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ACEEE Workshop on Energy and Economic Policy Models: A Reexamination of Fundamentals

Enhancing Technology Representations within the Stanford Energy Modeling Forum (EMF) Climate Economic Models

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EMF-22 on Climate Policy Transitions is seeking to enhance technology specifications, while being consistent with the integrating economic representation.

- My comments on GHG-Related Technology and Commercial Design
- How this manifests itself in Economic Models

Energy Technology and Commercial Design

- Technology has and must continue to evolve rapidly
- Commercial wind turbine rotors have grown from about 10 meters to 80 meters over the past 25 years
- Photovoltaics has enormous potential
  - United Solar intends to install 300 MW of its thin film PV
  - Research labs are working hard on nanotechnology applications
- Vehicle designs have great potential (batteries, fuel cells, controls)
- Polygeneration provides the opportunity to direct energy to its highest value use.
- We need to work harder on enabling technologies such as high temperature membranes.
- But we also need to start building and gaining experience with current commercial designs

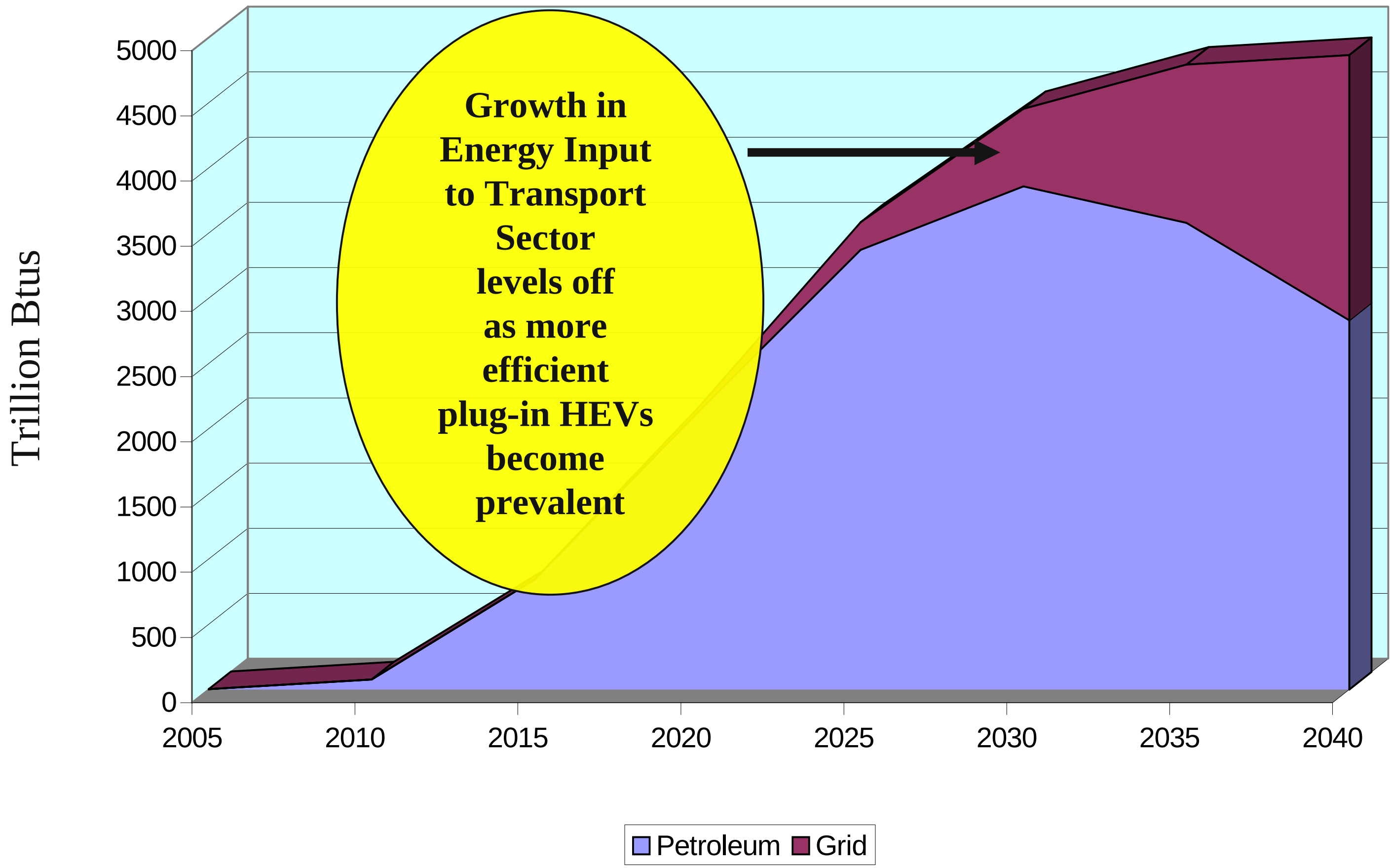
What are the Variables in Commercial Designs?

