Energy Statistics & Forecasting

Dr. Fahad Noor
Assosciate Professor
f.noor@uet.edu.pk

Engr. Adnan Qamar
Lecturer
adnan@uet.edu.pk

Integrated Energy-Environment Modeling and LEAP

Why Use a Model?

- Reflects complex systems in an understandable form.
- Helps to organize large amounts of data.
- Provides a consistent framework for testing hypotheses.

Scope of Energy Policy Models

- Energy System Models
  - Attempt to capture behavior of an entire energy system (e.g., a state, nation, region or the globe). Macroeconomic trends drive the model
- Energy Economy Models
  - Attempt to capture impact of energy system on the wider economy.
- Partial System Models
  - E.g. sectoral models, lifecycle tools, facility siting tools, etc.

A Taxonomy of Energy Policy Models

- Optimization Models
  - Typically used to identify least-cost configurations of energy systems based on various constraints (e.g. set policy goals, a CO_2 emissions target)
  - Selects among technologies based on their relative costs.
- Simulation Models
  - Simulate behavior of consumers and producers under various signals (e.g. prices, incomes, policies). May not be “optimal” behavior.
  - Typically uses iterative approach to find market clearing demand-supply equilibrium.
- Accounting Frameworks
  - Rather than simulate the behavior of a system in which outcomes are unknown, instead asks user to explicitly specify outcomes
  - Main function of these tools is to manage data and results
- Hybrids Models combining elements of each approach.

Optimization Models

- **Pros:**
  - Powerful & consistent approach for a common type of analysis called **Backcasting**. e.g. What will be the costs of meeting a certain policy goal?
  - Especially useful where many options exist. E.g. : What is the least cost combination of efficiency, fuel switching, pollution trading, scrubbers and low sulfur coal for meeting a SOx emissions cap?
- **Cons:**
  - Questionable fundamental assumption of perfect competition (e.g., no monopolistic practices, no market power, no subsidies, all markets in equilibrium).
  - Not well suited to simulating how systems behave in the real world.
  - Assumes energy is only factor in technology choice.
  - Not well suited to examining policy options that go beyond technology choice, or hard-to-cost options. E.g. *To reduce CO_2 you can either (a) use a large hybrid car, or (b) drive a smaller car.*
  - Relatively complex, opaque and data intensive: hard to apply for less expert users, so less useful in capacity building efforts.

Simulation Models

- Simulate behavior of energy consumers and producers under various signals (e.g. price, income levels, limits on rate of stock turnover).
- Pros:
  - Not limited by assumption of “optimal” behavior. (any option can be chosen
  - Do not assume energy is the only factor affecting technology choice (e.g. BALANCE uses a market share algorithm based on price and “premium multipliers” indicating quality of energy services).
- Cons:
  - Tend to be complex and data intensive.
  - Behavioral relationships can be controversial and hard to parameterize.
  - Future forecasts can be very sensitive to starting conditions and parameters.
- Energy 2020

