Pacific Northwest
NATIONAL LABORATORY

GCAM Tutorial

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The GCAM Development Team

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U.S. DEPARTMENT OF ENERGY BATTELLE

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General Outline

- Preliminary: Software to Download
- Part 1: Running the GCAM Reference Scenario
- Part 2: Running alternative scenarios
- Part 3: Changing input files
- Part 4: Debugging
- Part 5: Additional Resources
- Part 6: Theory and meaning of parameters

Preliminary: software to download

- GCAM: https://github.com/JGCRI/gcam-core/releases
- Java Runtime Environment (64 bit) https://openjdk.java.net
- To compile GCAM code:
  - http://jgcri.github.io/gcam-doc/gcam-build.html
- R: https://cran.r-project.org/ and Rstudio https://www.rstudio.com
- On Windows you may need the Visual Studio Redistributable (for 2015/2017/2019 / Arch x64)
  - https://support.microsoft.com/en-us/topic/the-latest-supported-visual-c-downloads-2647da03-1eea-4433-9aff-95f26a218cc0
- Check our tutorial videos:
  - Windows: https://youtu.be/EGxh-MFqRIs
  - Mac: https://youtu.be/c8DmPHHO6DA

Preliminary: software to download

Optional but helpful

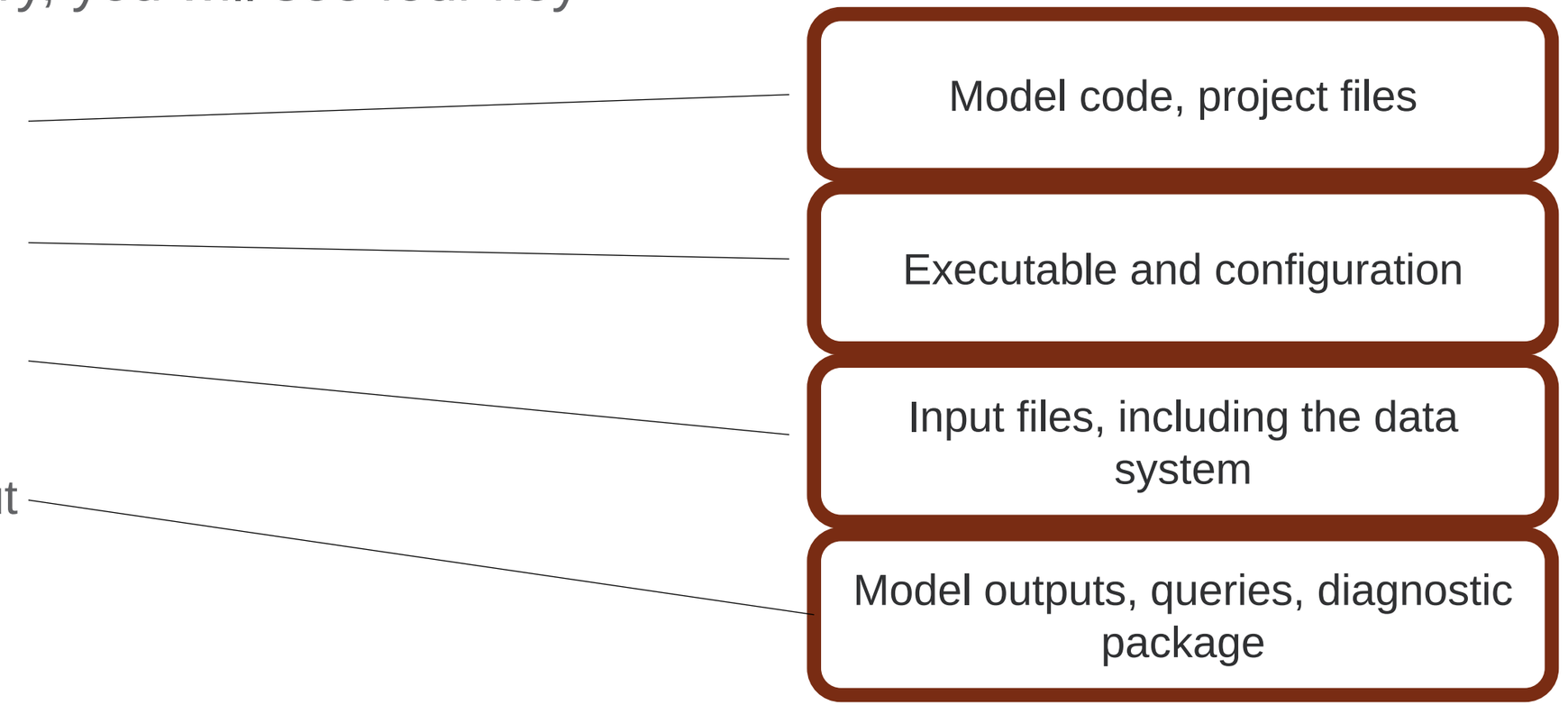
- On linux (or Mac), you can use vi, emacs, or your favorite text editor. On Mac/windows, XML files will open in a text editor, but there are other options
  - Windows: XML Marker: http://symbolclick.com/xmlmarker_1_1_setup.exe
  - Mac: BBEdit: http://www.barebones.com/products/bbedit/
  - Mac: XML Author: http://www.oxygenxml.com/
- On Mac and linux, you can use `diff` to compare files, but for more visual options:
  - Windows: Tortoise Git: https://tortoisegit.org/download/
  - Windows: WinMerge: http://winmerge.org/downloads/
  - Mac or Windows: DiffMerge: https://sourcegear.com/diffmerge/downloads.php

Part 1: Running the GCAM Reference Scenario

- Location of key files
- Building GCAM and the GCAM data system
- How to run the model
- Looking at, interpreting, and exporting the output
- Introduction to the diagnostics package

The GCAM repository

- If you have cloned the full GCAM repository, you will see four key folders:
  - cvs
  - exe
  - input
  - output



Building GCAM

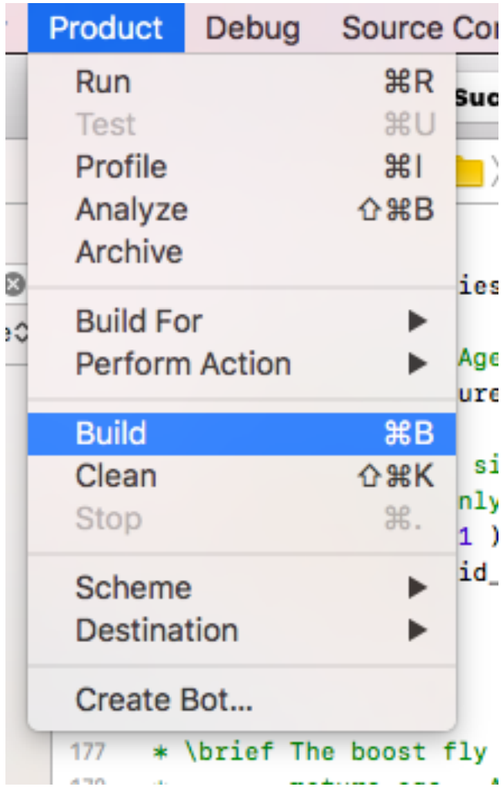
- Most users will not need to build GCAM and can use the pre-built package.

- If you do need to build GCAM, getting everything set up the first time can be challenging, but it is typically easy after that. The instructions on the next slide assume that you have gotten it set up correctly (including having installed all the third-party libraries GCAM relies on).
  - For more information, see http://jgcri.github.io/gcam-doc/gcam-build.html

Building GCAM

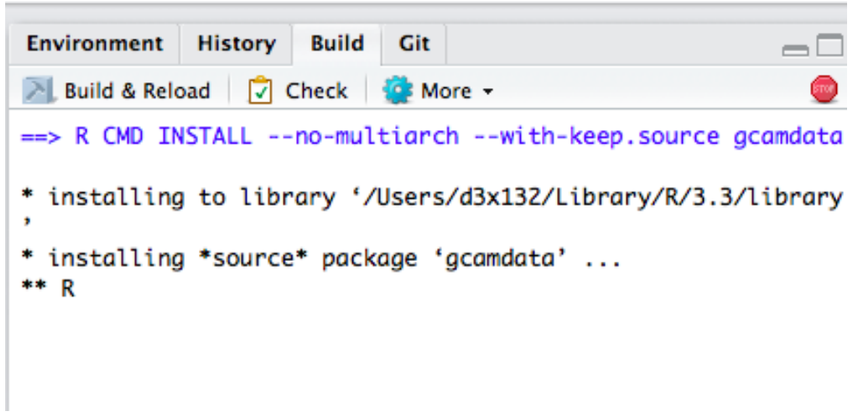
- First, make sure you have installed Hector.
  - From a command prompt, type `make install_hector`
  - Or: `git submodule update --init ../../climate/source/hector`

- Then, build GCAM
  - From Visual Studio, use the “Build Solution” option in the “Build” menu.
  - From Xcode, use the `Build` option in the `Product` menu.
    - ✓ Legacy Build System seems to be more reliable and can be set under File→ Project Settings -> Build System
  - From a command prompt, type `make gcam`
    - ✓ Note you can use the –j option to speed this up.



Building the GCAM data system

- From R,
  - Navigate to the data system (input/gcamdata) and open the project file (gcamdata.Rproj)
  - Build the package (either from the Rstudio `Build & Reload` option or by typing `library(gcamdata)`)
  - Run the driver (`driver(write_output=FALSE, write_xml=TRUE)`)
- From a command prompt,
  - Navigate to the top of the repository (gcam-core)
  - Type `make xml`
- xml outputs will be saved in `input/gcamdata/xml` when the data system finishes
- Note: R package compatibility is an issue. Use our renv: https://youtu.be/EO6NPCf7lKc




```
> library(gcamdata)
> driver(write_output=FALSE, write_xml=TRUE)
GCAM Data System v5.1
Found 356 chunks
Found 3129 chunk data requirements
Found 1828 chunk data products
1021 chunk data input(s) not accounted for
|=========================================================================================
==================| 100%    4 MB
|=========================================================================================
==================| 100%  268 MB
|=========================================================================| 100%    1 MB
[1] "module_aglu_LA100.0_LDS_preprocessing"
[1] "- make 3.17"
[1] "module_aglu_LA100.FAO_downscale_ctry"
[1] "- make 3.41"
[1] "module_aglu_LA100.GTAP_downscale_ctry"
[1] "- make 0.11"
[1] "module_aglu_LA100.IMAGE_downscale_ctry_yr"
[1] "- make 1.17"
[1] "module_aglu_LA101.ag_FAO_R_C_Y"
```

Building the GCAM data system with driver_drake

- You can get “make” functionality when building the GCAM data system by using `driver_drake` instead of `driver`
- An additional R package will need to be installed: `drake`
- Extremely useful when developing in the GCAM data system or using it to generate alternative XMLs by tweaking assumptions
- All of the features are documented in `input/gcamdata/vignettes/driverdrake_vignette.Rmd`

```
> devtools::load_all()
i Loading gcamdata
> driver_drake()
Loading required namespace: drake
GCAM Data System v5.1
Found 351 chunks
Found 3507 chunk data requirements
Found 1992 chunk data products
1186 chunk data input(s) not accounted for
▶ target energy.A21.globalrsrctech_coef
▶ target module_energy_L210.resources
▶ target module_energy_LA121.liquids
▶ target module_energy_batch_resources_xml
▶ target resources.xml
▶ target xml.resources.xml
All done.
>
```

The GCAM Configuration File

- Default versions for 32 region GCAM (configuration_ref.xml) and GCAM-USA (configuration_usa.xml) are provided in the `exe` folder.
- The configuration file defines the GCAM scenario that is run, including what inputs to use, what mode to run, etc.
- Unless otherwise specified, GCAM will use `configuration.xml` in the `exe` folder.
  - This file does not exist when you download the gcam repository and will need to be created.

The GCAM Configuration File

- Six different sections:
  - Files
  - Scenario Components
  - Strings
  - Bools
  - Ints
  - Doubles

The GCAM Configuration File: Files

```
<Files>
    <Value name="xmlInputFileName">../in
    <Value name="BatchFileName">batch
    <Value name="policy-target-file">../in
    <Value name="GHGInputFileName">../input/magicc/inputs/input_gases.emk</Value>
    <Value write                                    ="xmldb-location">../output/database_basexdb</Value>
    <Value write-output="1" append-scenario-name="0" name="restart">./restart/restart</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="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="flow-graph">gcam-flow-graph.dot</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>
</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

The GCAM Configuration File: Scenario Components

```
<ScenarioComponents>
    <Value name = "climate">../input/gcamdata/xml/hector.xml</Value>
    <Value name = "interest_rate">../input/gcamdata/xml/interest_rate.xml</Value>
    <Value name = "socioeconomics">../input/gcamdata/xml/socioeconomics_gSSP2.xml</Value>

    <Value name = "resources">../input/gcamdata/xml/resources.xml</Value>
    <Value name = "energy_supply">../input/gcamdata/xml/en_supply.xml</Value>
    <Value name = "energy_transformation">../input/gcamdata/xml/en_transformation.xml</Value>
    <!--Value name = "electricity">../input/gcamdata/xml/electricity.xml</Value-->
    <Value name = "elec_water_base">../input/gcamdata/xml/electricity_water.xml</Value>
    <Value name = "heat">../input/gcamdata/xml/heat.xml</Value>
    <Value name = "hydrogen">../input/gcamdata/xml/hydrogen.xml</Value>
    <Value name = "energy_distribution">../input/gcamdata/xml/en_distribution.xml</Value>
    <Value name = "industry">../input/gcamdata/xml/industry.xml</Value>
    <Value name = "industry_income_elas">../input/gcamdata/xml/industry_incelas_gssp2.xml</Value>
    <Value name = "cement">../input/gcamdata/xml/cement.xml</Value>
    <Value name = "cement_income_elas">../input/gcamdata/xml/cement_incelas_gssp2.xml</Value>
    <Value name = "fertilizer_energy">../input/gcamdata/xml/en_Fert.xml</Value>
    <Value name = "hddcdd">../input/gcamdata/xml/HDDCDD_constdd_no_GCM.xml</Value>
    <Value name = "building">../input/gcamdata/xml/building_det.xml</Value>
    <Value name = "transportation">../input/gcamdata/xml/transportation_UCD_CORE.xml</Value>
    <Value name = "carbon_content">../input/gcamdata/xml/Ccoef.xml</Value>
    <Value name = "carbon_storage">../input/gcamdata/xml/Cstorage.xml</Value>


    <Value name = "ag_base">../input/gcamdata/xml/ag_For_Past_bio_base_IRR_MGMT.xml</Value>
    <Value name = "ag_cost">../input/gcamdata/xml/ag_cost_IRR_MGMT.xml</Value>
```

The GCAM Configuration File: Strings, Bools, Ints, Doubles

