Development and Application of a US TIMES Model

Joe DeCarolis, Samaneh Babaee
North Carolina State University

ETSAP Meeting
Stanford, CA
July 9, 2011

jdecarolis@ncsu.edu

Goals

Analyze system-wide response to energy and environmental policy with a focus on rigorous treatment of uncertainty

I want to simplify and streamline the modeling process as much as possible.

1. Minimize data maintenance
2. Shallow learning curve to increase productivity
3. Speed model iteration and reduce data storage

Challenge #1: Working in a Linux environment

To utilize the compute cluster, must iterate MARKAL/TIMES in a Linux environment

Initial preference for MARKAL:

- Familiarity with ANSWER
- EPA MARKAL (NMD and US9r) databases available

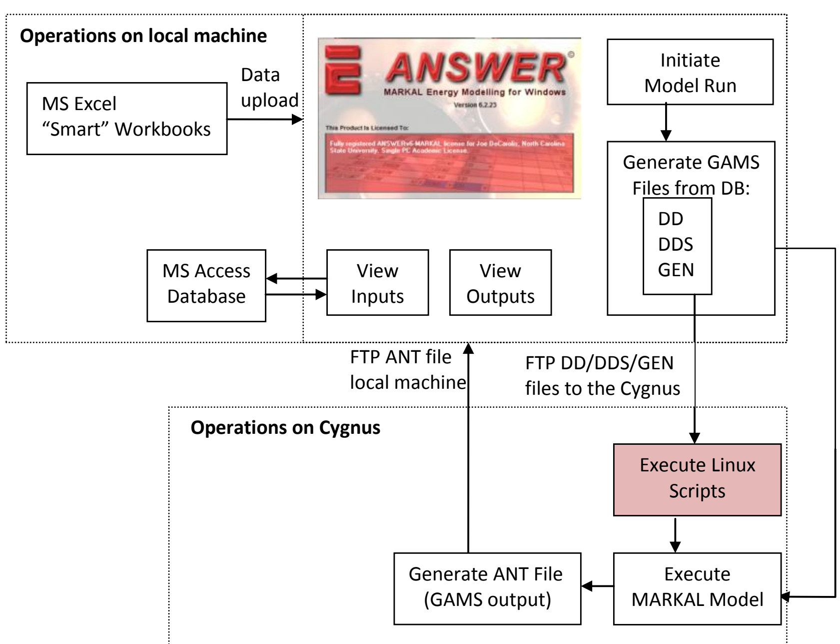
Problems:

- Convert DOS → bash scripts
- Further scripting required for multi-region model generator

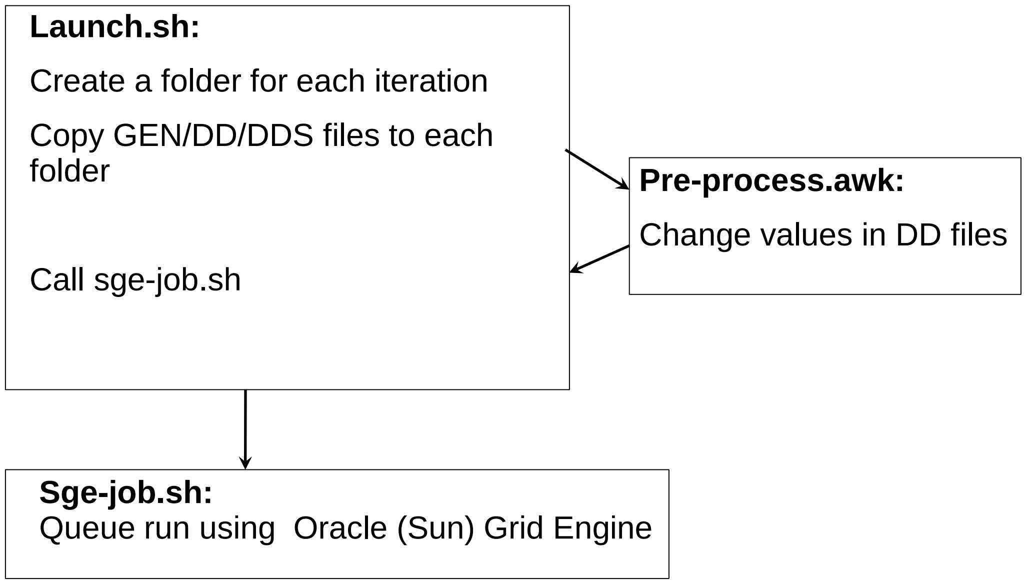
Benefits of TIMES:

- Almost exclusively GAMS → platform independent
- Technology vintaging
- Flexible processes based on flow variables

MARKAL ←→ Cluster workflow



Iterating TIMES on the computer cluster



Challenge #2: Managing data

My problem is not having too little data, it’s having too much!

In bottom-up models, there is an inclination to add more technology detail over time

Technology detail should be sufficient to make accurate projections of key quantities but within plausible levels of uncertainty

Quantities of interest:
- System cost
- Emissions levels (system-wide and sector-level)
- Marginal cost of emissions and fuels
- Fuel consumption
- Choice of technologies (coarse resolution)

Looking for a systematic way to simplify to reduce the volume of data

Using the EPA-ORD MARKAL database

5 team members continuously improving / updating the model has led to a highly detailed model database

Used database directly for awhile, but over time realized that we didn't "own the data".

Decided to treat the EPA database as a data source to be mined, supplemented with over data where appropriate.

Resource supply in the EPA-ORD database

Coal supply: 440 supply steps; 279 transport technologies
(Coal, Northern Appalachian, Bituminous, Medium Sulfur, Underground, Step A)

Oil supply: 10 domestic supply steps; 418 supply steps for imported crude oil and refined products. (Imported jet fuel, PADD3, Step A)

Natural gas supply: 10 domestic supply steps; 5 supply steps for imported natural gas. (Imported natural gas from Canada – Step 1)

Biomass supply: 30 domestic supply steps
corn grain, corn stover (3 steps), soybeans, grasses (4 steps), woody biomass (4 steps), ag residues (4 steps), forest residues (4 steps), primary mill residues (4 steps), urban wood waste (4 steps), timber production

Resource supply strategy

Consolidate supply curves as follows:

- **Coal supply:** maintain distinction between coal types, coal regions, and sulfur level
- **Oil supply:** only include refined product import if it makes (or is likely to make) a significant contribution
- **Natural gas supply:** maintain current representation
- **Biomass supply:** focus on feedstocks that could have a measurable impact (e.g., not urban wood waste)

Coal supply simplification

- Preserve coal type, region, sulfur level
- Build a single supply curve with all steps
- Condense number of steps by calculating % change in price from lowest value.
- Keep steps that represent incremental 10% changes relative to the starting value.

Result: Coal supply steps reduced from 417 → 89

End-Use Sectors

Transportation: 1100 vehicle representations, including 1054 Light Duty Vehicles (9 fuels, 8 vehicle classes); 44 Heavy Duty Vehicles (HDVs); 2 Off-Highway (OH); 9 end-use demands

Commercial: 283 technologies, including 50 heating techs, 90 cooling techs, 40 water heating techs, 14 ventilation techs, 6 cooking techs, 62 refrigeration techs, 15 lighting techs, 6 misc techs; 8 fuels, 13 end-use demands

Residential: 224 technologies, including 77 heating techs, 92 water heating techs, 12 refrigeration techs, 41 lighting techs, 2 misc techs; 7 fuels, 8 end-use demands

Industrial: 8 industry sub-sectors, 231 technologies, including chemical (38 techs), food (29 techs), primary metals (34 techs), non-metallic materials (29 techs), other industry (40 techs), paper (31 techs), transportation equipment (25 techs), non-manufacturing technology (5 techs); 17 fuels, 52 end-use demands

Drawn from input data to the National Energy Modeling System (NEMS)

Approach #1: Aggregation through set covering

Demand categories: if demand category represents less than **<u>5%</u>** of total demand, then subdivide among the misc fuel categories according to current proportions.

Fuels: maintain representation of different fuels (i.e., do not simplify by removing fuel options)
→<u>UNLESS</u> (1) there is no tangible benefit to the fuel (i.e., lower cost and/or emissions) AND (2) residuals are insignificant, i.e. less than **<u>5%</u>** of total current demand.