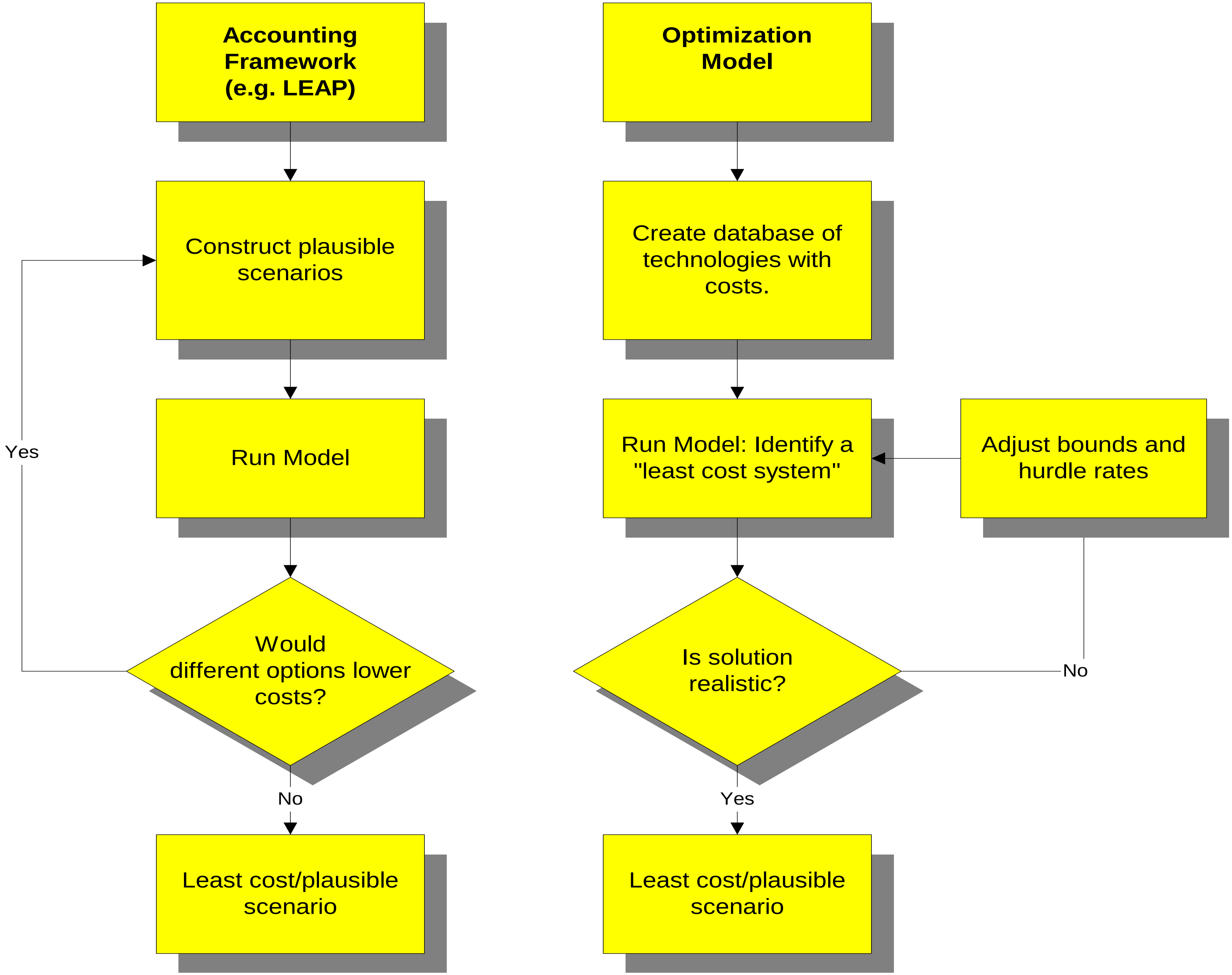
Accounting Frameworks (1)

- Physical description of energy system, costs & environmental impacts
- Rather than simulating <u>decisions</u> of energy consumers and producers, modeler explicitly accounts for <u>outcomes of decisions</u> *So instead of calculating market share based on prices and other variables, Accounting Frameworks simply examine the implications of a scenario*
- Explores the resource, environment and social cost implications of alternative future “what if” energy scenarios.
- **Example:** “What will be the costs, emissions reductions and fuel savings if we invest in more energy efficiency & renewables vs. investing in new power plants?”
- Examples: Long range energy alternative planning system (LEAP), Model for analysis energy demand (MAED)

Accounting Frameworks (2)

- Pros:
  - Simple, transparent & flexible, lower data requirements
  - Does not assume perfect competition.
  - Capable of examining issues that go beyond technology choice or are hard to cost.
  - Especially useful in capacity building applications.
- Cons:
  - Does not automatically identify least-cost systems: less suitable where systems are complex and a least cost solution is needed.

Accounting Frameworks and Optimizing Models in Practice



Hybrid Models

- Current generation models combine elements of optimization, simulation and accounting:
  - LEAP operates at two levels: basic accounting relationships are built-in and users can add their own simulation models on top.
  - The U.S. National Energy Modeling System (NEMS) includes optimization modules for the electricity sector, along with simulation approaches for each demand sector, all packaged together into a general equilibrium system.