```
<Strings>
    <Value name="scenarioName">Reference</Value>
    <Value name="debug-region">USA</Value>
    <Value name="MAGICC-input-dir">../input/magicc/in
    <Value name="MAGICC-output-dir">../output</Value>
    <Value name="AbatedGasForCostCurves">CO2</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>
    <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>
    <Value name="restart-period">-1</Value>
</Ints>
<Doubles>
</Doubles>
```

No spaces or special characters

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

Always keep calibration on

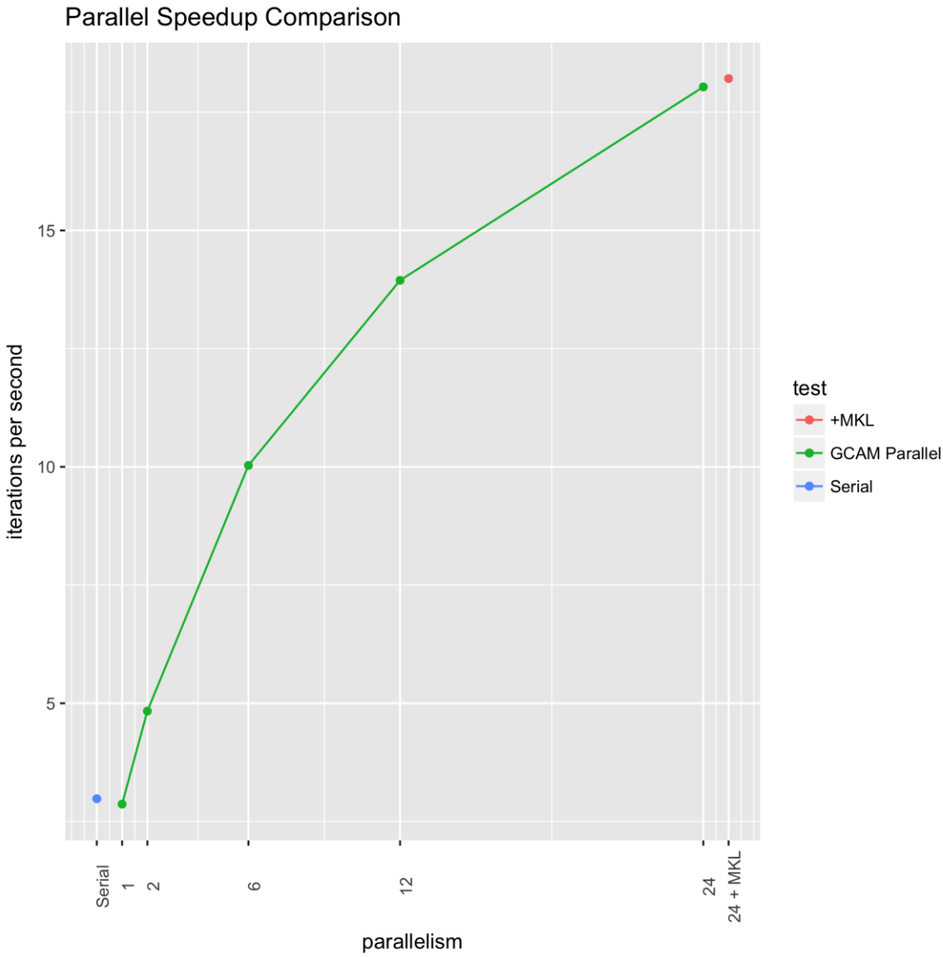
If true, appends XML files listed in BatchFile

If true, uses policy-target-file

If true, calculates cost (area under the MAC curve)

GCAM Parallel

- Users can control the number of CPU cores GCAM will use to perform calculations by changing "max-parallelism” in the <Ints> section of the configuration file.
- The default value, -1, indicates use all available CPUs
- There are diminishing returns in terms of speed up when adding more CPUs
- Since GCAM 7, GCAM results are always deterministic. Even with parallelism enabled.

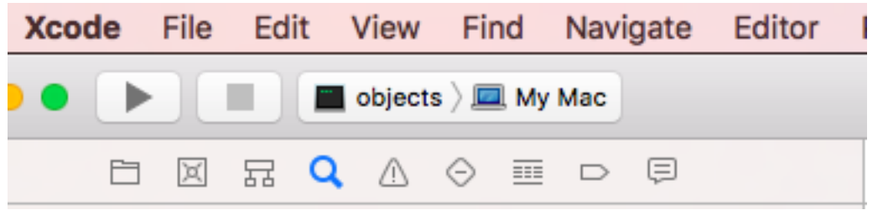


Running the GCAM Reference Scenario: Windows

1. Navigate to the `exe` folder.
2. Create a `configuration.xml` file by copying the `configuration_ref.xml`.
3. Run GCAM:
    1. From Visual Studio press the green play button
    2. From windows explorer, double click `run-gcam.bat`

Running the GCAM Reference Scenario: Mac

1. Navigate to the `exe` folder.
2. Create a `configuration.xml` file by copying the `configuration_ref.xml`.
3. Run GCAM
    1. From Xcode, hit the play button
    2. From terminal, type `./Release/gcam` or `./gcam.exe` (depending on how you've compiled)
    3. From Finder, double click `run-gcam.command`



Mac: Security Permissions

- Note on recent versions of Mac OS users will have to manually allow GCAM and maybe each third-party library that GCAM uses when double clicking `run-gcam.command`
- This can be done by opening System Preferences -> Security & Privacy -> General
  - At the bottom an option will appear to allow GCAM to run
- You may need to do this a few times before all required software is allowed

Running the GCAM Reference Scenario: Linux

1. Navigate to the `exe` folder.
2. Create a `configuration.xml` file by copying the `configuration_ref.xml`.
3. Run GCAM
    1. Type `./gcam.exe`

Running GCAM

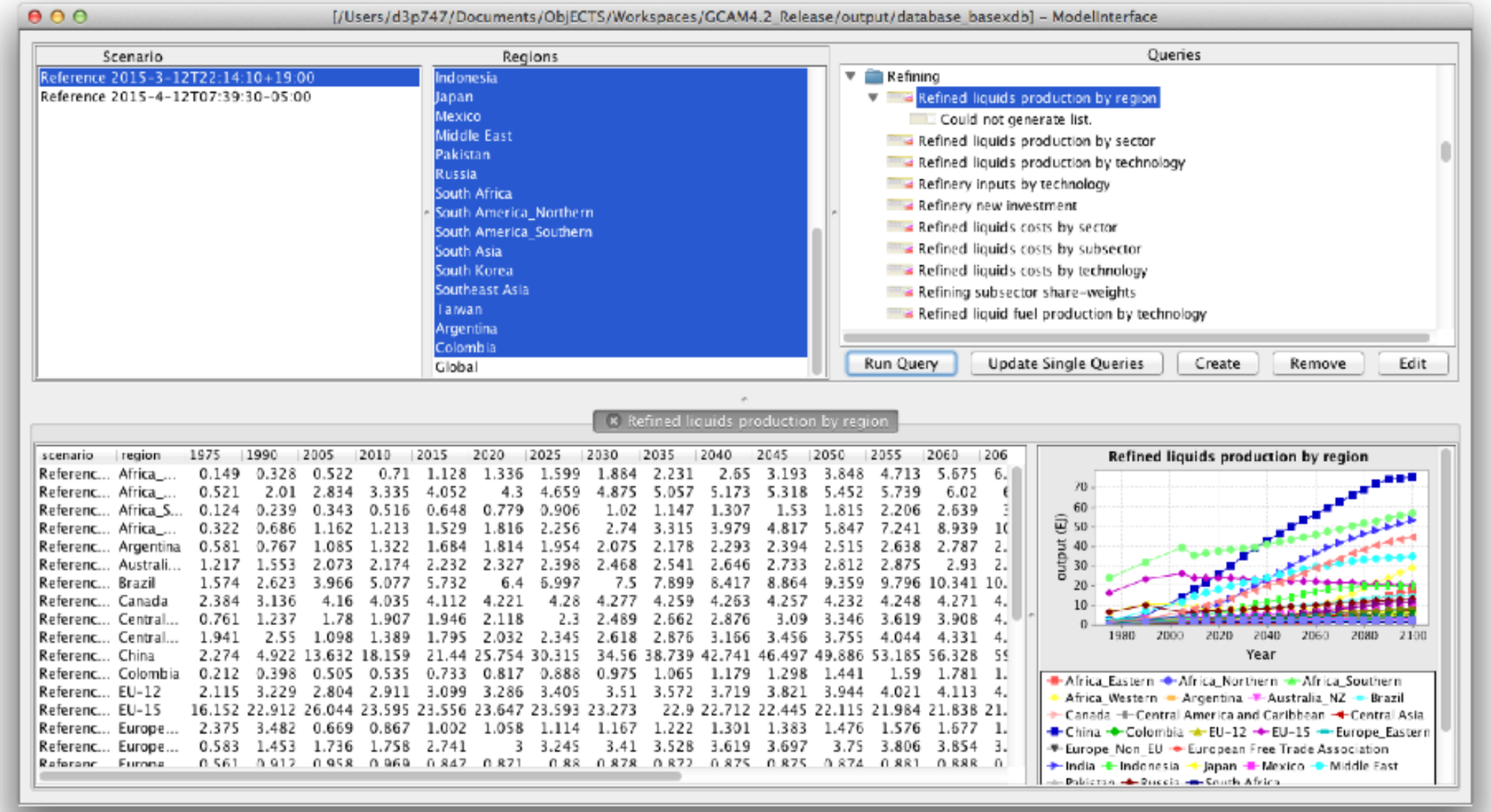
```
Running GCAM model code base version 5.1 revision gcam-v5.1.3

Configuration file:  configuration.xml
Parsing input files...
Parsing ../input/gcamdata/xml/hector.xml scenario component.
Parsing ../input/gcamdata/xml/interest_rate.xml scenario component.
Parsing ../input/gcamdata/xml/socioeconomics_gSSP2.xml scenario component.
Parsing ../input/gcamdata/xml/resources.xml scenario component.
Parsing ../input/gcamdata/xml/en_supply.xml scenario component.
Parsing ../input/gcamdata/xml/en_transformation.xml scenario component.
Parsing ../input/gcamdata/xml/electricity_water.xml scenario component.
Parsing ../input/gcamdata/xml/heat.xml scenario component.
Parsing ../input/gcamdata/xml/hydrogen.xml scenario component.
Parsing ../input/gcamdata/xml/en_distribution.xml scenario component.
Parsing ../input/gcamdata/xml/industry.xml scenario component.
Parsing ../input/gcamdata/xml/industry_incelas_gssp2.xml scenario component.
Parsing ../input/gcamdata/xml/cement.xml scenario component.
Parsing ../input/gcamdata/xml/cement_incelas_gssp2.xml scenario component.
Parsing ../input/gcamdata/xml/en_Fert.xml scenario component.
Parsing ../input/gcamdata/xml/HDDCDD_constdd_no_GCM.xml scenario component.
Parsing ../input/gcamdata/xml/building_det.xml scenario component.
Parsing ../input/gcamdata/xml/transportation_UCD_CORE.xml scenario component.
Parsing ../input/gcamdata/xml/Ccoef.xml scenario component.
Parsing ../input/gcamdata/xml/Cstorage.xml scenario component.
Parsing ../input/gcamdata/xml/ag_For_Past_bio_base_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/ag_cost_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/ag_prodchange_ref_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/resbio_input_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/an_input.xml scenario component.
Parsing ../input/gcamdata/xml/ag_Fert_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/land_input_1.xml scenario component.
Parsing ../input/gcamdata/xml/land_input_2.xml scenario component.
Parsing ../input/gcamdata/xml/land_input_3_IRR.xml scenario component.
Parsing ../input/gcamdata/xml/land_input_4_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/land_input_5_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/demand_input.xml scenario component.
Parsing ../input/gcamdata/xml/bio_trade.xml scenario component.
Parsing ../input/gcamdata/xml/ag_trade.xml scenario component.
Parsing ../input/gcamdata/xml/ind_urb_processing_sectors.xml scenario component.
Parsing ../input/gcamdata/xml/all_energy_emissions.xml scenario component.
Parsing ../input/gcamdata/xml/all_fgas_emissions.xml scenario component.
Parsing ../input/gcamdata/xml/all_unmgd_emissions.xml scenario component.
Parsing ../input/gcamdata/xml/all_aglu_emissions_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/unlimited_water_supply.xml scenario component.
Parsing ../input/gcamdata/xml/water_mapping.xml scenario component.
Parsing ../input/gcamdata/xml/ag_water_input_IRR_MGMT.xml scenario component.
Parsing ../input/gcamdata/xml/electricity_water_coefs.xml scenario component.
Parsing ../input/gcamdata/xml/water_elec_emissions.xml scenario component.
Parsing ../input/gcamdata/xml/water_demand_industry.xml scenario component.
Parsing ../input/gcamdata/xml/water_demand_livestock.xml scenario component.
```

- Command prompt/terminal window contains log messages
  - These are also written out to exe/logs/main_log.txt. Main log will also contain more information than is printed to screen.
- Input files are read in the order that they appear in the configuration.xml 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 the same outcome

Output

- The debug file
  - exe/debugReference.xml (filename set in config and merged with scenario name)
  - This writes out at the end of each time period, and contains a larger number of parameters for debugging
  - It is only written for one region, set in the configuration file
- The output database
  - output/database_basexdb (set in configuration.xml)
  - Contains the results from the scenario in a database that can be queried
  - Results can also be exported from the database to xml

The output database



- Open ModelInterface
- File -> Open -> DB Open (output/database_basexdb)

What is in the GCAM Reference scenario?

- A high level intro to the XML Inputs

Scenario Components: Climate, Socioeconomics

```
<ScenarioComponents>
    <Value name = "climate">../input/gcamdata/xml/hector.xml</Value>
    <Value name = "socioeconomics">../input/gcamdata/xml/socioeconomics_gSSP2.xml</Value>
```

Climate

- Default model is Hector, but MAGICC5.3 is still available as an (unsupported) option.
- Some options (e.g., when emissions switch from a historical file to GCAM and when to start the carbon cycle) are specified in an xml file. All other options are controlled through the Hector ini file.

