Overview and Special Features of SAGE

System for Analysis of Global Energy markets

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Overview of Previous International Energy Modeling at EIA

World Energy Projection System (WEPS)

- Integrated set of pc-based spreadsheets
- Incorporates projections from independently documented models, and assumptions regarding future energy intensity (E/GDP) trends & the rate of incremental energy requirements met by each fuel type over time
- Used to develop forecasts for the *International Energy Outlook (IEO):*
    - Total energy consumption, by fuel (oil, natural gas, coal, nuclear, renewables)
    - Net electricity consumption
    - Energy consumption for transportation sector, by fuel
    - Energy-related carbon dioxide emissions, by fuel

Overview of SAGE

- 15-region, pc-based, linear programming model of world energy markets
- Developed using MARKAL modeling framework
- User-friendly input structure & output reporting capability
- Projection horizon up to 50 years, in 5-year steps
- Inter-region trade in energy and/or emissions
- Two operational modes: myopic and clairvoyant
- Intended use:
  1) develop set of *International Energy Outlook* forecasts
  2) tool for policy/scenario analysis involving international energy markets

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15 SAGE Country/Region Models

USA
Canada
Mexico
Central & South America
Western Europe
Eastern Europe
Former Soviet Union
China
India
Other Developing Asia
South Korea
Japan
Africa
Middle East
Australia & New Zealand

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Each SAGE Regional Model…

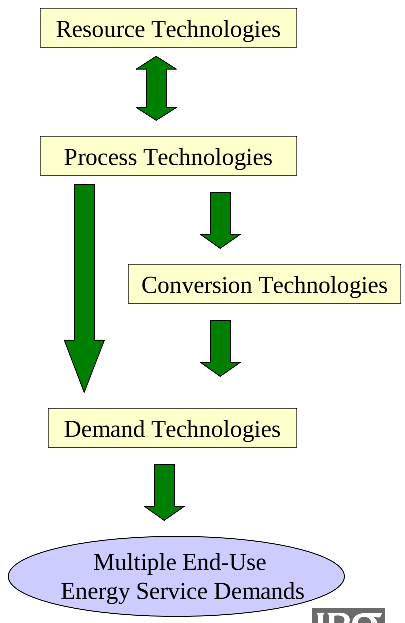
- Depicts a Reference Energy System (RES) for that region
- Employs common naming conventions & units
- Draws from comparable energy and economic/demographic data

    Energy Statistics and Balances (International Energy Agency)
    International Energy Annual (Energy Information Administration)
    World Economic Outlook, World Industry Monitor (DRI/WEFA)
    World Populations, Global Report on Human Settlements (United Nations)

Comprehensive Inputs & Assumptions Templates

RES Building Blocks

1. **Energy Carriers**
   e.g. crude oil
   liquefied petroleum gas
   gasoline
   distillate
   jet fuel
2. **Technologies**
   e.g. extraction
   import
   refining
   electricity generation
   light duty vehicles
   airplanes
   cookstoves
   home heating furnaces
3. **End-Use Energy Service Demands categorized by sector**



End-Use Energy Services Represented in SAGE

Residential Sector (11)
Space Heating (x4)
Space Cooling (x4)
Refrigeration
Water Heating
Cooking (x4)
Lighting (x4)
Clothes Washing
Clothes Drying
Dishwashing
Residential Electric Appliances
Other Residential Energy Services

Commercial Sector (8)
Space Heating (x4)
Space Cooling (x4)
Refrigeration
Water Heating
Cooking
Lighting
Electric Office Equipment
Other Commercial Energy Services

Industrial Sector (6)
Iron & Steel
Non-Ferrous Metals
Chemicals
Non-Metallic Minerals
Pulp & Paper
Other Industries

Transportation Sector (13)
Personal Automobiles
Personal Light Duty Trucks
Buses
Commercial Heavy Trucks
Commercial Medium Trucks
Commercial Light Trucks
Two & Three Wheeled Vehicles
Domestic Aviation
International Aviation
Passenger Rail
Freight Rail
Internal Navigation
International Water Shipping

Agriculture Sector (1)
Total Agriculture Energy Demand

Technology Representation in SAGE

Each technology is described by a set of parameters, including:

Technical Parameters
Efficiency
Availability Factor
Physical Lifetime
Energy Carrier Input & Output Mix
Bound on activity levels or capacity

Economic Parameters
Investment Costs
Fixed O&M Costs
Variable O&M Costs
Discount Rate
Bound on Investment

Environmental Parameters
Emissions factors
Bound on Emissions

SAGE RES Modeling

- Demand drivers vary according to region/country and sector
- Energy Carriers are fixed to the energy balances of each region
- Technologies compete within market share groups
- ADRATIOs control primary splits within groups (e.g., conventional versus alternative vehicles), with additional group ADRATIOs or the market share algorithms guiding final choices within groups; the ADRATIOs are easily constructed by means of functions available in the templates