Models vs. Decision Support Systems

- Model methodology is only one issue for analysts, planners and decision makers.
- They also require the full range of assistance provided by decision support systems including: data and scenario management, reporting, units conversion, documentation, and online help and support.
- Some modern tools such as LEAP focus as much on these aspects as on the modeling methodology.

LEAP
Long range Energy Alternatives Planning System

- **Key Characteristics:** accounting framework, user-friendly, scenario-based, integrated energy-environment model-building tool.
- **Scope:** energy demand, energy supply, resources, environmental loadings, cost-benefit analysis, non-energy sector emissions. Most aspects optional.
- **Flexible Approach to Modeling:** basic relationships are all based on non-controversial physical accounting. Also allows for spreadsheet-like “expressions”, for the creation of econometric and simulation models.
- **Time:** medium to long-term, annual time-step, unlimited number of years.
- **Data requirements:** flexible, low initial data requirements.   Includes *TED* database, with technical characteristics, costs and emission factors of ~ 1000 energy technologies.
- **Geographic Applicability:** local, national, regional.

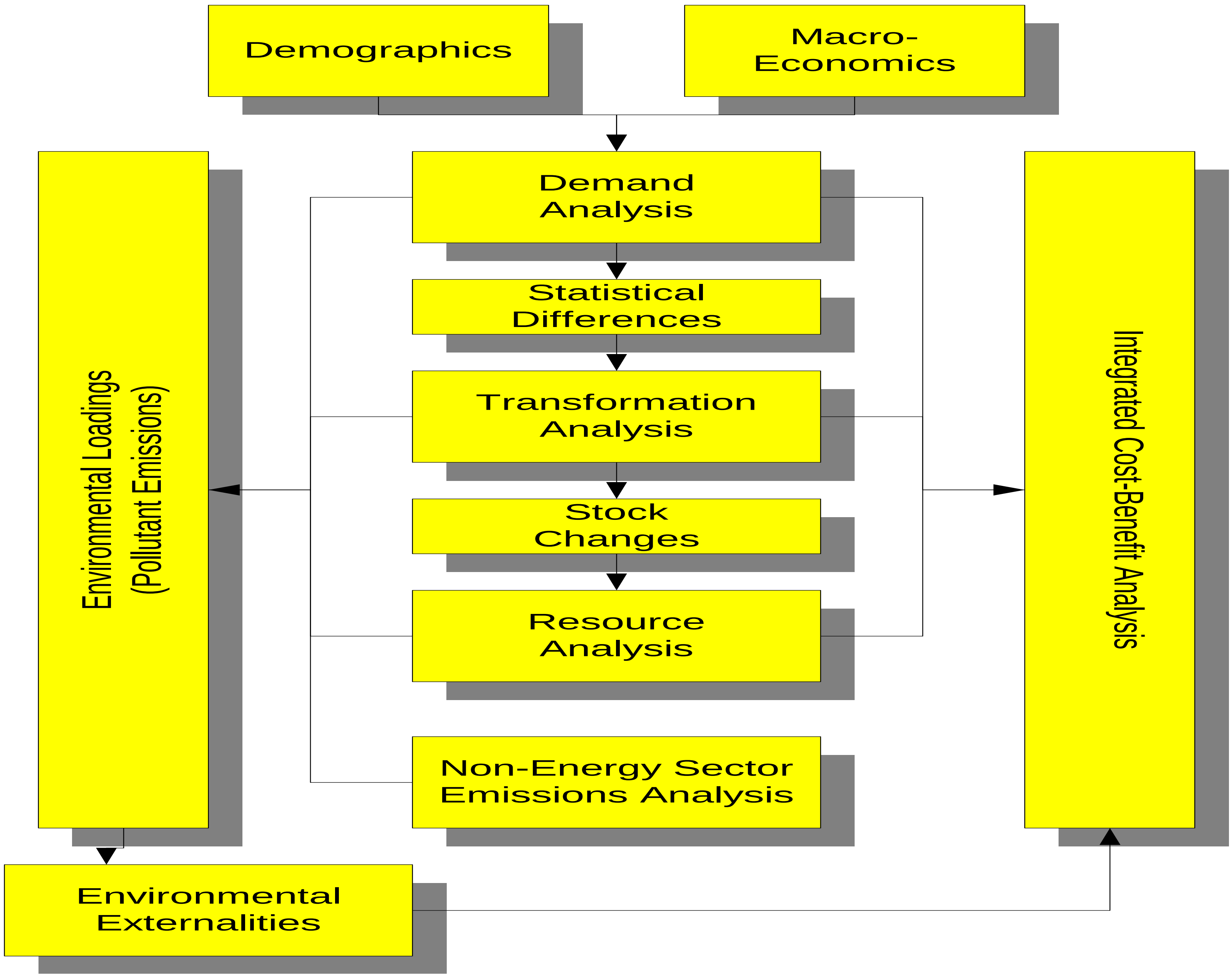
What Can You Do With LEAP?