```
<scenario>
    <world>
        <HectorModel>
            <hector-end-year>2300</hector-end-year>
            <emissions-switch-year>2005</emissions-switch-year>
            <hector-ini-file>../input/climate/hector-gcam.ini</hector-ini-file>
            <carbon-model-start-year>1705</carbon-model-start-year>
        </HectorModel>
    </world>
</scenario>
```

GDP and population

```
<?xml version="1.0" encoding="UTF-8"?>
<scenario>
    <world>
        <region name="USA">
            <demographics>
                <populationMiniCAM year="1975">
                    <totalPop>222133</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="1990">
                    <totalPop>256971</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2005">
                    <totalPop>300712</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2010">
                    <totalPop>314242</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2015">
                    <totalPop>326649</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2020">
                    <totalPop>339508</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2025">
                    <totalPop>352372</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2030">
                    <totalPop>364622</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2035">
                    <totalPop>376039</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2040">
                    <totalPop>386598</totalPop>
                </populationMiniCAM>
                <populationMiniCAM year="2045">
```

- Population and GDP are based on SSP: Shared Socioeconomic Pathways
  - Population is strictly exogenous (i.e., not modified by other modeled variables)
- Socioeconomics_macro.xml
  - Contains all of the parameters which govern endogenous GDP feedbacks to energy system changes.
  - Only relevant when intending to run with “Open” GDP model (configuration option “FixedGDP-Path” set to 0)

GDP Modes and Calibration

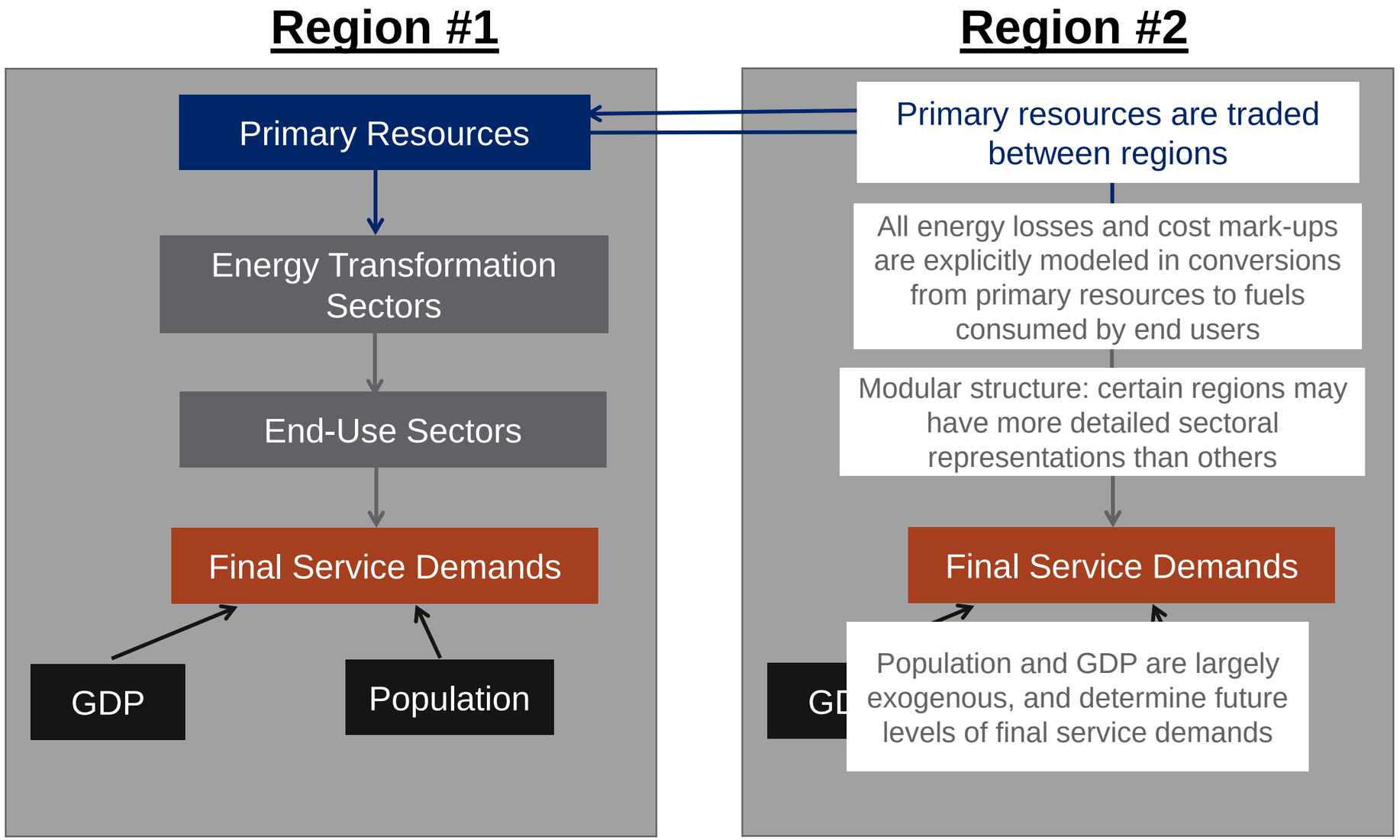
```
<Bools>
    <Value name="CalibrationActive">1</Value>
    <!-- Fixed GDP will calibrate to exogenous path -->
    <Value name="FixedGDP-Path">1</Value>
    <Value name="BatchMode">0</Value>
    <Value name="find-path">0</Value>
```

- By default GCAM will be running in fixed GDP mode.
- But will still generate calibrated GDP parameters (total factor productivity) which are included in the XMLDB results
  - Dependent to the exact configuration used
- Use “update_macro_productivity.R” then gcamdata to feed the calibration params back into a GCAM input XML
- Can now run in ”Open” GDP mode (“FixedGDP-Path” set to 0)
  - Exactly replicate the original scenario
  - Dynamic feedbacks in alternative scenarios

Scenario Components: Energy

```
<Value name = "resources">../input/gcamdata/xml/resources.xml</Value>
<Value name = "energy_supply">../input/gcamdata/xml/en_supply.xml</Value>
<Value name = "energy_transformation">../input/gcamdata/xml/en_transformation.xml</Value>
<!--Value name = "electricity">../input/gcamdata/xml/electricity.xml</Value-->
<Value name = "elec_water_base">../input/gcamdata/xml/electricity_water.xml</Value>
<Value name = "heat">../input/gcamdata/xml/heat.xml</Value>
<Value name = "hydrogen">../input/gcamdata/xml/hydrogen.xml</Value>
<Value name = "energy_distribution">../input/gcamdata/xml/en_distribution.xml</Value>
<Value name = "industry">../input/gcamdata/xml/industry.xml</Value>
<Value name = "industry_income_elas">../input/gcamdata/xml/industry_incelas_gssp2.xml</Value>
<Value name = "iron_steel">../input/gcamdata/xml/iron_steel.xml</Value>
<Value name = "iron_steel_income_elas">../input/gcamdata/xml/iron_steel_incelas_gssp2.xml</Value>
<Value name = "Off_road">../input/gcamdata/xml/Off_road.xml</Value>
<Value name = "Off_road_income_elas">../input/gcamdata/xml/Off_road_incelas_gssp2.xml</Value>
<Value name = "chemical">../input/gcamdata/xml/chemical.xml</Value>
<Value name = "chemical_income_elas">../input/gcamdata/xml/chemical_incelas_gssp2.xml</Value>
<Value name = "aluminum">../input/gcamdata/xml/aluminum.xml</Value>
<Value name = "aluminum_income_elas">../input/gcamdata/xml/aluminum_incelas_gssp2.xml</Value>
<Value name = "cement">../input/gcamdata/xml/cement.xml</Value>
<Value name = "cement_income_elas">../input/gcamdata/xml/cement_incelas_gssp2.xml</Value>
<Value name = "fertilizer_energy">../input/gcamdata/xml/en_Fert.xml</Value>
<Value name = "hddcdd">../input/gcamdata/xml/HDDCDD_constdd_no_GCM.xml</Value>
<Value name = "building">../input/gcamdata/xml/building_det.xml</Value>
<Value name = "transportation">../input/gcamdata/xml/transportation_UCD_CORE.xml</Value>
<Value name = "carbon_content">../input/gcamdata/xml/Ccoef.xml</Value>
<Value name = "carbon_storage">../input/gcamdata/xml/Cstorage.xml</Value>
```

General energy system structure



Resources

```
<scenario>
    <world>
        <region name="USA">
            <depresource name="coal">
                <output-unit>EJ</output-unit>
                <price-unit>1975$/GJ</price-unit>
                <market>global</market>
                <price year="1975">0.4</price>
                <price year="1990">0.435</price>
                <price year="2005">0.438</price>
                <price year="2010">0.5</price>
                <subresource name="coal">
                    <techChange fillout="1" year="1975">0.005</techChange>
                    <techChange fillout="1" year="2005">0.0075</techChange>
                    <cal-production year="1975">14.8206957</cal-production>
                    <cal-production year="1990">22.4542682</cal-production>
                    <cal-production year="2005">23.6084627</cal-production>
                    <cal-production year="2010">21.1880386</cal-production>
                    <grade name="grade 1">
                        <available>284</available>
                        <extractioncost>0.34</extractioncost>
                    </grade>
                    <grade name="grade 2">
                        <available>6851</available>
                        <extractioncost>0.37</extractioncost>
                    </grade>
                    <grade name="grade 3">
                        <available>9469</available>
                        <extractioncost>1.2</extractioncost>
                    </grade>
                    <grade name="grade 4">
                        <available>13456</available>
                        <extractioncost>1.7</extractioncost>
                    </grade>
                    <grade name="grade 5">
```

- resources.xml
- 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.

Energy supply

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

- en_supply.xml
- Domestic energy supply =
  - Sum of all consumption within a region
  - Production minus net exports
- These sectors may be used to compete domestic vs imported production
- They can be used to implement region-specific energy price adders or subsidies
  - We currently apply the same cost adders in all regions.
  - Regional energy prices are not currently calibrated; instead, differences in price/cost across regions are implicitly captured in the derived calibration parameters (i.e., share weights)

Energy transformation sectors

```
<scenario>
    <world>
        <region name="USA">
            <supplysector name="electricity">
                <relative-cost-logit>
                    <logit-exponent fillout="1" year="1975">-3</logit-exponent>
                </relative-cost-logit>
                <output-unit>EJ</output-unit>
                <input-unit>EJ</input-unit>
                <price-unit>1975$/GJ</price-unit>
                <subsector name="coal">
                    <share-weight fillout="1" year="1975">1</share-weight>
                    <interpolation-rule apply-to="share-weight"
                        from-year="2010" to-year="2300">
                        <to-value>1</to-value>
                        <interpolation-function name="s-curve"/>
                    </interpolation-rule>
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">-10</logit-exponent>
                    </relative-cost-logit>
                    <stub-technology name="coal (conv pul)">
                        <period year="1975">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>3.2070672</calOutputValue>
                            </CalDataOutput>
                        </period>
                        <period year="1990">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>6.0288372</calOutputValue>
                            </CalDataOutput>
                        </period>
                        <period year="2005">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>7.6805172</calOutputValue>
                            </CalDataOutput>
                        </period>
```

- Five XML files
  - electricity_water.xml
  - hydrogen.xml
  - heat.xml
  - en_transformation.xml: refining, gas processing, and nuclear fuel enrichment
  - en_distribution.xml: delivered fuels
- Structure: supplysector / subsector / technology
  - Subsector and technology market shares are currently determined by two-level nested logit choice competition. Infinite nesting is possible and used in GCAM-USA electricity_water.xml for instance.
- 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)

Energy end-use sectors

- Sector-specific XML files
  - building_det.xml
  - industry
    - ✓ other_industry.xml
    - ✓ iron_steel.xml
    - ✓ Off_road.xml
    - ✓ chemical.xml
    - ✓ Aluminum.xml
    - ✓ cement.xml
    - ✓ en_Fert.xml
  - transportation_UCD_CORE.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)

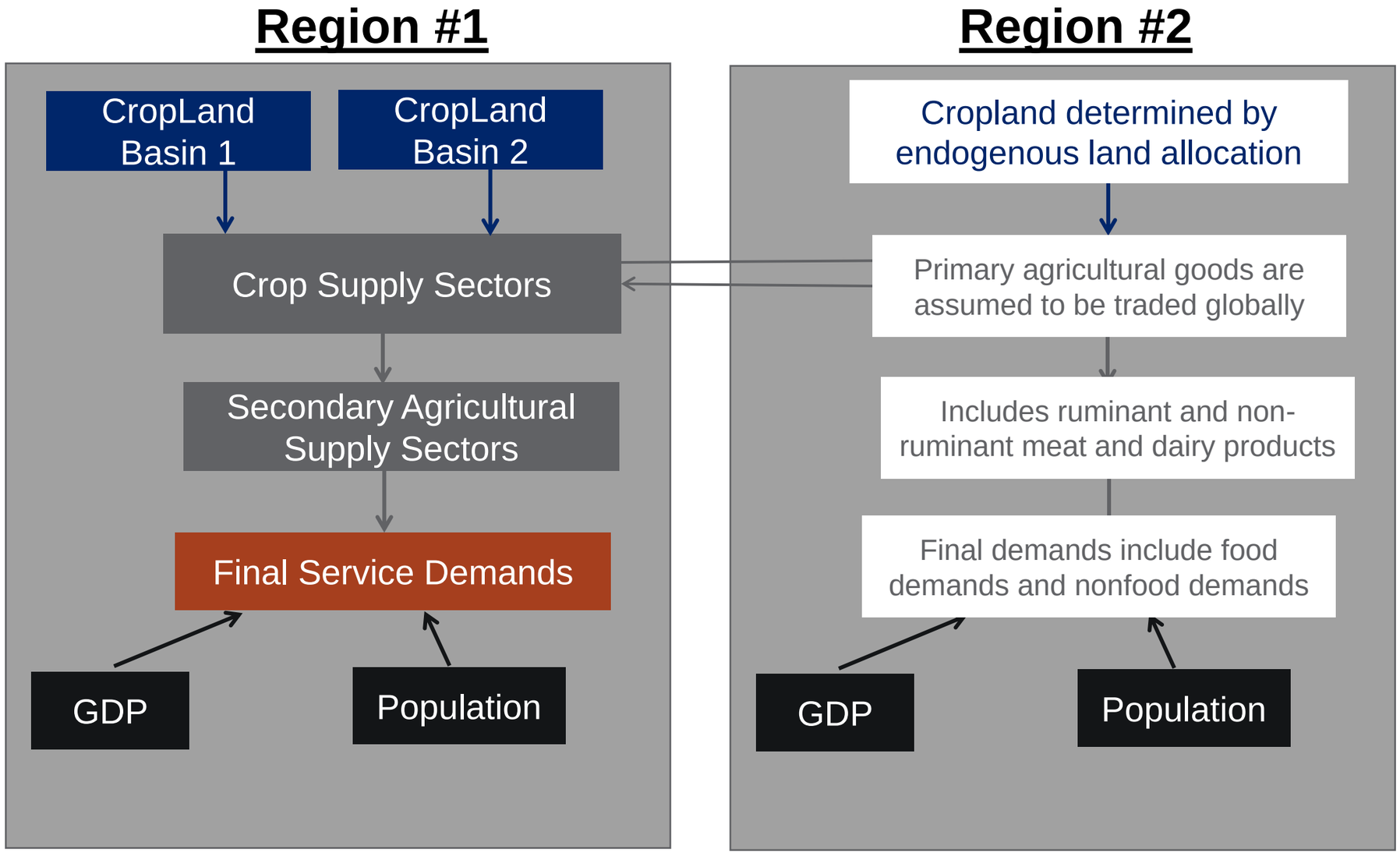
```
<scenario>
    <world>
        <region name="USA">
            <supplysector name="cement">
                <relative-cost-logit>
                    <logit-exponent fillout="1" year="1975">-3</logit-exponent>
                </relative-cost-logit>
                <output-unit>Mt</output-unit>
                <input-unit>EJ or Mt</input-unit>
                <price-unit>1975$/kg</price-unit>
                <keyword final-energy="industry"/>
                <subsector name="cement">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">-12</logit-exponent>
                    </relative-cost-logit>
                    <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="2010">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>73.8961075</calOutputValue>
                            </CalDataOutput>
                            <minicam-energy-input name="elect_td_ind">
                                <coefficient>0.0005148</coefficient>
                                <market-name>USA</market-name>
                            </minicam-energy-input>
                            <minicam-energy-input name="process heat cement">
                                <coefficient>0.0039847</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="1975">
                            <share-weight>1</share-weight>
```

Pacific Northwest NATIONAL LABORATORY

Scenario Components: Agriculture and Land Use