- Transportation efficiency example: More diesel fuel use in LDVs?
  - To vary refinery output from gasoline to diesel requires more (expensive) catalytic hydrotreating
  - In our economic model we must account for an upward shift in natural gas demand as refiners produce more hydrogen

- Energy efficiency on the margin: How much additional labor effort and capital will be incorporated into production designs
  - Depends on household and corporate decision-making
  - Well-designed public programs can yield win-win-win rewards

- Adoption of available and advanced vehicle technologies
- Choice of existing or advanced catalysts
- Joint output optimization: Wet corn milling output to food or ethanol

National Energy Technology Laboratory & Argonne Joint Scenario Study: HEV Case including Plug-in Vehicles



Source: Peter Balash, NETL, AMIGA Presidential Goals Scenario Runs - HEV case

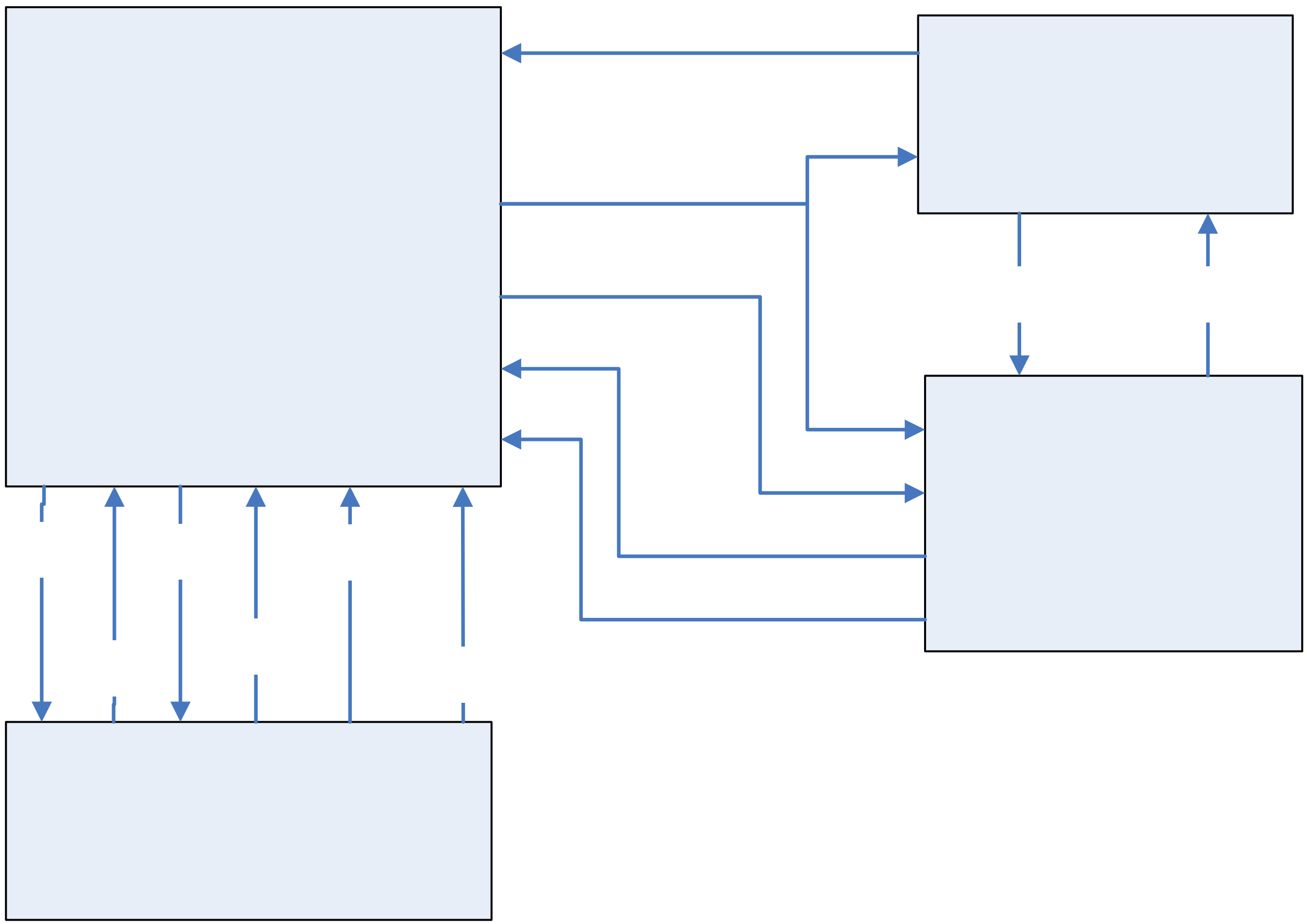
What Kind of Specification Does the Integrating Economic Model Need?