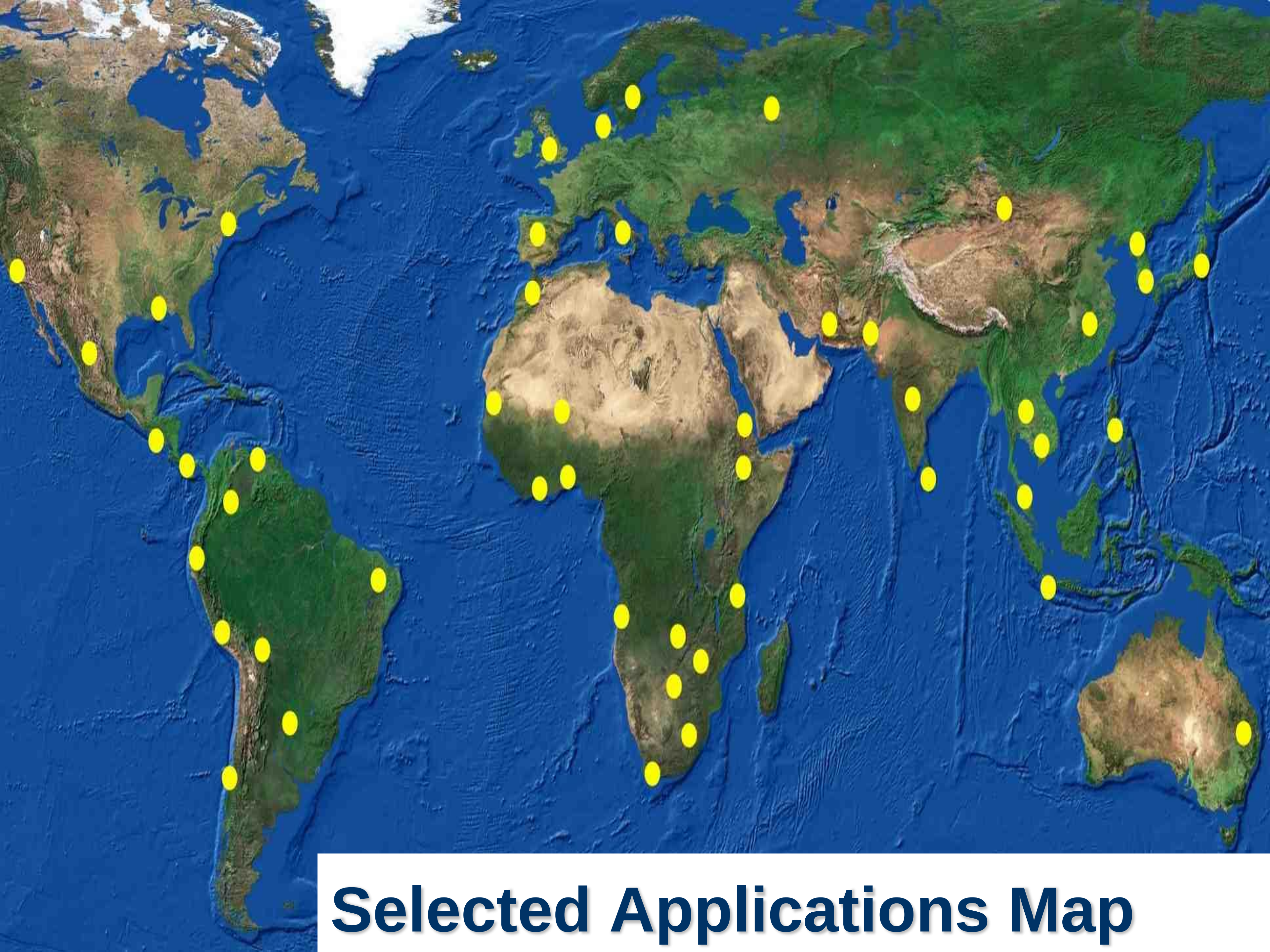
- Tool for Strategic Integrated Energy-Environment Scenario Studies:
  - Energy Outlooks (forecasting)
  - Integrated Resource Planning.
  - Greenhouse gas mitigation analysis.
  - Energy balances and environmental inventories.