```
<Value name = "ag_base">../input/gcamdata/xml/ag_For_Past_bio_base_IRR_MGMT.xml</Value>
<Value name = "ag_cost">../input/gcamdata/xml/ag_cost_IRR_MGMT.xml</Value>
<Value name = "ag_prodchange">../input/gcamdata/xml/ag_prodchange_ref_IRR_MGMT.xml</Value>
<Value name = "residue_bio">../input/gcamdata/xml/resbio_input_IRR_MGMT.xml</Value>
<Value name = "animal">../input/gcamdata/xml/an_input.xml</Value>
<Value name = "fertilizer">../input/gcamdata/xml/ag_Fert_IRR_MGMT.xml</Value>
<Value name = "land1">../input/gcamdata/xml/land_input_1.xml</Value>
<Value name = "land2">../input/gcamdata/xml/land_input_2.xml</Value>
<Value name = "land3">../input/gcamdata/xml/land_input_3_IRR.xml</Value>
<Value name = "land4">../input/gcamdata/xml/land_input_4_IRR_MGMT.xml</Value>
<Value name = "land5">../input/gcamdata/xml/land_input_5_IRR_MGMT.xml</Value>
<Value name = "protected_land2">../input/gcamdata/xml/protected_land_input_2.xml</Value>
<Value name = "protected_land3">../input/gcamdata/xml/protected_land_input_3.xml</Value>
<Value name = "demand">../input/gcamdata/xml/demand_input.xml</Value>
<Value name = "bio_trade">../input/gcamdata/xml/bio_trade.xml</Value>
<Value name = "ag_trade">../input/gcamdata/xml/ag_trade.xml</Value>
```

General structure



Land allocation

```
<scenario>
    <world>
        <region name="USA">
            <LandAllocatorRoot name="root">
                <relative-cost-logit>
                    <logit-exponent fillout="1" year="1975">0</logit-exponent>
                </relative-cost-logit>
                <landAllocation fillout="1" year="1975">9124.19</landAllocation>
                <soilTimeScale>50</soilTimeScale>
                <LandNode name="AgroForestLand_PacArctic">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">2</logit-exponent>
                    </relative-cost-logit>
                    <unManagedLandValue>40842</unManagedLandValue>
                </LandNode>
                <LandNode name="AgroForestLand_MexCstNW">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">2</logit-exponent>
                    </relative-cost-logit>
                    <unManagedLandValue>3487112</unManagedLandValue>
                </LandNode>
                <LandNode name="AgroForestLand_California">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">2</logit-exponent>
                    </relative-cost-logit>
                    <unManagedLandValue>33921750</unManagedLandValue>
                </LandNode>
                <LandNode name="AgroForestLand_UsaColoRN">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">2</logit-exponent>
                    </relative-cost-logit>
                    <unManagedLandValue>1638595</unManagedLandValue>
                </LandNode>
                <LandNode name="AgroForestLand_UsaColoRS">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">2</logit-exponent>
                    </relative-cost-logit>
                    <unManagedLandValue>6067099</unManagedLandValue>
                </LandNode>
```

- Land data are read in 5 XML files that correspond to the 5 “node” levels of the land nesting diagram
  - land_input_1.xml, land_input_2.xml, and land_input_3_IRR.xml, land_input_4_IRR_MGMT.xml, land_input_5_IRR_MGMT.xml
- Top-level base-year land allocations are fixed in all future periods
- At lower levels, land allocations are endogenous
  - In GCAM, the land use shares shift in response to changes in relative land profit rates
  - Calibration is performed on land use shares, not present-day rates of land use change

Agricultural production

```
<scenario>
    <world>
        <region name="USA">
            <AgSupplySector name="Corn">
                <relative-cost-logit>
                    <logit-exponent fillout="1" year="1975">-3</logit-exponent>
                </relative-cost-logit>
                <output-unit>Mt</output-unit>
                <input-unit>thous km2</input-unit>
                <price-unit>1975$/kg</price-unit>
                <calPrice>0.062564286381648</calPrice>
                <market>USA</market>
                <AgSupplySubsector name="Corn_NelsonR">
                    <relative-cost-logit>
                        <logit-exponent fillout="1" year="1975">-3</logit-exponent>
                    </relative-cost-logit>
                    <AgProductionTechnology name="Corn_NelsonR_IRR_hi">
                        <period year="1975">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>0.0686824</calOutputValue>
                            </CalDataOutput>
                            <harvests-per-year>1</harvests-per-year>
                        </period>
                        <period year="1990">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>0.088438</calOutputValue>
                            </CalDataOutput>
                            <harvests-per-year>1</harvests-per-year>
                        </period>
                        <period year="2005">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>0.1335222</calOutputValue>
                            </CalDataOutput>
                            <harvests-per-year>1</harvests-per-year>
                        </period>
                        <period year="2010">
                            <share-weight>1</share-weight>
                            <CalDataOutput>
                                <calOutputValue>0.1427132</calOutputValue>
                            </CalDataOutput>
                            <harvests-per-year>1</harvests-per-year>
                        </period>
```

- Each ag production technology has a corresponding land leaf of the same name
  - The sharing/competition takes place in the land allocator, not in the ag sectors. Share weights are ignored in the ag sectors.
- Exogenous variables
  - Calibrated commodity price (1975$/kg)
  - Calibrated output (Mt/yr)
  - Calibrated land quantity (thous km^2)
  - Residue biomass supply curve
  - Non-CO_2 coefficients (kg gas per kg crop)
    - ✓ MAC curves
  - Fertilizer inputs (kg N per kg crop)
  - Costs (1975$/kg)
  - Future agricultural productivity growth rate (and therefore yield)
  - Annual harvested area:cropland
- Key endogenous variables
  - Future commodity prices
  - Future profit rates and production volumes

Scenario Components: Non-CO_2

```
<Value name = "ind_urb_proc">../input/gcamdata/xml/ind_urb_processing_sectors.xml</Value>
<Value name = "nonco2_energy">../input/gcamdata/xml/all_energy_emissions.xml</Value>
<Value name = "nonco2_fgas">../input/gcamdata/xml/all_fgas_emissions.xml</Value>
<Value name = "nonco2_unmgd">../input/gcamdata/xml/all_unmgd_emissions.xml</Value>
<Value name = "nonco2_aglu">../input/gcamdata/xml/all_aglu_emissions_IRR_MGMT.xml</Value>
<Value name = "nonco2_aglu_prot">../input/gcamdata/xml/all_protected_unmgd_emissions.xml</Value>