- Supply equals demand in all markets including physical flows of electricity and transportation fuels
- Specification of technology designs for electric generation, end-use equipment, vehicles, and transportation fuels production (production function under current technology)
- Provides reproducible designs to the model for any given time period, satisfying conditions of entry: Total Revenue >= Total Costs
- Characteristics of these technology designs include the energy efficiency dimension
- Rates of substitutability between inputs and joint outputs (where price equals full marginal cost including opportunity costs due to reducing other outputs)
  - Baseload, shoulder, peak load
  - Gasoline, diesel, and other refinery outputs
- Technology characteristics improve over time

An EMF Integrated Assessment Model

- Background Slides on the AMIGA/MARS Model
- Linked to the IPCC MAGICC model relating multi GHG emissions trajectories to radiative forcing
- Positioning ourselves to make good future decisions
- Presented at the DOE/EERE Renewable Energy Workshop, November 3, 2006

Energy and Economic Flows Within the AMIGA Modeling System



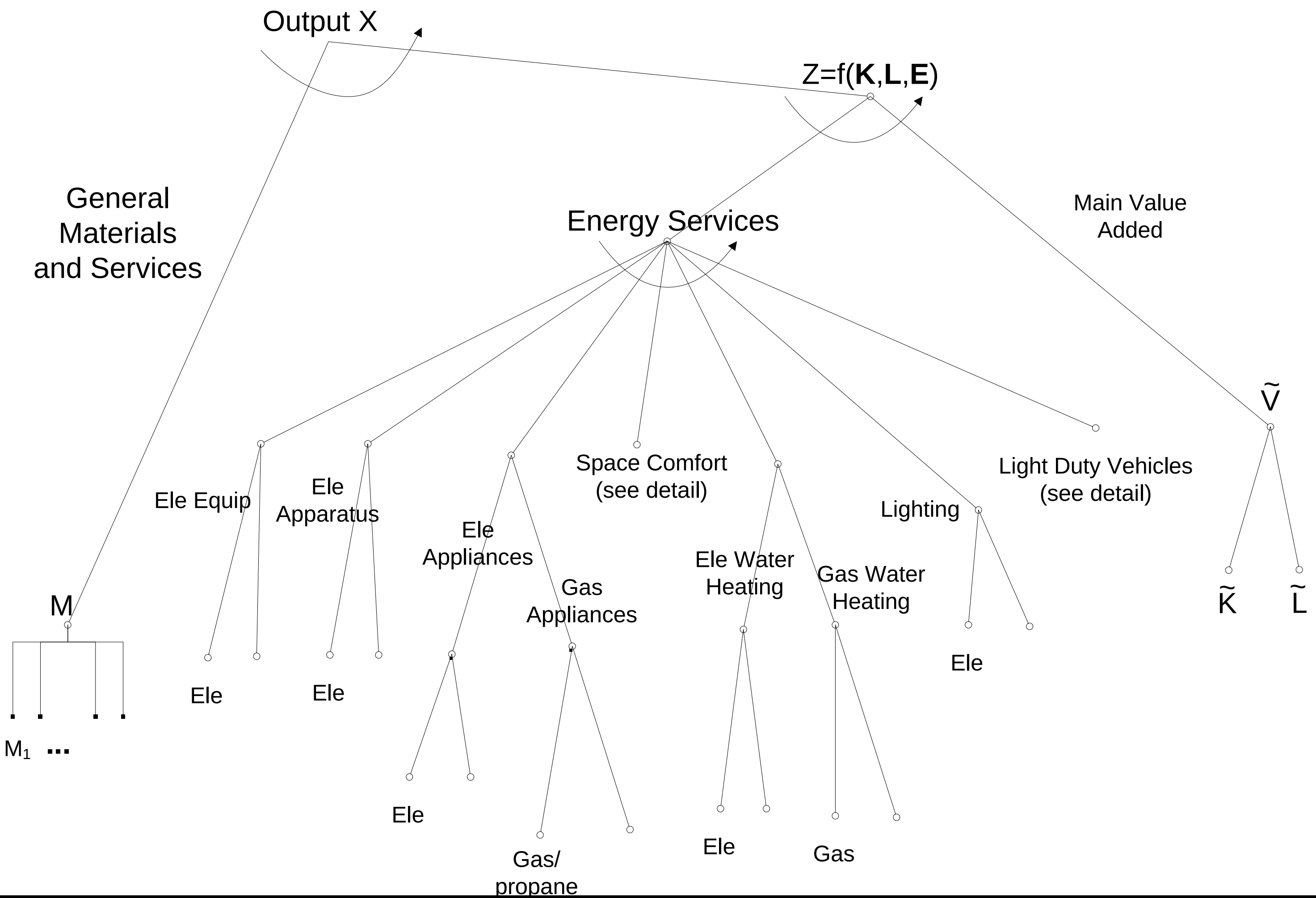
The AMIGA Modeling System Solves Three Sub-Problems, Which Cross-Cut Across Modules

- Modules are groupings of source code pertaining to a specific subject matter, e.g., electricity supply, vehicle stock, etc.

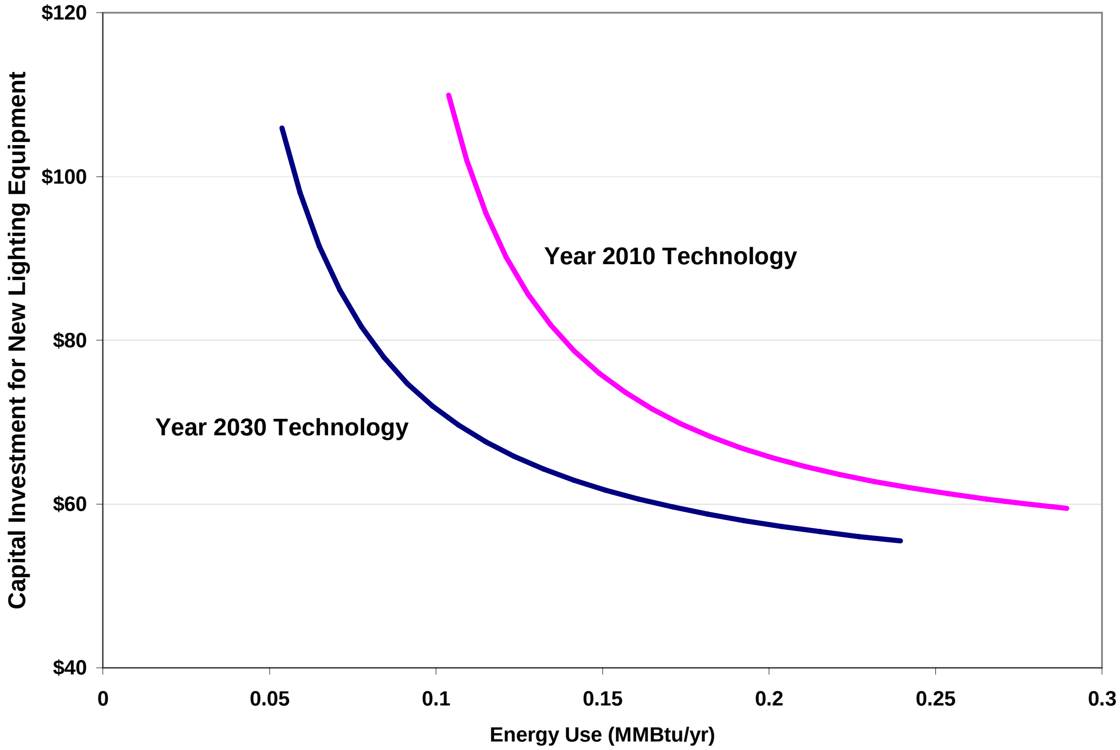
- Three key Sub-Problems:
  - Sector cost and price sub-problem, p=MC
  - Intermediate demand and sector output, S=D
  - Calculation of price sensitive
    - *Factor intensities*
    - *Household demands*
    - *Technology market shares, etc.*