LEAP Modeling Capabilities

- **Energy Demand**
  - Hierarchical accounting of energy demand (activity levels x energy intensities).
  - Choice of methodologies.
  - Optional modeling of stock turnover.
- **Energy Conversion**
  - Simulation of any energy conversion sector (electric generation, transmission and distribution, CHP, oil refining, charcoal making, coal mining, oil extraction, ethanol production, etc.)
  - Electric system dispatch based on electric load-duration curves.
  - Exogenous and endogenous modeling of capacity expansion.
- **Energy Resources:**
  - Tracks requirements, production, sufficiency, imports and exports.
  - Optional land-area based accounting for biomass and renewable resources.
- **Costs:**
  - All system costs: capital, O&M, fuel, costs of saving energy, environmental externalities.
- **Environment**
  - All emissions and direct impacts of energy system.
  - Non-energy sector sources and sinks.

LEAP Calculation Flows





Selected Applications Map

Selected Applications

- **Energy and Carbon Scenarios:** U.S. National Labs, Chinese Energy Research Institute (ERI).
- **Model of U.S. Light Duty Vehicle Energy Use and Emissions:** for ACEEE, UCS and the Energy Foundation.
- **Envisioning a Hydrogen Economy in 7 U.S. Cities:** for NREL.
- **Multi-stakeholder Greenhouse Gas Action Plan:** Rhode Island, DEM.
- **Greenhouse Gas Abatement Studies**: Argentina, Bolivia, Cambodia, Ecuador, El Salvador, Lebanon, Mali, Mongolia, Korea, Senegal, Tanzania, etc.
- **APERC Energy Outlook:** energy forecasts for each APEC economy.
- **East Asia Energy Futures Project**: Nautilus Institute, various institutes from East Asian countries including the Koreas, China, Mongolia, Russia, Japan.
- **Rural Wood Energy Planning in South Asia**: FAO-RWEDP.
- **Integrated Resource Planning:** Malaysia, Indonesia, Ghana.
- **Transportation in Asian Cities:** AIT, Thailand.
- **Integrated Transportation Study**: Texas
- **Sulfur Abatement Scenarios for China:** Chinese EPA/UNEP.
- **Global Energy Studies** Tellus Institute & Greenpeace.
- **“America’s Energy Choices”** Tellus and UCS.