Technologies: Calculate annual cost of each demand technology by demand category and fuel type. If several technologies have an annual cost that differs by less than **<u>±10%</u>** between different versions or vintages, then condense to a single representation.

Annual Cost Calculation

Annual cost of each technology estimated as follows (m$/PJ·yr):

$$ANNCOST = INVCOST \cdot \frac{DISCOUNT}{1-(1+DISCOUNT)^{LIFE}} + FIXOM + VAROM \cdot CF + \frac{FUELCOST}{EFF} \cdot CF$$

Assumed fuel cost ranges:
Natural gas: 4-30 m$/PJ
Electricity: 8-70 m$/PJ
Distillate: 10-20 m$/PJ
Kerosene: 2-40 m$/PJ
LPG: 4-23 m$/PJ

Problem: ordering of technology-specific annual costs changes with the assumed fuel costs

Set Covering

Given several input sets the objective is to:

Select a minimum number of sets so that the sets you have picked contain all the elements that are contained in the input sets.

E.g., Placement of fire stations to cover a city w/ a max. 5 min response time using min. number of stations.

Can be setup as integer linear programming (ILP) model

3rd aggregation rule defined an annual cost threshold of ±10%.

Each tech can represent a set of techs within ±10% of annual cost

Find the smallest technology set such that all techs are covered.

Excel Set Covering Procedure

	threshold:		10												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	16	21	33	22	46	51	34	52	61	68	80	85	86	89
2	19	0	6	20	22	36	42	33	52	54	62	80	82	83	89
3	27	7	0	15	23	31	38	34	53	53	59	80	81	82	89
4	49	25	17	0	21	19	27	32	51	51	52	80	77	79	89
5	28	28	30	26	0	32	39	18	38	51	60	74	81	82	86
6	85	55	45	24	48	0	9	22	40	40	41	75	72	74	86
7	104	71	61	37	63	10	0	34	38	38	37	74	70	71	86
8	52	49	52	47	21	19	26	0	28	41	51	70	77	78	84
9	108	108	112	105	63	66	62	39	0	22	36	58	69	71	77
10	157	115	112	106	105	66	62	69	27	0	18	58	61	64	77
11	212	162	145	109	149	69	60	105	55	22	0	59	53	56	78
12	398	398	407	391	289	297	287	233	139	139	142	0	58	61	47
13	557	451	416	340	424	255	237	332	226	156	111	141	0	7	53
14	606	492	455	373	463	281	245	364	251	175	126	159	7	0	53
15	826	824	841	812	623	638	618	519	344	343	349	90	113	111	0

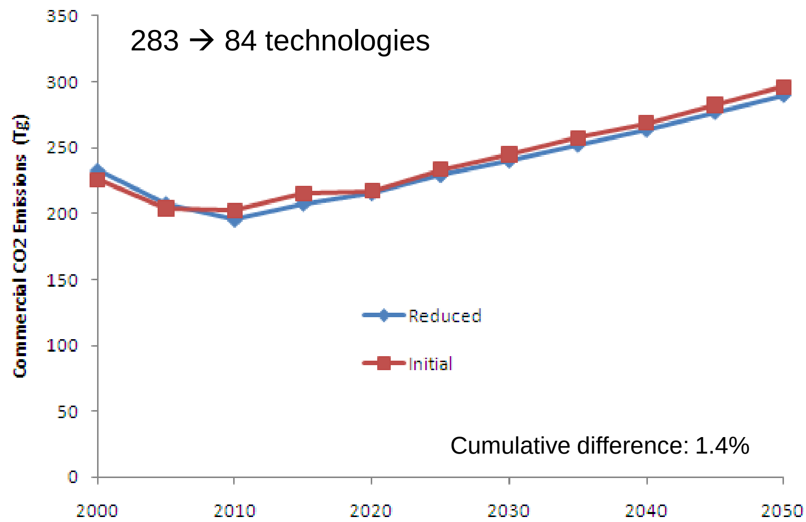
1. Find % difference in annual cost of row tech w.r.t. column tech at both min/max fuel prices
2. Select larger annual cost difference, if difference > threshold, cell =1
3. Use solver to find min set of techs to cover all techs given threshold 15