SAGE Solutions

- Demand-driven or price driven (elastic demands)
- Objective function minimizes discounted energy system costs or maximizes producer/consumer surplus
- Identify least-cost combinations of technologies and fuels for each 5-year solution period, employing either fixed energy service demands, or price-elastic energy service demands*
- Various modes of operation:
  1. Single Region, or Multiple Region* runs
  2. Energy & Emissions Trading*
  3. Dynamic LP (perfect foresight), or Time-Stepped Approach* (imperfect foresight)
- With/without endogenous technology learning
- Market share "control" by means of ADRATIO and/or MKTSHR algorithm

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Time-Stepped Market Share Algorithm

- User input
  - Market identifiers (g), and the list of technologies in each market group
  - "close-enough" criteria, percent of market to reallocated, degree of optimization (γ) for each market group
  - Technology preference factor (defaults to 1)
- Determine the market size as the fraction of each market segment (group) that should be reallocated to marginally uncompetitive technologies
- Solve SAGE for the "reduced costs"
- Use "reduced costs" and "close enough" parameter to determine technologies within each market group that deserve a piece of the market

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Time-Stepped Market Share Algorithm (Cont.)

- Recalculate market shares for technologies that were "close enough," based on their relative economics in their markets
  - Market $Share_j = \alpha_j * abs(\pi_j)^{-\gamma_g} / \{ \Sigma(\alpha_j * abs(\pi_g)^{-\gamma_g})$
    - for each market group g, for each technology j ε "close enough" for said group
    - π_j is the variable's reduced cost of a technology in j
    - γ_g ε (.1, 5) is the degree of optimization within a group, where the larger the γ the more optimizing the choices
    - α_j is a technology preference weighting factor
- If necessary, handle reallocation conflict (where some "close enough" technology would gain a share above the smallest competitive technology)
- Re-solve for the current period with the "close enough" technologies grabbing a share of the market

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Learning-By-Doing
Returns to Adoption

Background

- Learning-by-doing--well documented since 1930's
- Wright (1936) -- direct labor costs of manufacturing an airframe fell by 20% with every doubling of cumulative output
- Subsequent authors broadened analysis of learning to other costs and showed costs declined with experience

Application in SAGE

- Costs decline as the market accumulates operational and manufacturing experience
- Cumulative capacity built is a surrogate for "market experience"
- Credit for international builds

Learning Curves – Electricity Sector

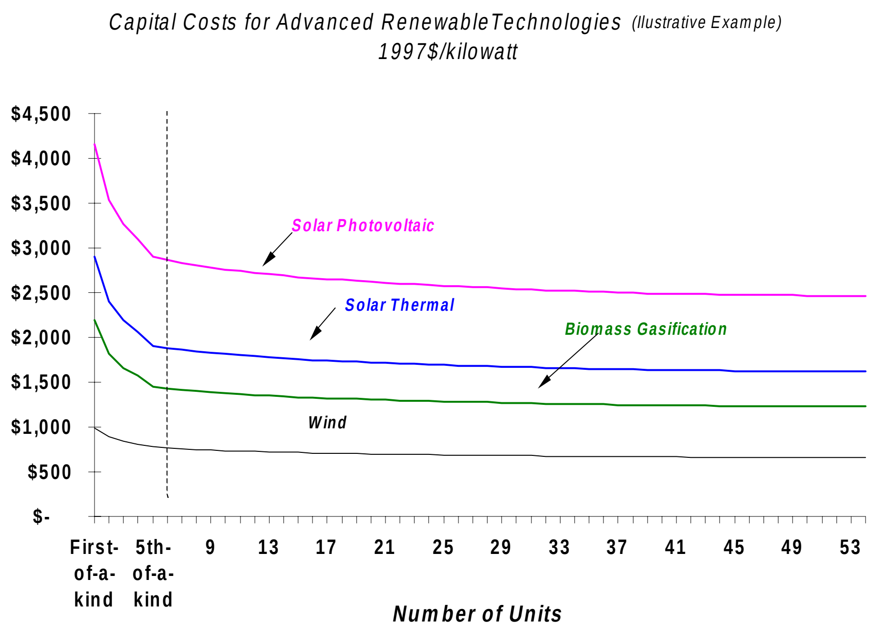
- Three piece-wise non-linear curves for overnight costs, one for each learning interval
- Overnight Cost (C) is a function of Cumulative Capacity (Q)

$$C(Q) = a * Q^{-b}$$

- Progress Ratio (pr) defines the speed of learning: f = % cost decline with doubling of cumulative capacity

$$pr = 2^{-b} = (1 - f)$$

$$b = -\ln(1-f)/\ln(2); \quad a = C(Q_0)/Q_0^{-b}$$



Status of SAGE Development

- ✓ Proof of Concept has been completed and tested for 15 regions
- ✓ User interface software for front-end (inputs & assumptions) and back-end (results & analysis) has been developed
- ✓ Internal review and adjustment of inputs and assumptions is underway (transportation sector for all regions is close to final for all 15 regions; other sectors are being enhanced simultaneously) – expected completion by this fall
- ✓ Initial market share algorithm for the time-stepped version has been implemented and will be extensively tested over next few months
- ➢ Energy and emissions trading to be implemented and tested over the next few months
- ➢ Learning Curve structure to be implemented and tested by this fall
- ➢ Anticipate using SAGE for *IEO2003* and policy analysis thereafter
- ➢ Additional enhancements to the formulation anticipated (e.g., expectation, multi-sector economic linkages)

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