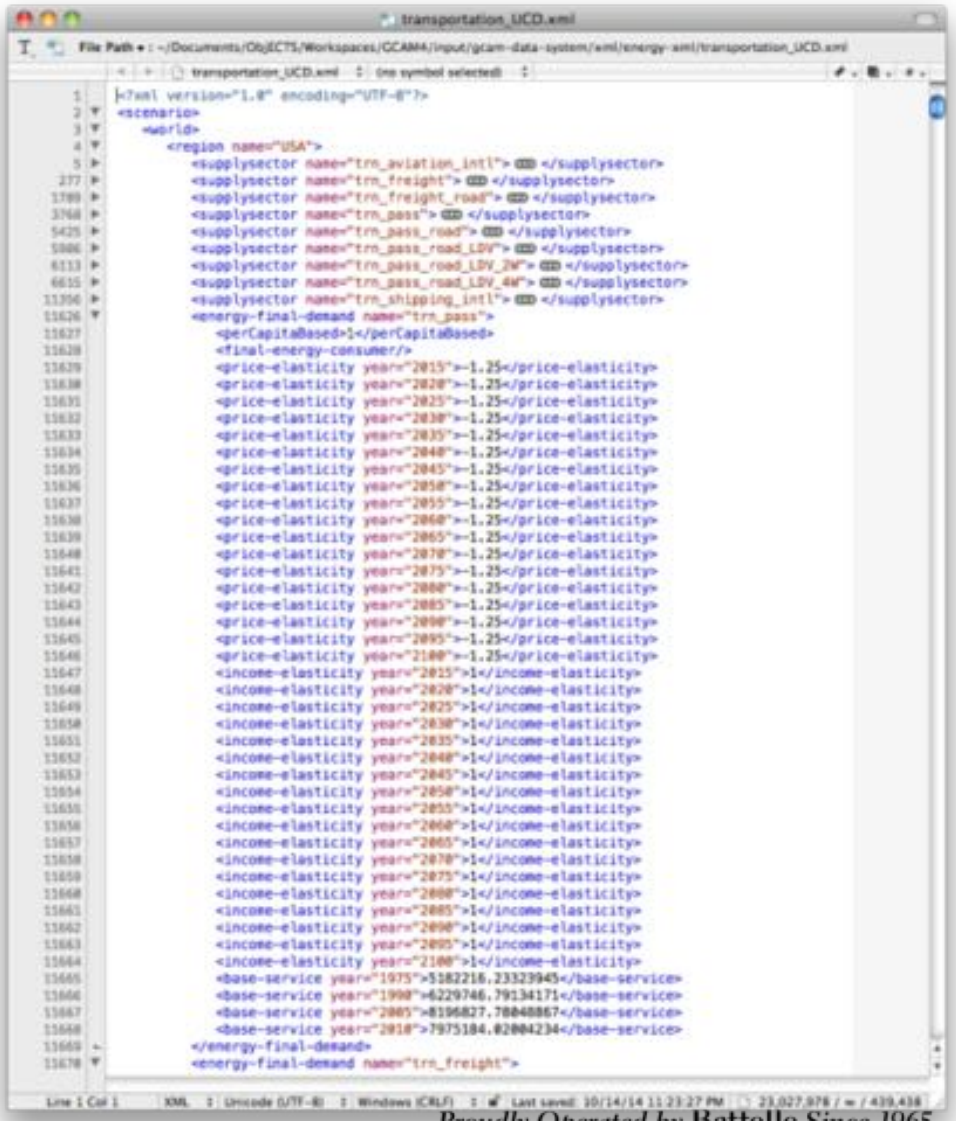


1: Energy final demands

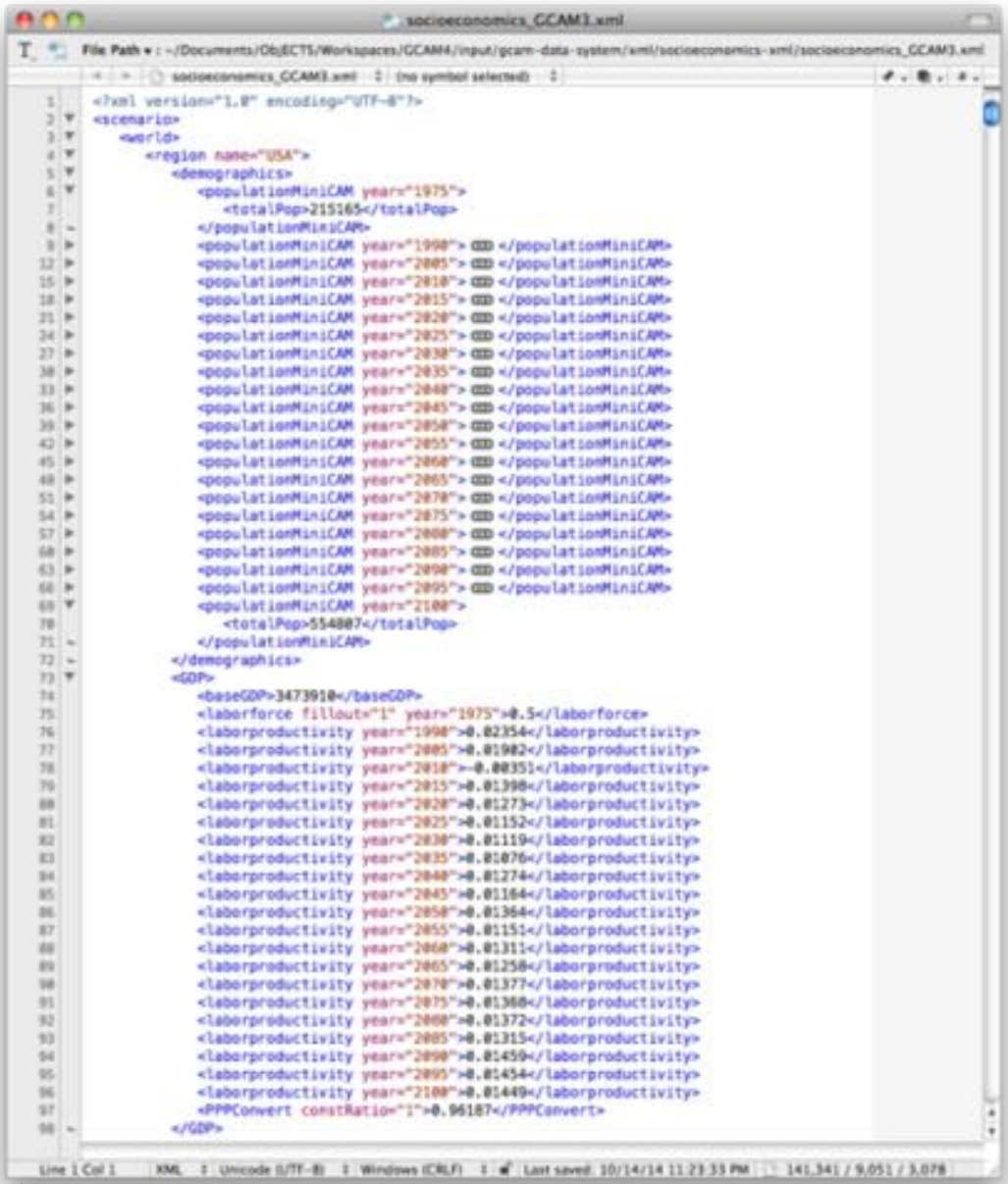
- Residential and commercial: specific representation
  - Final demand (floorspace) and intermediate demands (heating, cooling, other) are driven by “satiated demand” functions designed to de-couple service demand from income as incomes increase
- Industry and cement: generic per-capita based demand functions

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

  - 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: GDP and population



- 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:

$$GDP_{R,t1} = GDP_{R,t0} \bullet \left(\frac{Pop_{t1} \bullet laborForceParticipation_{R,t1}}{Pop_{t0} \bullet laborForceParticipation_{R,t0}}\right) \bullet (1 + labor\ \mathrm{Pr}odGrowthRate)^{(t1-t0)}$$

  - All parameters to the GDP function are strictly exogenous

1: Non-CO_2 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)