<!-- Global nonCO2 GHG MAC files -->
<Value name = "nonco2_energy">../input/gcamdata/xml/all_energy_emissions_MAC.xml</Value>
<Value name = "nonco2_fgas">../input/gcamdata/xml/all_fgas_emissions_MAC.xml</Value>
<Value name = "nonco2_aglu">../input/gcamdata/xml/all_aglu_emissions_IRR_MGMT_MAC.xml</Value>
<Value name = "nonco2_proc">../input/gcamdata/xml/ind_urb_processing_sectors_MAC.xml</Value>
```

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.

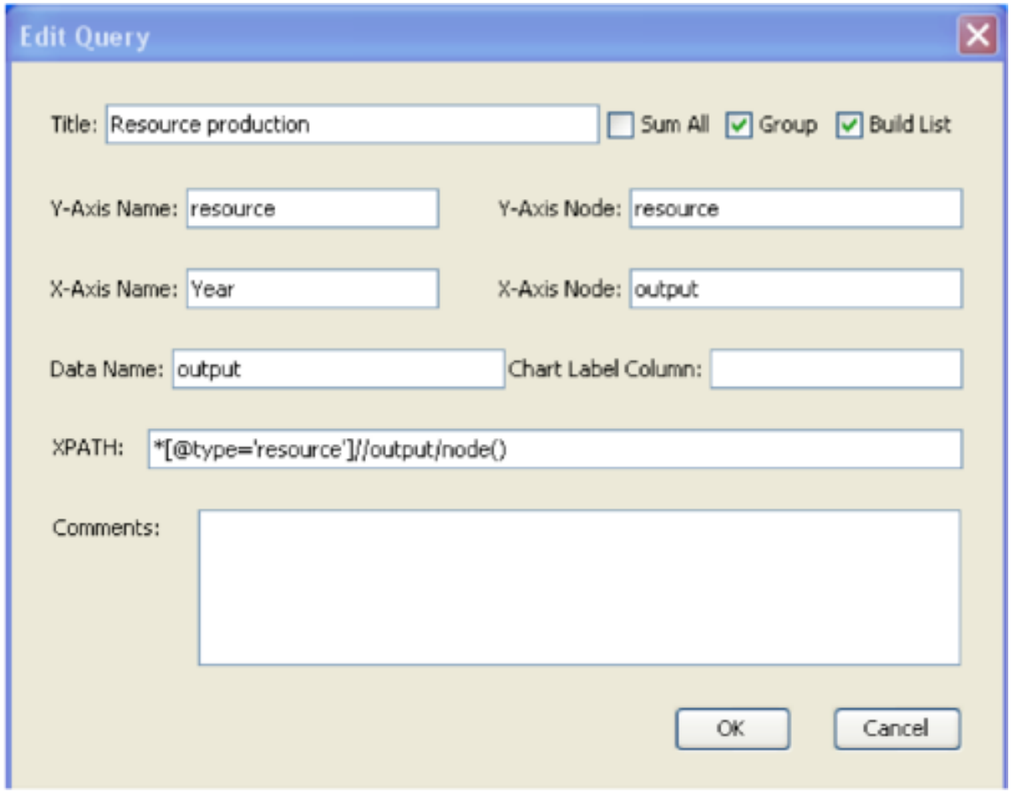
```
<scenario>
    <world>
        <region name="USA">
            <supplysector name="comm cooling" nocreate="1">
                <subsector name="gas" nocreate="1">
                    <stub-technology name="gas" nocreate="1">
                        <period year="1975">
                            <Non-CO2 name="SO2_1">
                                <input-emissions>1.545649464e-05</input-emissions>
                                <input-driver/>
                            </Non-CO2>
                            <Non-CO2 name="CO">
                                <input-emissions>0.01191697365</input-emissions>
                                <input-driver/>
                                <gdp-control name="GDP_control">
                                    <max-reduction>68.5446345299612</max-reduction>
                                    <steepness>3.5</steepness>
                                </gdp-control>
                            </Non-CO2>
                            <Non-CO2 name="NH3">
                                <input-emissions>8.208039469e-10</input-emissions>
                                <input-driver/>
                            </Non-CO2>
                            <Non-CO2 name="NMVOC">
                                <input-emissions>0.004107744706</input-emissions>
                                <input-driver/>
```

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

Queries

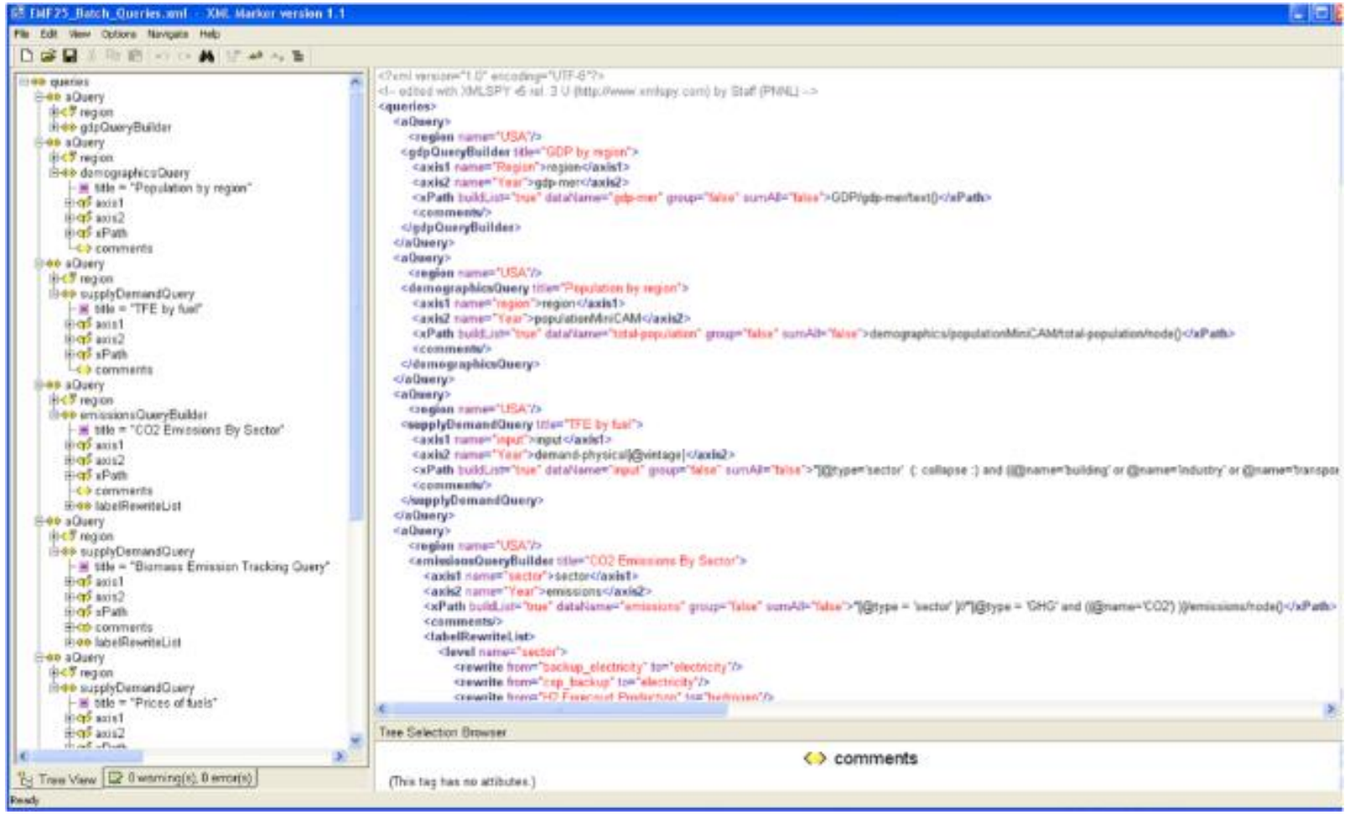
- Update single queries: allows a query to focus on an individual element

- 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.



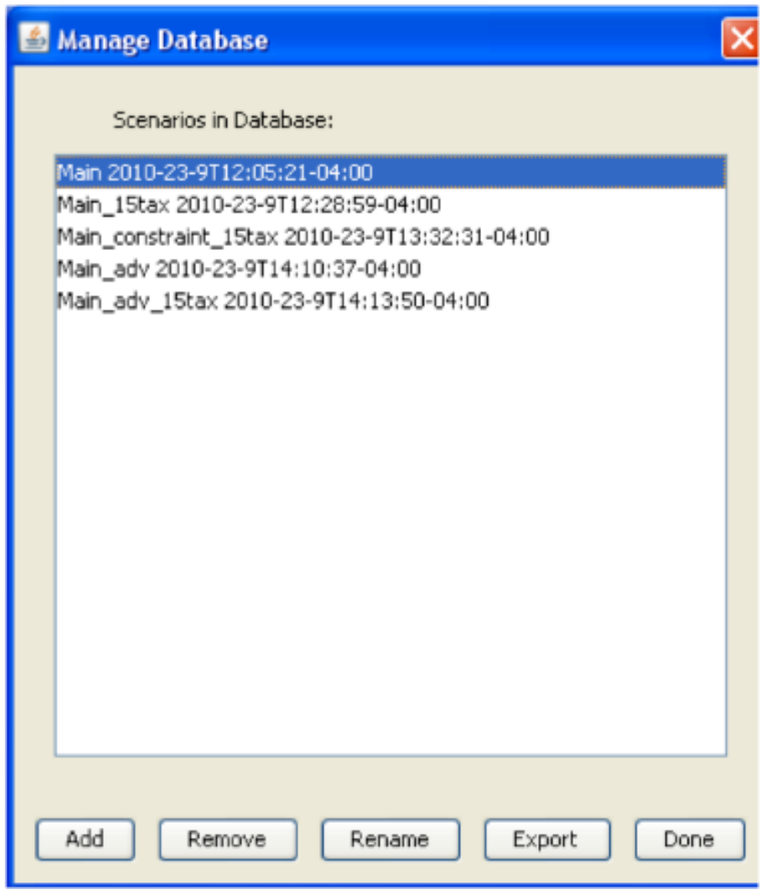
Exporting data to Excel

- Drag and drop (e.g. into Excel)
- Highlight cells and cut and paste
- Use a batch query to export a large number of queries directly into an Excel spreadsheet
  - The basex database 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
- rgcam/gcamreader
  - R/python based tools to import GCAM results directly into R/python.
  - Available on github.com/jgcri



Exporting, importing runs

- File -> Manage DB
- This allows one to rename, export (as an xml file, that can be imported into another BaseX DB), 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



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 MtC/yr. 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 and agricultural 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)

Part 2: Running alternative scenarios

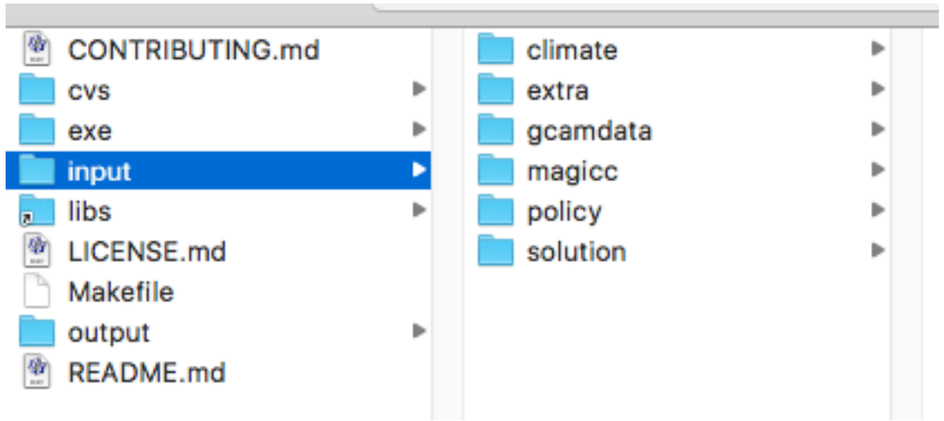
- Including additional “add-on” XML files
- Policies
- Running multiple scenarios in batch mode

Running alternative scenarios

- Most studies using GCAM will run alternative scenarios
  - Not an optimization model
  - “Reference” scenario should not be seen as a most likely scenario; it is simply a no additional policy scenario starting from middle of the road socioeconomic and technological assumptions
- Many possible variables of interest:
  - Different technology 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

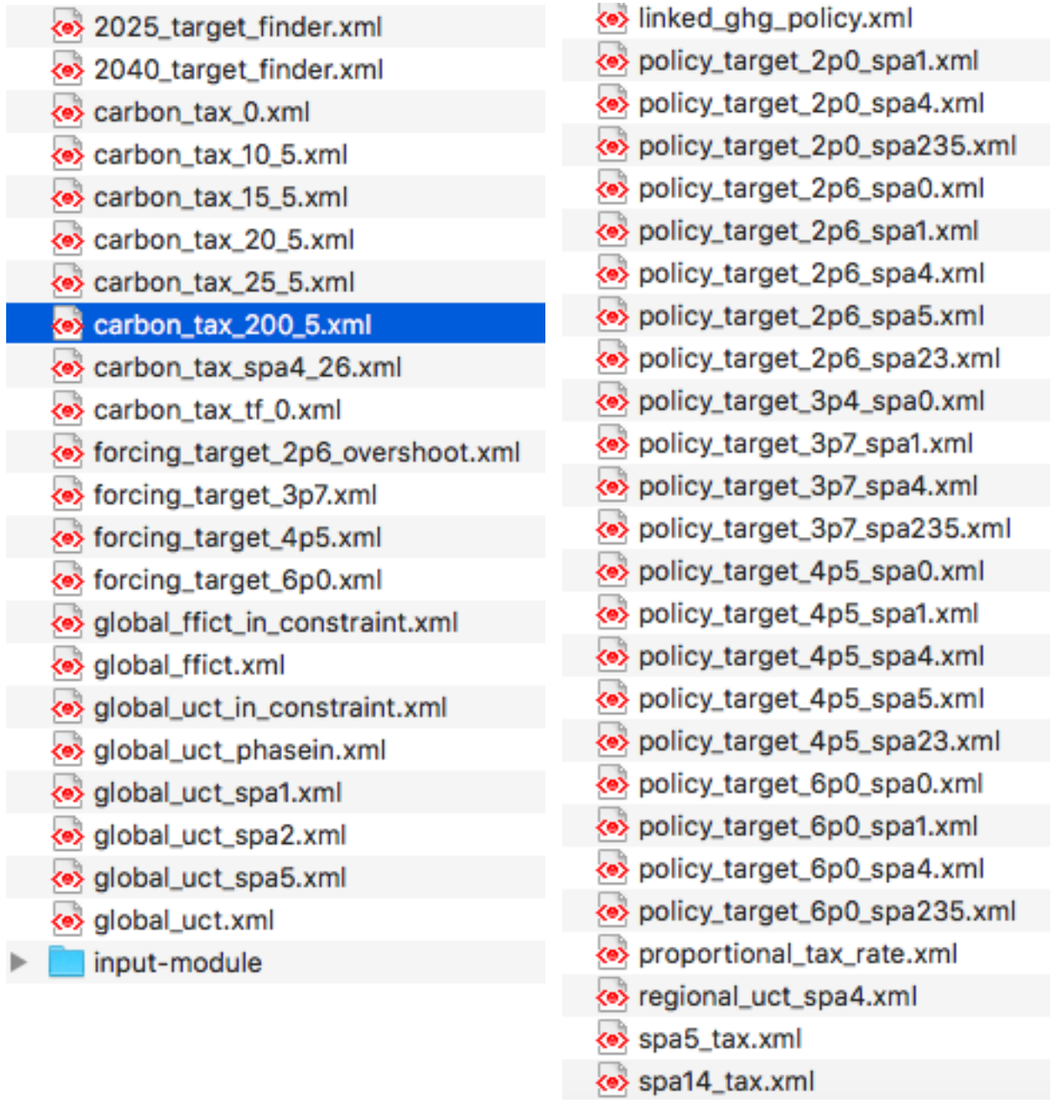
The input folder

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



- Folder structure
  - gcamdata: generates the XML files from an R package and a set of csv based raw inputs
  - climate: information for the Hector climate model
  - magicc: information for the MAGICC climate model
  - policy: selected policies that can be run
  - extra: additional files used for the SSPs
  - solution: solver configuration files

Provided policy files



Carbon cap: constraint on annual CO_2 emissions in each time period (Mt C)

Carbon tax: exogenous CO_2 price in each time period (1990$/t C)

Forcing target: radiative forcing (W/m^2). 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)

Configuration

- Alternative scenarios may be run as follows:
  - **Note:** if running a CO2/GHG policy start from configuration_policy.xml
  - 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="findPath">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>
```

Pacific Northwest
NATIONAL LABORATORY

```
<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>
```

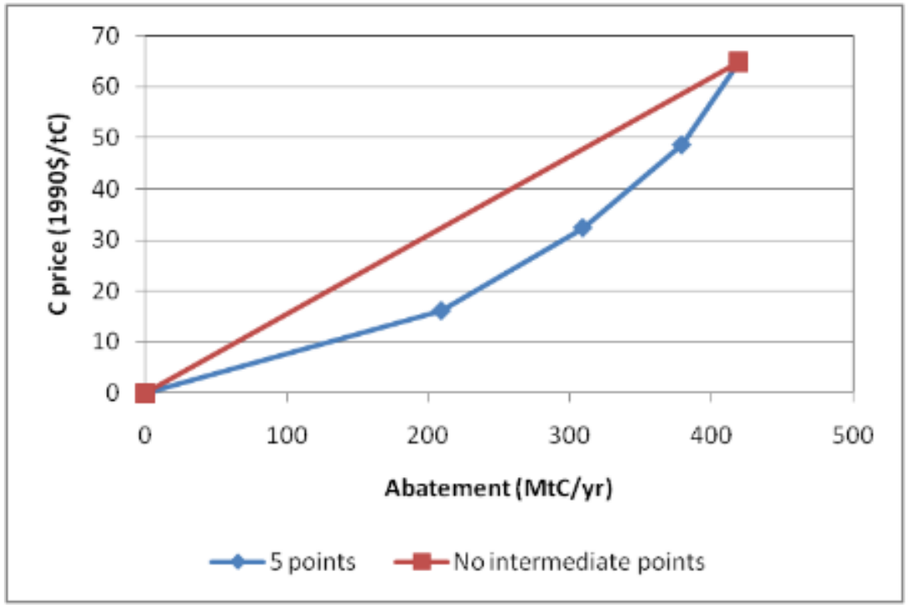
```
<world>
   <region name="USA">
      <ghgpolicy name="CO2">
         <market>global</market>
         <constraint year="2020">7912</constraint>
         <constraint year="2035">7880</constraint>
         <constraint year="2050">6834</constraint>
         <constraint year="2065">4980</constraint>
         <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>
```

- 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*

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.

- 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



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>
```

```
<ComponentSet 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>
```

Set the bool and batch file name

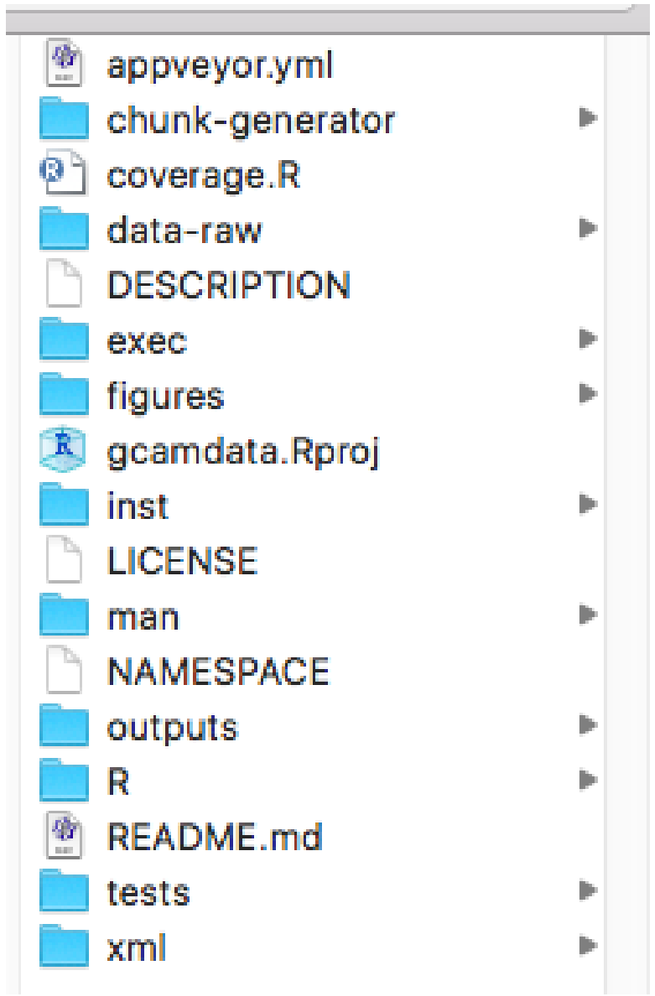
Files in FileSet will be added to the scenarioComponents in the config file

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

Part 3: Changing Input Files

- The gcamdata system
- Modifying xml input files

The gcamdata system



- Folder structure
  - xml: GCAM input files (in xml format)
  - outputs: csv files generated by the data system
  - R: code files used to generate GCAM input files
    - zmodule_L1*: convert raw data to GCAM regions, sectors, technologies
    - zmodule_L2*: generate all data needed for GCAM
    - zmoduoe_xml*: generate xml input files
  - inst: external data used as inputs into the R code
  - data-raw: generates package related data

Modifying the xml input files

- The best approach for modifying GCAM depends on what you are changing, what your intention is, and whether you want your modification to be put into the GCAM master version
  - Possible things to change:
    - ✓ Parameter that is either specified in `input/gcamdata/inst/extdata` or the `constants.R` file in the gcamdata package.
    - ✓ Parameter or file that is derived in the gcamdata package
    - ✓ Structure of a region or sector
  - Possible intentions:
    - ✓ Quick understanding
    - ✓ Project or paper
- If your goal is to make changes for a specific project or for understanding, use the gcamdata user-modified functions capability. If you intend to update the GCAM master version, you should make changes directly to gcamdata input files and code. See wiki for instructions on how to do this: https://github.com/JGCRI/gcamdata/wiki

User Modification Functions

- Allows users to write their own function to modify a gcamdata input/output, without modifying input CSVs or gcamdata chunks directly
- Modified object gets “plugged into” data system and passed to all dependent chunks
- New XML(s) get created with user-specified suffixes, to distinguish them from core gcamdata XMLs
  - Note: Remember to update configuration.xml to include the custom XMLs before running GCAM
- Motivation: Keep track of gcamdata changes from user vs. core GCAM assumptions, ensuring user-implemented changes can be automated and are reproducible
- Video: https://youtu.be/S9PwWAEpLIE

Writing a User-Mod Function