- Capital stocks are accumulated over time through real investments

Hierarchical Representation of Commercial/Industrial Production Allows Capital Disaggregation and Differing Elasticities of Substitution



The Hierarchy of CES Production Functions Implies Isoquants Reflecting Specific Factor Substitution Opportunities. These Functions may Shift due to Technological Change



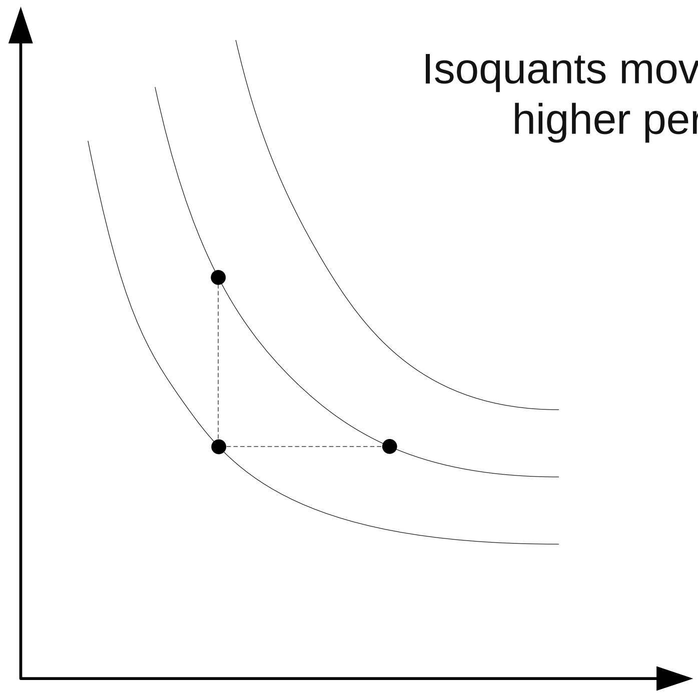
A tangent point at the factor price ratio implies explicit, closed-form solutions to factor demand intensity equations

See Daron Acemoglu, "Directed Technical Change," Review of Economic Studies, Oct. 2002, for representation of factor augmenting technical progress

According to the National Academy's Report, There Are Opportunities to Improve Both/Either Vehicle Efficiency and Performance (with strong price and income effects)

Mathematically the functions and optimal choice are described as follows:

Isoquants move out with higher performance



$$Perform_{0yz} = f_{yz}^{\kappa}(Vehpric_{yz}^{eeffc}, 1/MPG_{yz})$$

$$\left(\frac{f'_E}{f'_K}\right) = \left(\frac{P_{E,t}}{r_e^h}\right) \cdot \left(\frac{VMT_{0yz}^h}{NV_{0yz}^h}\right)$$

$$f_{yz} = \left[\Theta_{yz}\left(\frac{Vehpric_{yz}^{eeffc}}{\omega_{yz}}\right)^{-\zeta} + \Phi_{yz}\left(\frac{1/MPG_{yz}}{\tau_{yz}}\right)^{-\zeta}\right]^{\frac{-1}{\zeta}}$$

$$\frac{f'_E}{f'_K} = \left(\frac{\Phi_{yz}}{\Theta_{yz}}\right) \cdot \left(\frac{\tau_{yz}}{\omega_{yz}}\right)^{\varsigma} \cdot \left(\frac{Vehpric_{yz}^{eeffc}}{1/MPG}\right)^{1+\varsigma}$$

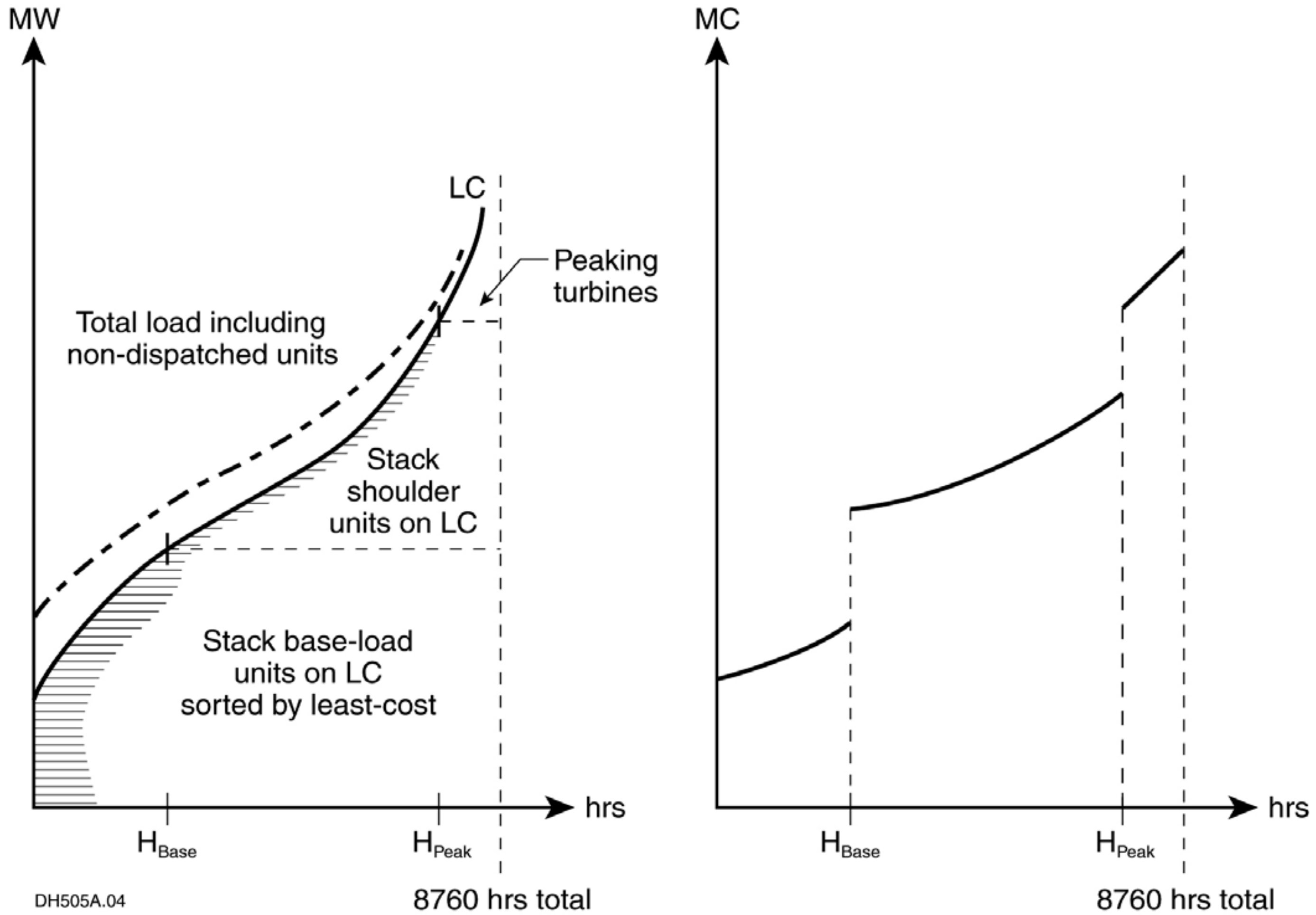
The AMIGA Model is Expandable

- Add disaggregated goods and services (insert a row index)
- Add disaggregated or new production process or activity (insert column index)