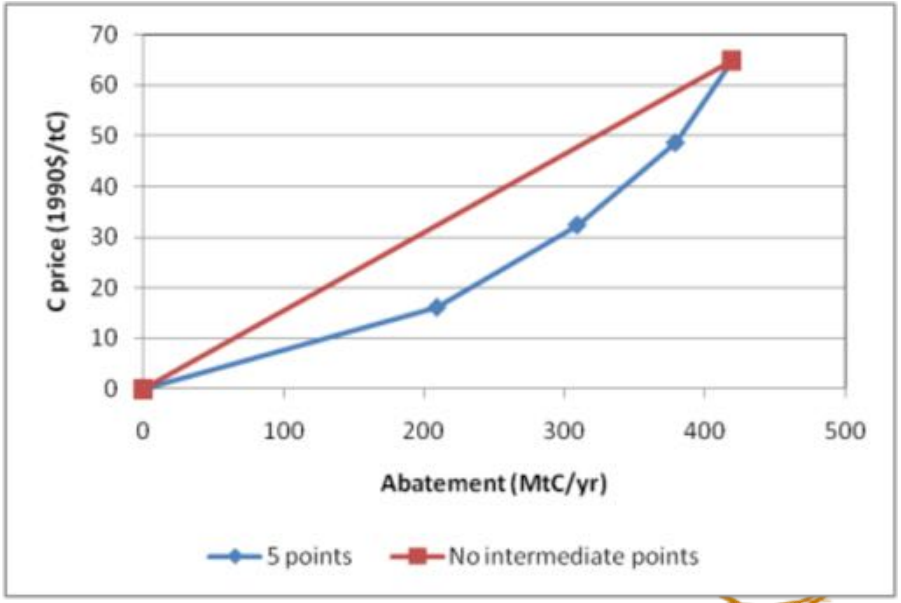
- Can be read in as input-emissions (Tg/yr) or as emissions coefficients (kg/GJ)
- GDP control function: emissions coefficients are reduced as GDP increases
- MAC = marginal abatement cost curve; decreases coefficients as carbon price increases.

$$Coef_{t1} = Coef_{t0} \bullet (1 - \min(\max \mathrm{Re}\, duction, 1 - \frac{1}{1 + \frac{(pcGDP_{t1} - pcGDP_{t0})}{Steepness}})$$

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



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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

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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 heirarchy, one can choose how many levels of the heirarchy 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()