```
usermod_fert <- function(command, ...) {
  if(command == driver.DECLARE_MODIFY) {
    return(c(FILE = "L2322.SubsectorShrwtFllt_Fert"))

  } else if(command == driver.DECLARE_INPUTS) {
    return()

  } else if(command == driver.MAKE) {
    all_data <- list(...)[[1]]
    L2322.SubsectorShrwtFllt_Fert <- get_data(all_data, "L2322.SubsectorShrwtFllt_Fert")

    # Read in additional inputs from outside gcamdata, if necessary
    Fert_Shwt_Additions <- read.csv("mod_inputs/Fert_Shwt_Additions.csv", header = TRUE)

    # Make changes
    L2322.SubsectorShrwtFllt_Fert %>%
      bind_rows(Fert_Shwt_Additions) -> L2322.SubsectorShrwtFllt_Fert

    # Return modified gcamdata object
    return_modified("L2322.SubsectorShrwtFllt_Fert" = L2322.SubsectorShrwtFllt_Fert)

  } else {
    stop("Unknown command")
  }
}

# Run driver_drake with new chunk in the call
# Include a suffix to append to any affected objects
driver_drake(user_modifications = c("usermod_fert"), xml_suffix = "_1")
```

Declare input/output gcamdata object you want to change (dstrace function may be useful for finding the object initially)

Declare any other gcamdata inputs that you need but won't modify

Read in other custom inputs. (Don't include custom files in driver.DECLARE_INPUTS since we don't want to mix custom files with core gcamdata files)

Make any changes and return object. Note returned object name must match the original object name we asked for in driver.DECLARE_MODIFY

Run driver_drake and include the new chunk in our function call, along with a suffix to append to any affected XMLs (currently mandatory to include suffix)

Writing a User-Mod Function: Creating Multiple XMLs

- We can also generate multiple modified XMLs with this feature.
  - Note: We must include an argument to the user mod function that we can update in a loop. For this example, instead of reading in the file directly, we modify usermod_fert() to read in a CSV with the name of the value of “file_name”

```
Fert_Shwt_Additions <- read.csv(file_name, header = TRUE)
```

```
# Loop to create multiple user-modified XMLs
for (i in 1:length(list.files("mod_inputs"))){
  # Ensures that drakes knows to run usermod_fert
  drake::clean(list="usermod_fert")

  file_name <- list.files("mod_inputs", full.names = TRUE)[i]

  driver_drake(user_modifications = c("usermod_fert"),
         xml_suffix = paste0("_", i))
}
```

Run through all files in mod_inputs folder

Clear the usermod_fert object from drake's cache as drake doesn’t recognize changes to the argument file_name. If you do not include this call, drake may assume that all downstream objects/xmls do not need to be updated.

Get new file name

Run driver_drake once for each file, ensuring each run is associated with a different suffix

- This creates separate outputs for each custom file in the user_mod folder

Modifying the structure of a region or sector

- It is difficult to give general advice in this case, because exactly how you make this change depends on what you are trying to do.
- Some general advice:
  - Start small. Make the smallest change possible at each step so you can identify when things go wrong.
  - If possible use the “add-on” approach so your changes are in its own XML and delete/replace some part of the model (GCAM-USA approach)
  - You can create your test xml file in whatever manner is easiest (e.g., typing by hand or copying and editing an existing one). However, if you are planning to use the end result in a paper or in the GCAM master, then you will need to create it via the data system at some point. This is likely to be easier sooner rather than later.
  - Be very careful when changing calibration values.
  - Use GitHub Discussions to ask for more help: https://github.com/jgcri/gcam-core/discussions

Additional notes for developments you wish to get into the GCAM master

- If you are intending for your change to become part of the GCAM master, you will need to ensure that the GCAM coding style is used and that the code is well documented.
  - HINT: starting from an existing code file will help ensure the guidelines are met.
  - More information is available at: http://jgcri.github.io/gcam-doc/dev-guide.html

Part 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

- Users are encouraged to post and review the GCAM discussions page where the GCAM team and community post solutions and discussions about common issues:

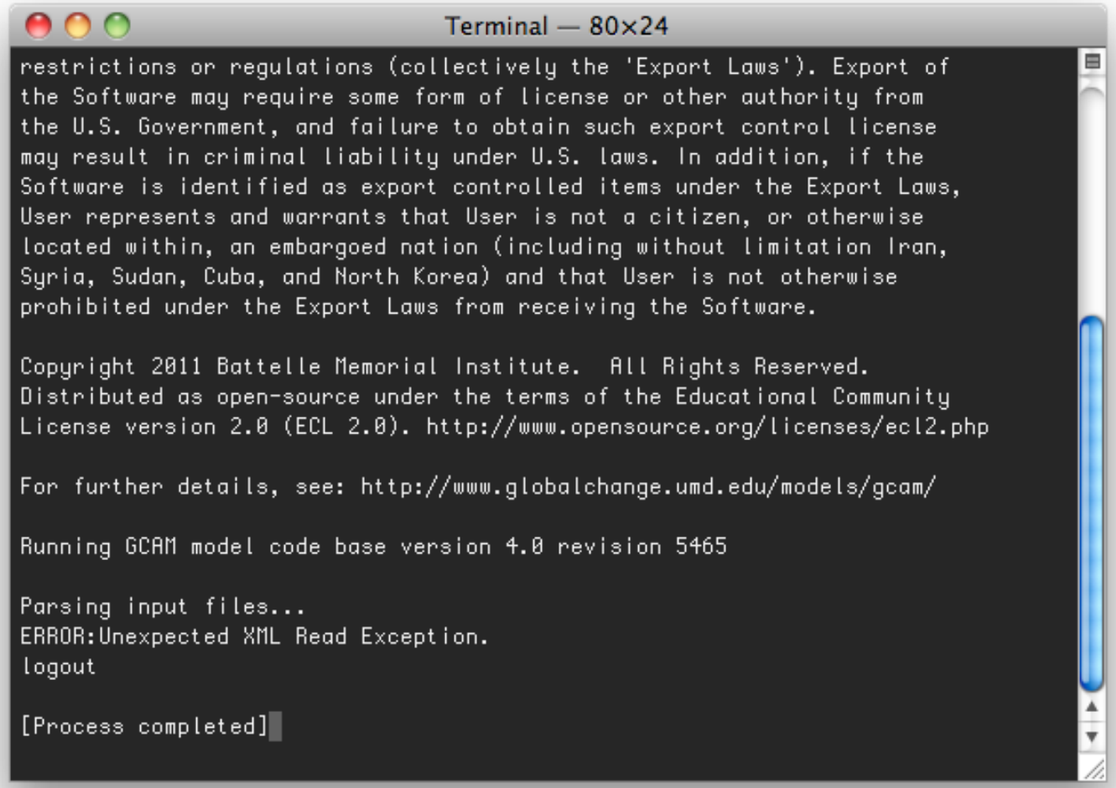
https://github.com/JGCRI/gcam-core/discussions

Types of messages

- GCAM prints different levels of messages to help identify issues.
  - WARNING: a notification of a potential problem; however, since this could be benign the model will continue (e.g., unrecognized text string in an xml input file)
  - ERROR: a notification of a likely problem. in some cases, the model will continue to run (e.g., the sum of area read in for all land leafs in a region is more than 0.1% different from the total area read in for that region); in other cases, the model will abort (e.g., if the difference is more than 5%)
  - SEVERE: Major issue that will prohibit the model from running properly (e.g., no world within the scenario container)

Configuration/input errors

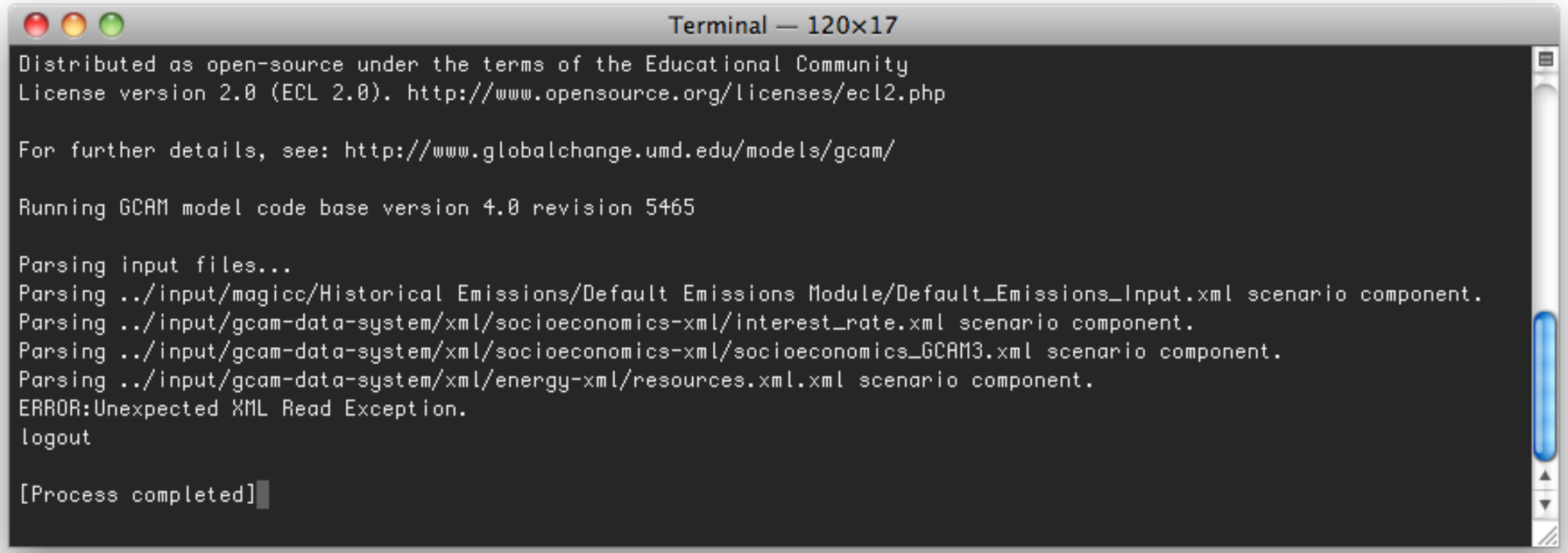
- Problem: Immediate crash



- Possible causes
  - The gcamdata system has not yet been run or did not produce XMLs
  - 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

Configuration/input errors

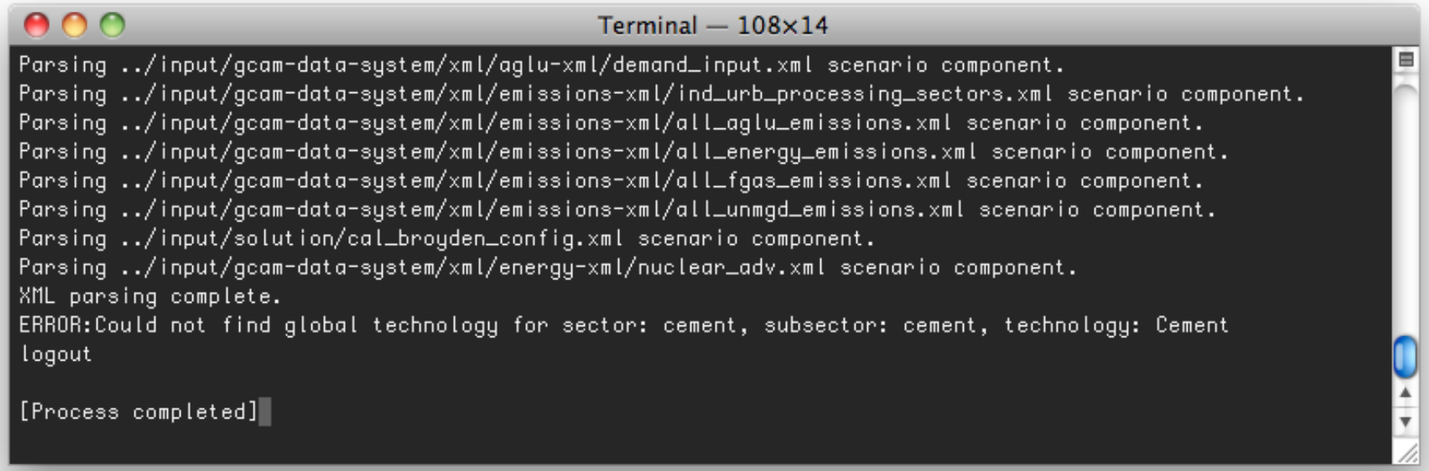
- Problem: crash while reading in the ScenarioComponents XML files



- Possible causes:
  - File was not found (look for typos in the file name)
  - File was not correctly formatted (when edited by hand)

Configuration/input errors

- Problem: crash after XML parsing, before first period



- Possible causes:
  - Mis-spelled a technology name (Cement instead of cement). Strings in GCAM are case-sensitive.
  - Missing technology
  - Added some land input in some region / basin / crop combination that does not exist

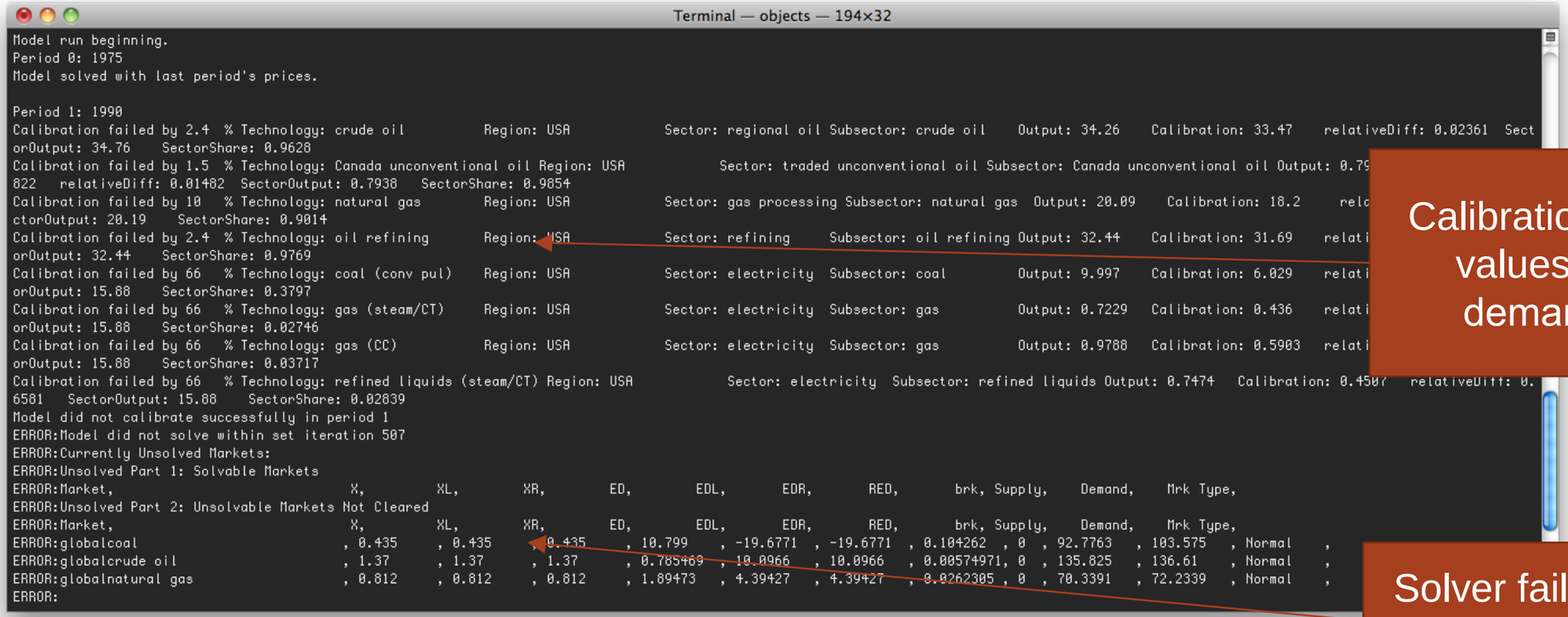
Configuration/input errors

- Problem: message printed to screen about explicitly creating a market for CO_2 (model will not abort, but will have solving problems later)