- Add vehicle technologies
- Add generation technologies
- Add End Use technologies

Utility Unit Planning & Compliance Model: Electricity Markets are Segmented

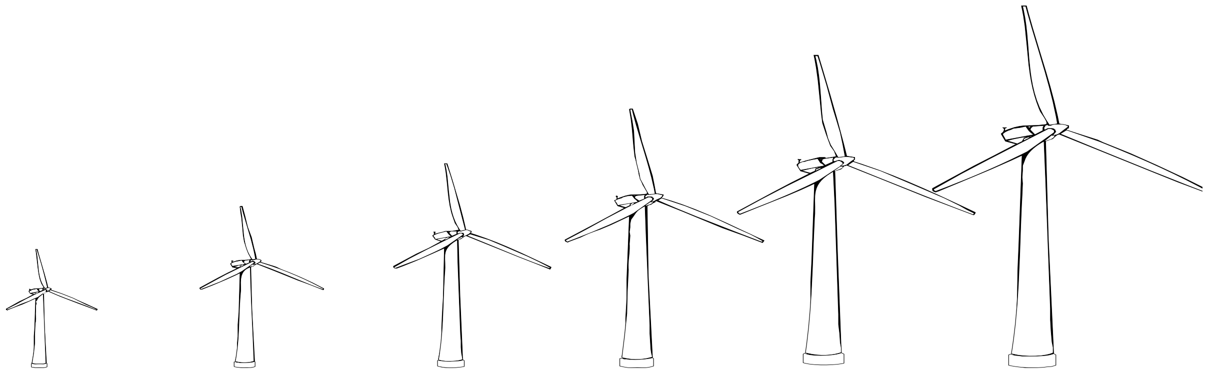
- We shouldn't consider electricity to be a single commodity in a uniform market, rather:
  - Base load – coal and nuclear
  - Shoulder load – NGCC
  - Peak load – gas and distillate oil combustion turbines
- The trend is toward base-load and non-dispatchable supplies
  - Coal and nuclear
  - Intermittent wind and solar energy
  - Industrial/commercial distributed CHP replacing small to medium gas boilers
- This trend makes flexible gas peaking turbines more valuable, but gas markets are already tight

Gross and Net Load Curves, Fossil & Renewable Power, Marginal Costs & Prices, Dispatch & Capacity Growth