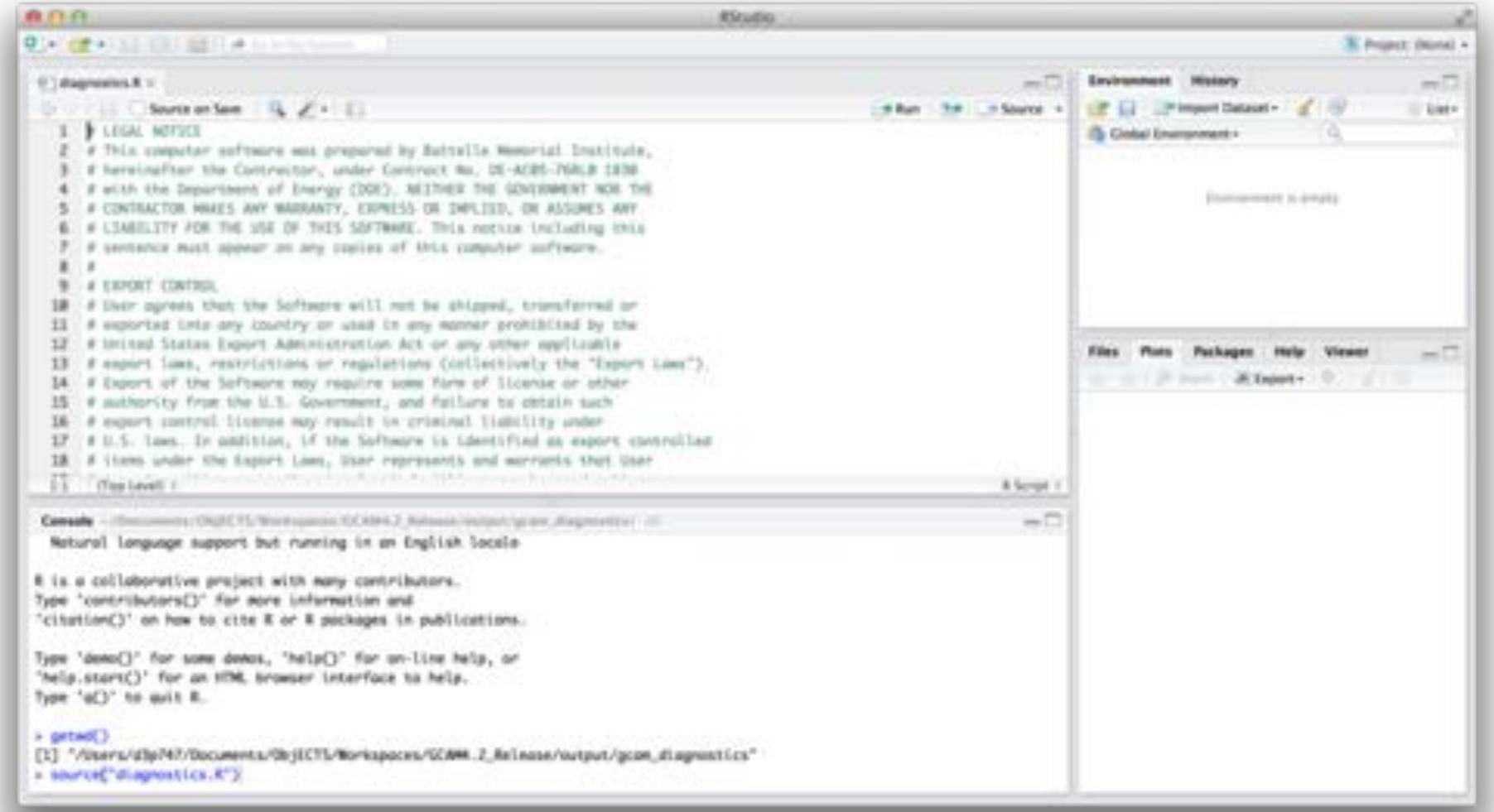
Gas production by technology

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

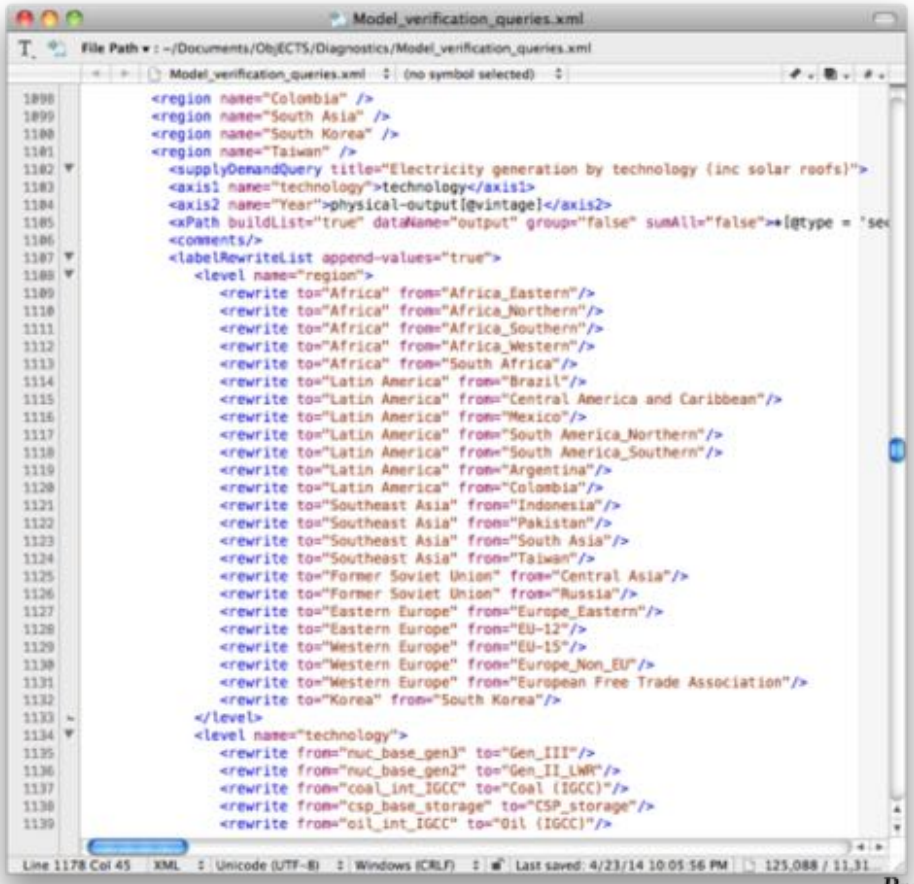
2: Running the diagnostics package



- 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



2: Running the diagnostics package

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