```
Parsing ../input/gcamdata/xml/water_elec_emissions.xml scenario component.
Parsing ../input/gcamdata/xml/water_demand_industry.xml scenario component.
Parsing ../input/gcamdata/xml/water_demand_livestock.xml scenario component.
Parsing ../input/gcamdata/xml/water_demand_municipal.xml scenario component.
Parsing ../input/gcamdata/xml/water_demand_primary.xml scenario component.
Parsing ../input/gcamdata/xml/liquids_limits.xml scenario component.
Parsing ../input/gcamdata/xml/water_elec_liquids_limits.xml scenario component.
Parsing ../input/gcamdata/xml/negative_emissions_budget_gSSP2.xml scenario component.
Parsing ../input/solution/cal_broyden_config.xml scenario component.
XML parsing complete.
Starting new scenario: Policy
un Oct 27 06:55:21 2019:WARNING:printLogHeader: hector version 2.0
un Oct 27 06:55:21 2019:WARNING:printLogHeader: hector version 2.0
un Oct 27 06:55:22 2019:WARNING:printLogHeader: hector version 2.0
Using negative-emissions-final-demand wth target-finder without explicitly creating a market for CO2 may hinder solution performance.
Please read in a policy file with a zero tax.
Reading advanced target finder configuration file ../input/policy/forcing_target_4p5.xml
Policy Target Runner:  scenario dispatch #0