Technological Advance Has Driven Down Wind Cost

20 Years of Wind Technology Development

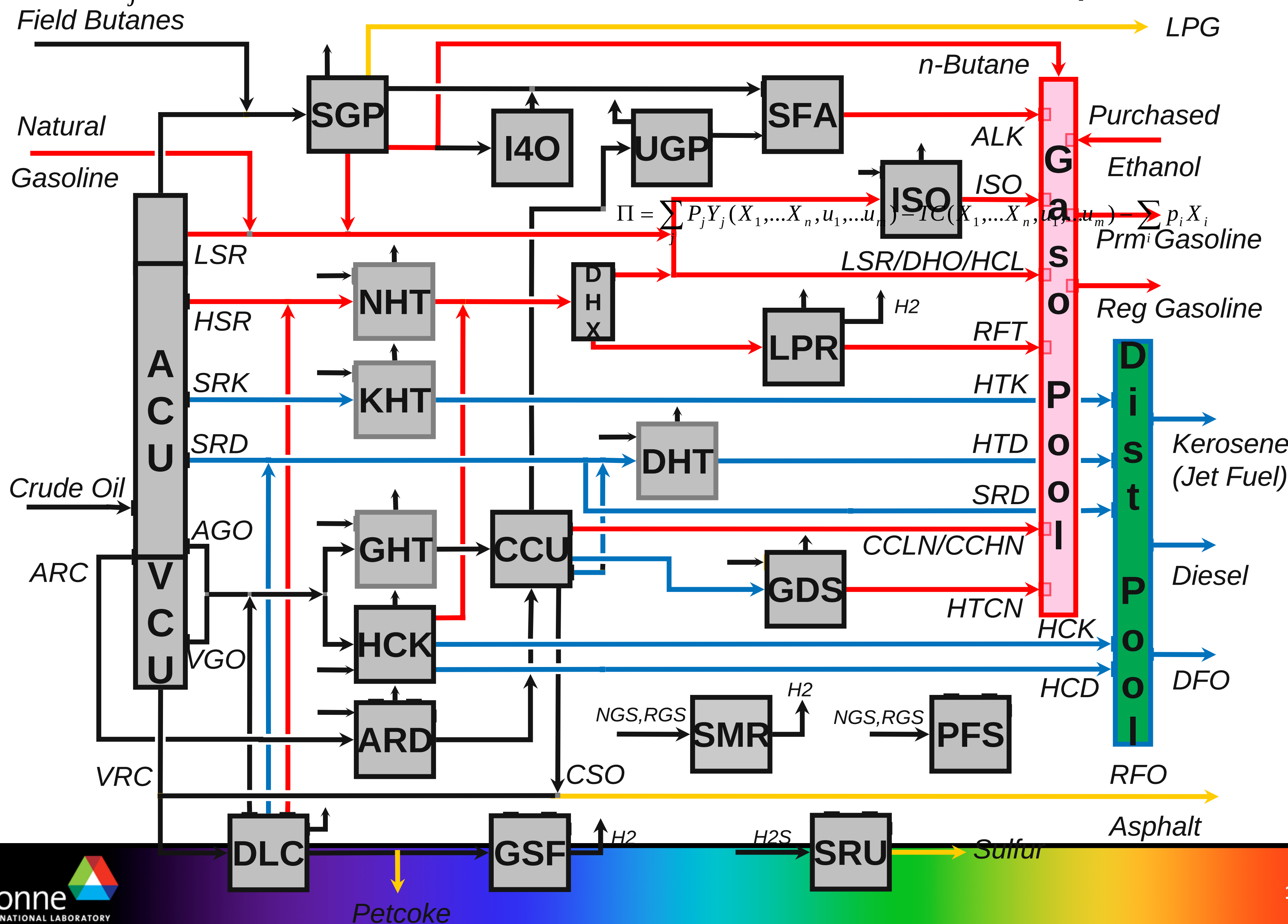


	1981	1985	1990	1996	1999	2002	2005
Rotor (meters)	10	17	27	40	50	70	80-85
kW	25	100	225	550	750	1,500	>2,000
Total Cost	$65	$165	$300	$580	$730	$1,100	
Cost/kW	$2,600	$1,650	$1,333	$1,054	$973	$733	
MWhr	45	220	550	1,480	2,200	5,600	

Bottom Line: 1981-1999 = 49x the power, 11x the cost;
1999-2000 = 2.6x the power, 1.8x the cost
Source: GE Wind Energy

MARS Model: Profit Maximizing Refining Market

$$\Pi = \sum_j P_j Y_j (X_1,\ldots X_n, u_1,\ldots u_m) - TC(X_1,\ldots X_n, u_1,\ldots u_m) - \sum_i p_i X_i$$



Biofuels Model

- Based on Wm Morrow's Ph.D. dissertation at CMU
- Both cellulosic and starch biomass
- Characterizing production plants and transportation costs
- Examining least-cost assignment of biomass to power generation versus liquid fuel production
- Helps to integrate electric power market and transportation fuels market
- Integrating Biofuels into the AMIGA Modeling System
- Calculates direct and total CO_2 emissions