Excel Set Covering Procedure

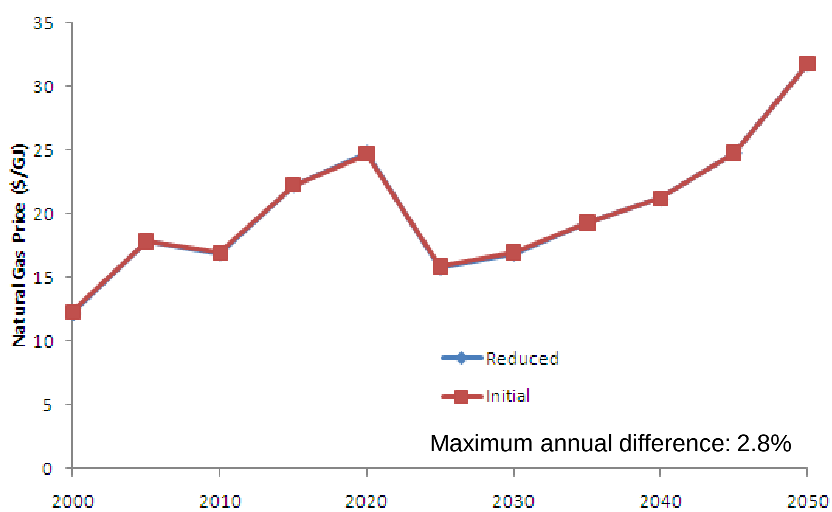
	threshold:		10																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Tech	LHS		RHS
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	>=	1
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
6	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	>=	1
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	>=	1
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	>=	1
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	>=	1
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	>=	1
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	>=	1
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	>=	1
13	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	>=	1
14	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	>=	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	>=	1
																12			

1. Find % difference in annual cost of row tech w.r.t. column tech at both min/max fuel prices
2. Select larger annual cost difference, if difference > threshold, cell =1
3. Use solver to find min set of techs to cover all techs given threshold 16

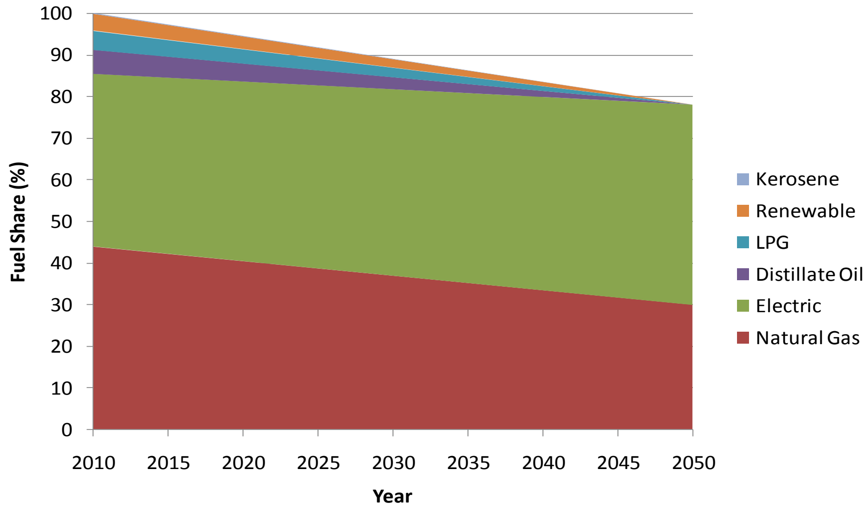
Commercial CO_2 emissions



Average price of natural gas to commercial sector



Approach #2: Represent fuel shares only



- Allow model to optimize fuel shares over time with increasing flexibility
- <u>No technology representation</u> → implicit assumption that fuel prices will drive future fuel shares (renewables are an exception)
- Easy to perform sensitivity analysis

Current Status and Next Steps

Electric Sector and Transport Sectors largely complete

End-use sectors with share constraints complete

Build resource supply

Add refinery representation

Incorporate elastic demands

Add heavy duty and off-road transport