Starting a model run. Running all periods.
Model run beginning.
Period 0: 1975
Model solved with last period's prices.
```

- Cause: A carbon price must be read in with target finder in order to set up dependencies. Be sure to start from configuration_policy.xml

Calibration Failures versus Solver Failures

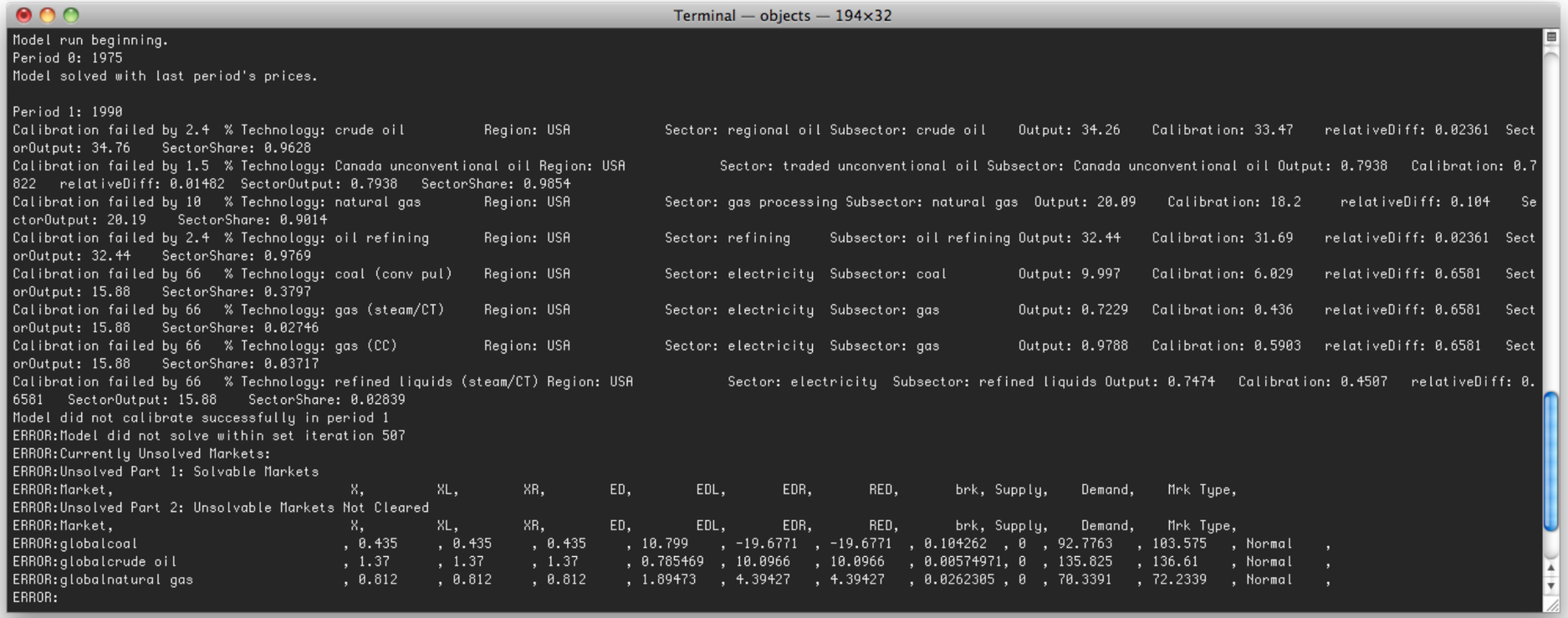


Calibration failure: Read-in values for supply and demand don't match

Solver failure: model cannot find a set of prices where supply and demand are equal for all commodities

Errors from changes to input files

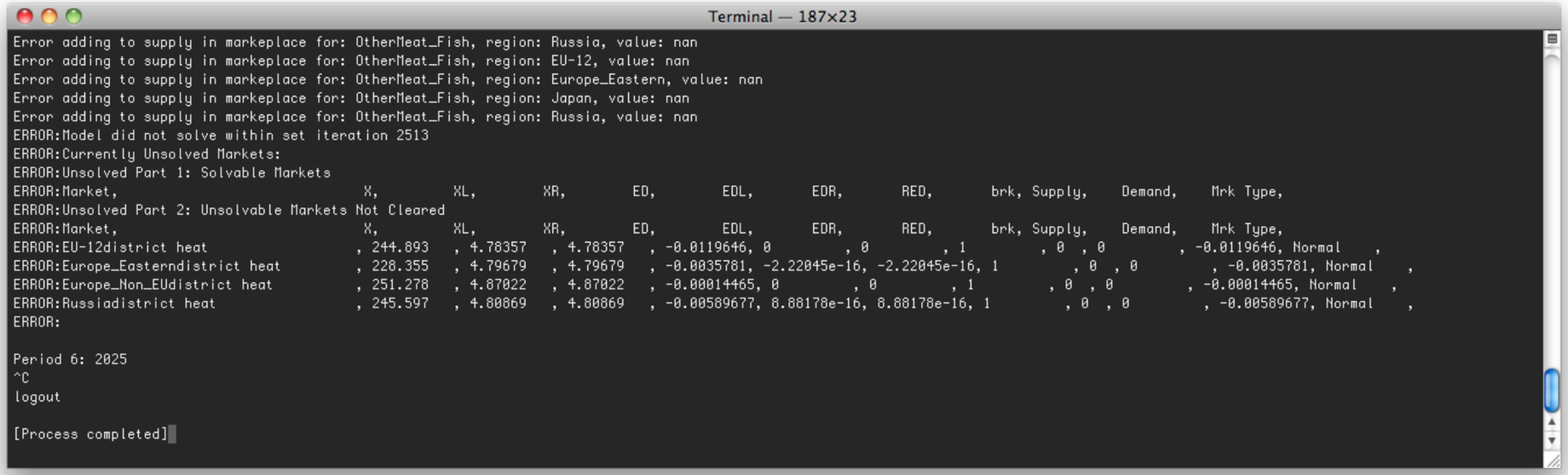
- Problem: the model does not calibrate or solve the base years:



- Cause: Unbalanced supply and demand in calibration years. Check all calibration data, including coefficients to debug. In this case, the base-year electricity input-output coefficient of cement production was changed, causing system-wide imbalances between electricity demand and supply.

Model not solving

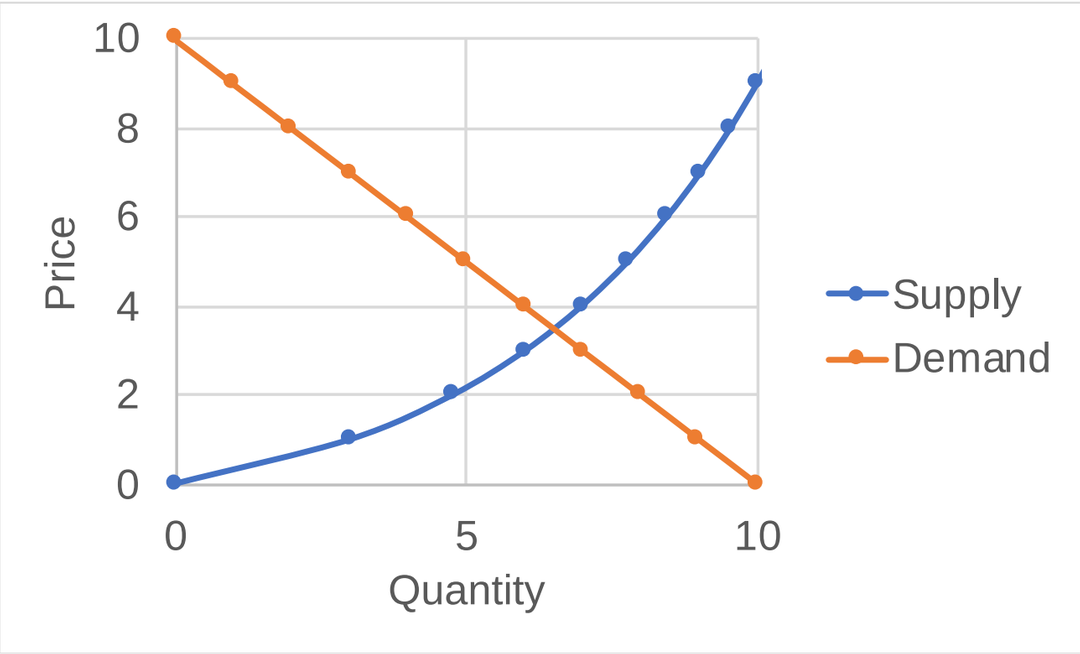
- Problem: the model fails to solve in some period



  - Cause: solution issues can be difficult to decipher
    - Useful to make ”one” change at a time
    - Double check your configuration
    - Use supply / demand curves feature to check problem markets (input/extra/supply_demand_curves.xml)

Model not solving

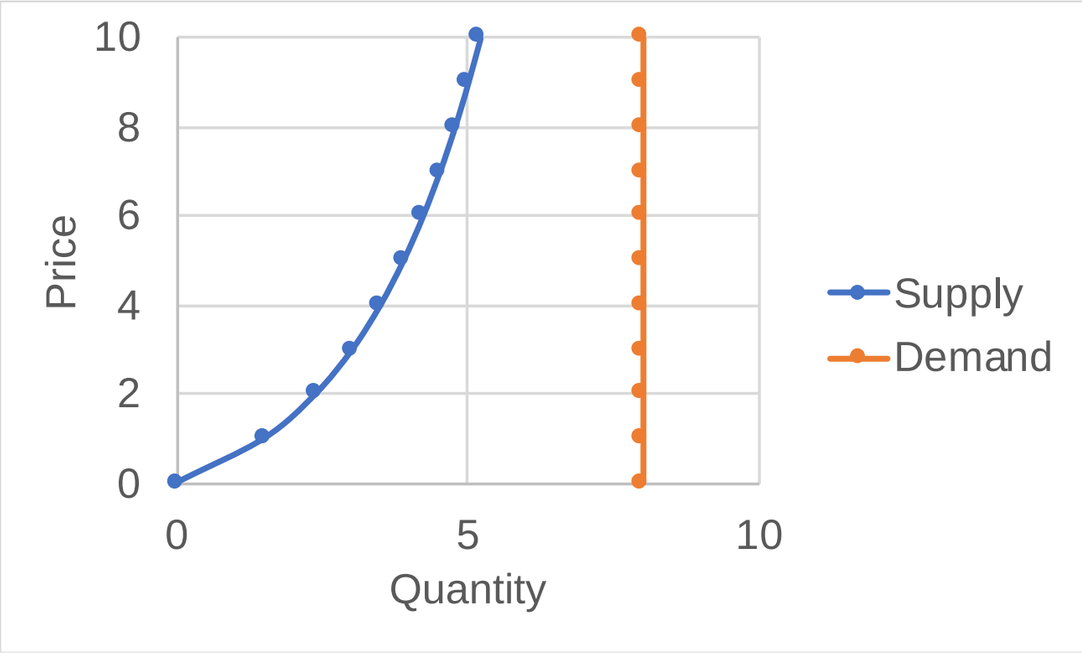
- Solver failures can be difficult to diagnose. Some things to try:
  - Look for discontinuities or vertical supply or demand curves, either by thinking about what you've changed that could have led to that OR by using the supply-demand curve calculator to print the curves.
  - Use https://github.com/JGCRI/gcamwrapper to debug interactively from R or Python



Well-behaved and intersecting.
Should solve easily.

Model not solving

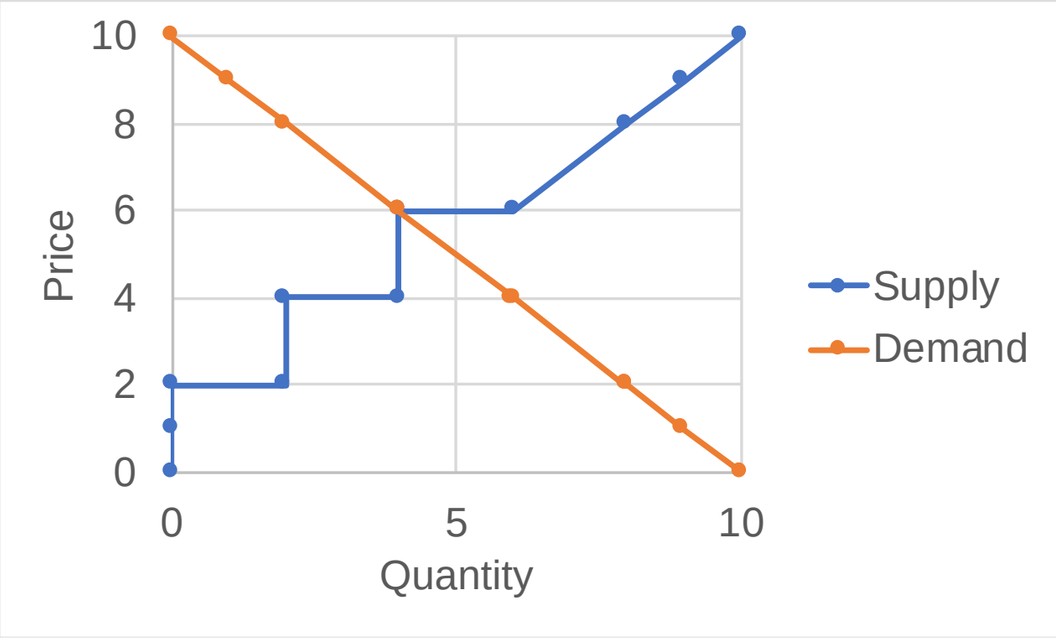
- Solver failures can be difficult to diagnose. Some things to try:
  - Look for discontinuities or vertical supply or demand curves, either by thinking about what you've changed that could have led to that OR by using the supply-demand curve calculator to print the curves.



Non-intersecting.
Will not solve.

Model not solving

- Solver failures can be difficult to diagnose. Some things to try:
  - Look for discontinuities or vertical supply or demand curves, either by thinking about what you've changed that could have led to that OR by using the supply-demand curve calculator to print the curves.



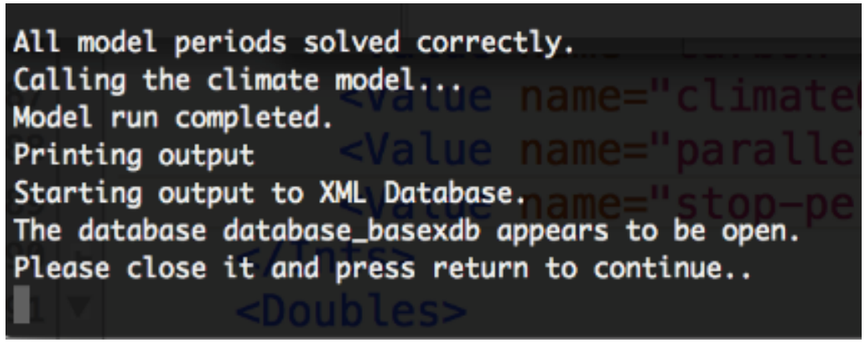
Intersecting, but includes a discontinuity. Can solve, but may be difficult.

Model not solving

- Solver failures can be difficult to diagnose. Some things to try:
  - Look for discontinuities or vertical supply or demand curves, either by thinking about what you've changed that could have led to that OR by using the supply-demand curve calculator to print the curves.
  - Increase the iteration count in the solver configuration file. [Note: there is no guarantee this will work, but it is easy to try and has helped in the past]
  - Ask for help on GitHub: https://github.com/JGCRI/gcam-core/discussions

Database open while trying to write

- The model can’t write to the output database

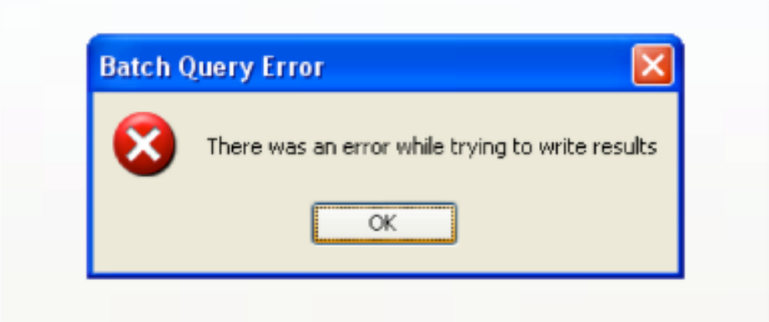


  - In prior versions, the database could be open while GCAM was writing to it; this is no longer the case with the switch to the basexdb

- Missing third party jars (https://github.com/JGCRI/modelinterface/releases)

Queries – general

- Null Pointer Exception: Make sure you have the most recent Model Interface
  - https://github.com/JGCRI/modelinterface/releases
- Message: “The query returned no results”
  - Misspelling the name of a variable or sector
  - 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)
- Batch query error:



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

Part 5: Additional Resources

- Online resources:
  - GCAM documentation: http://jgcri.github.io/gcam-doc/toc.html
  - Developer's guide: http://jgcri.github.io/gcam-doc/dev_guide.html

- Asking for help:
  - gcam-core Github issues/discussions: https://github.com/JGCRI/gcam-core/discussions
  - gcam-core GitHub bugs: https://github.com/jgcri/gcam-core/issues
  - gcam-doc GitHub issues: https://github.com/JGCRI/gcam-doc/issues

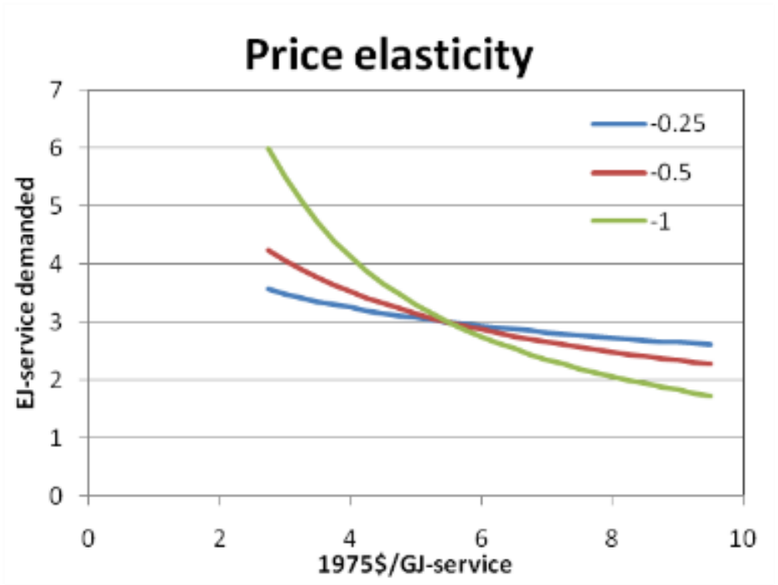
Part 6: Theory and meaning of parameters

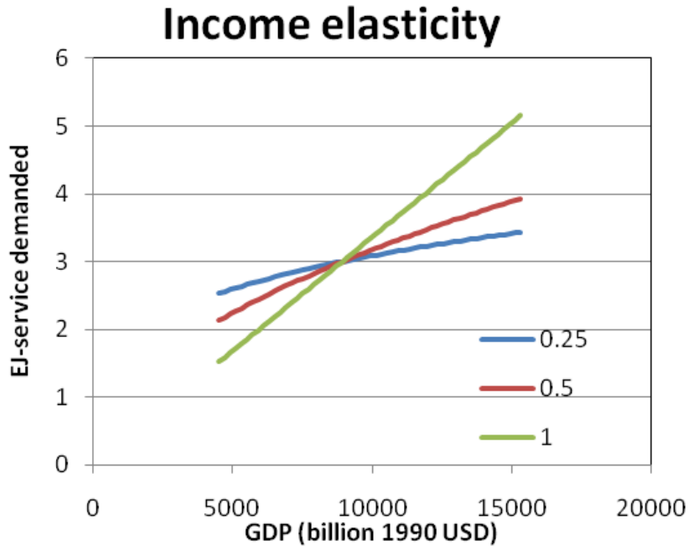
- This section focuses on the meaning of several key input parameters found throughout the input XML file set
  - Elasticities
  - Logit exponents
  - Share-weights and interpolation rules
  - Efficiencies and coefficients

Elasticity

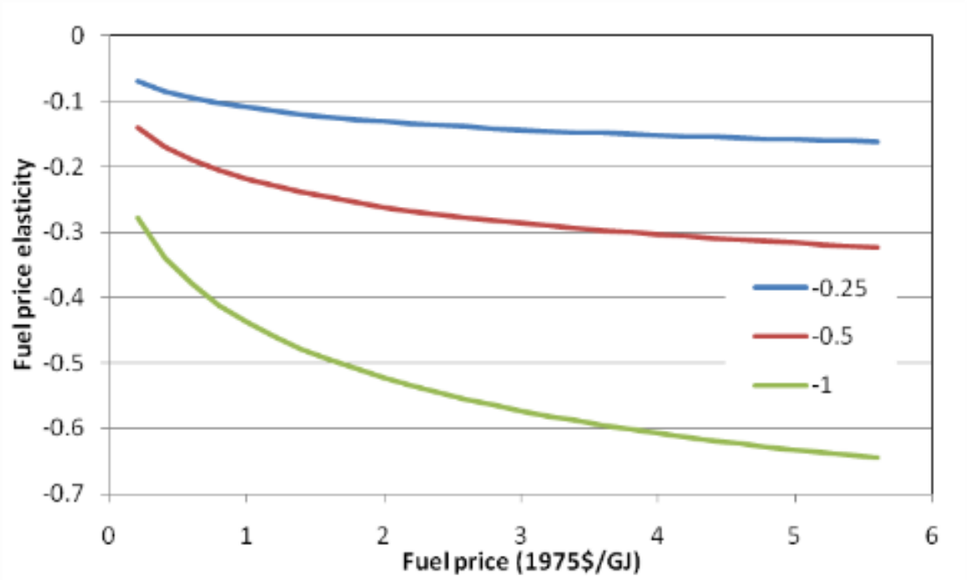
- Price elasticity: The percent change in demand of a good divided by the percent change in the price
- Income elasticity: The percent change in demand of a good divided by the percent change in GDP

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





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

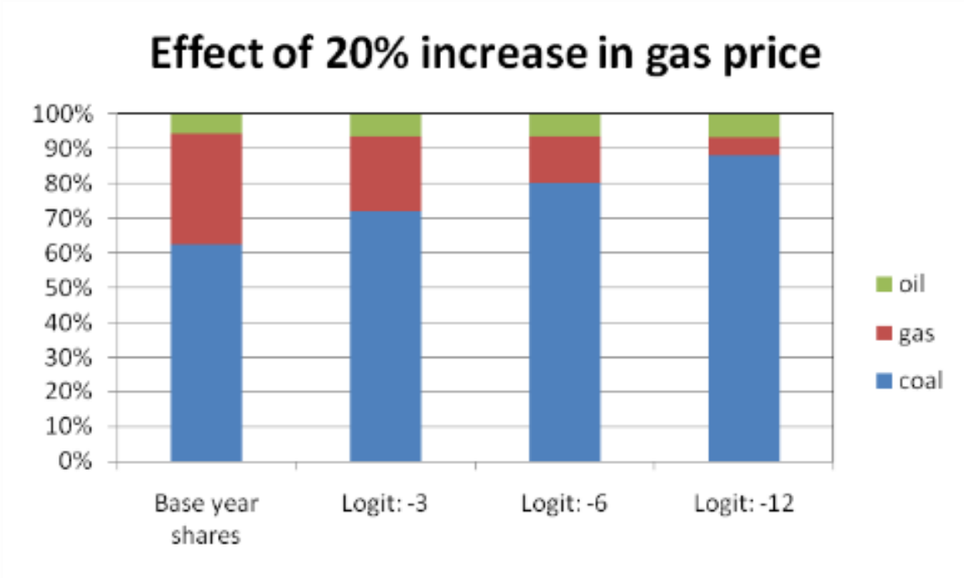
Efficiencies and coefficients

- Efficiency = output / input
- Coefficient = input / output
  - Coefficients make more sense where there are multiple inputs
- Where the input-unit and output-unit are the same, these parameters are unitless. For several sectors in GCAM, however, the input-unit and output-unit differ, e.g.:
  - 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

Logit-exponents and fuel-switching

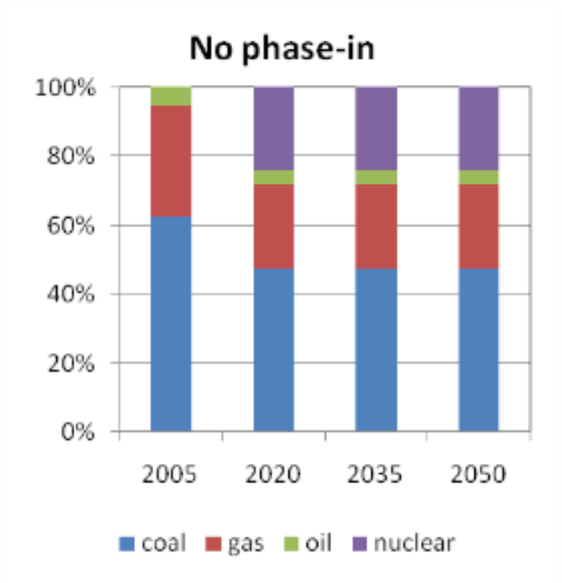
- The logit exponents control the degree of switching between technologies or fuels in response to price changes
  - Low values = low fuel-switching = strong influence of base year shares even far into the future
  - High values tend towards winner-take-all responses in response to changes in costs

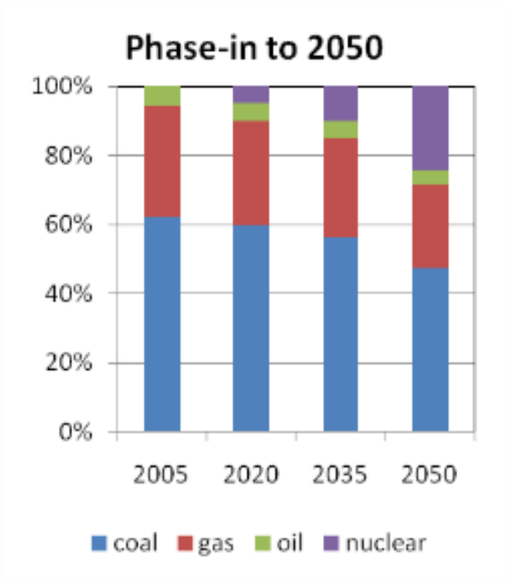
$$Share_i = \frac{sw_i \bullet P_i^{\beta}}{\sum_i sw_i \bullet P_i^{\beta}}$$



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

Interpolation

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

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

Pacific Northwest
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Thank you