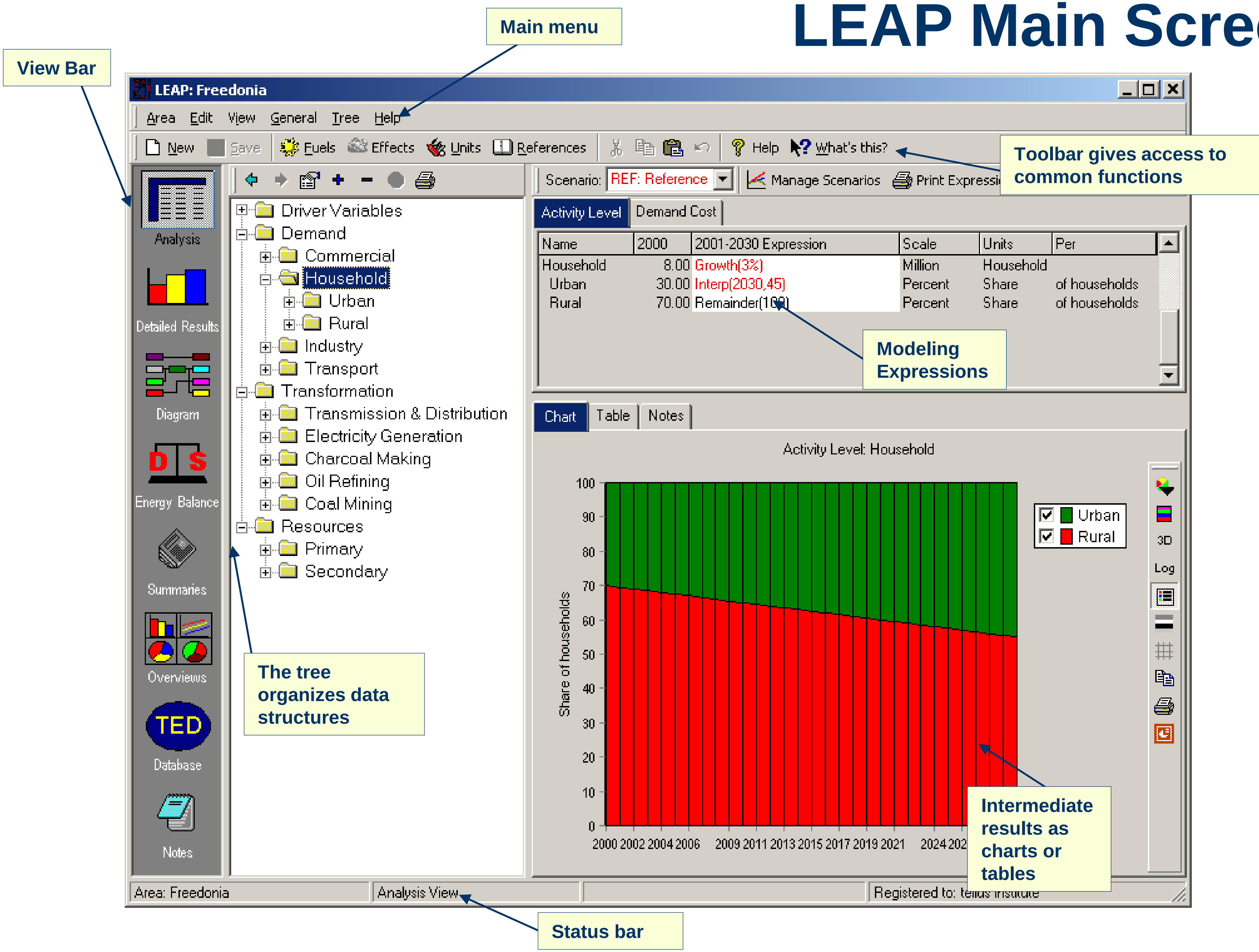
Minimum Hardware/Software Requirements

- Windows 98 or later
- 400 Mhz Pentium PC
- 64 MB RAM
- Internet Explorer 4.0 or later
- Minimum screen resolution: 800 x 600
- Optional: Internet connection, Microsoft Office

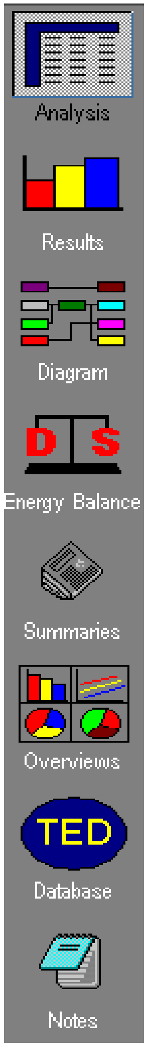
Status and Dissemination

- Available at no charge to qualified institutions based in developing countries.
- Download from http://www.seib.org/leap
- Support at leap@tellus.org
- User name and password required to fully enable software. Available on completion of license agreement.

LEAP Main Screen



The View Bar



Analysis View: where you create data structures, enter data, and construct models and scenarios.

Results View: where you examine the outcomes of scenarios as charts and tables.

Diagram View: “Reference Energy System” diagram showing flows of energy in the area.

Energy Balance: standard table showing energy production/consumption in a particular year.

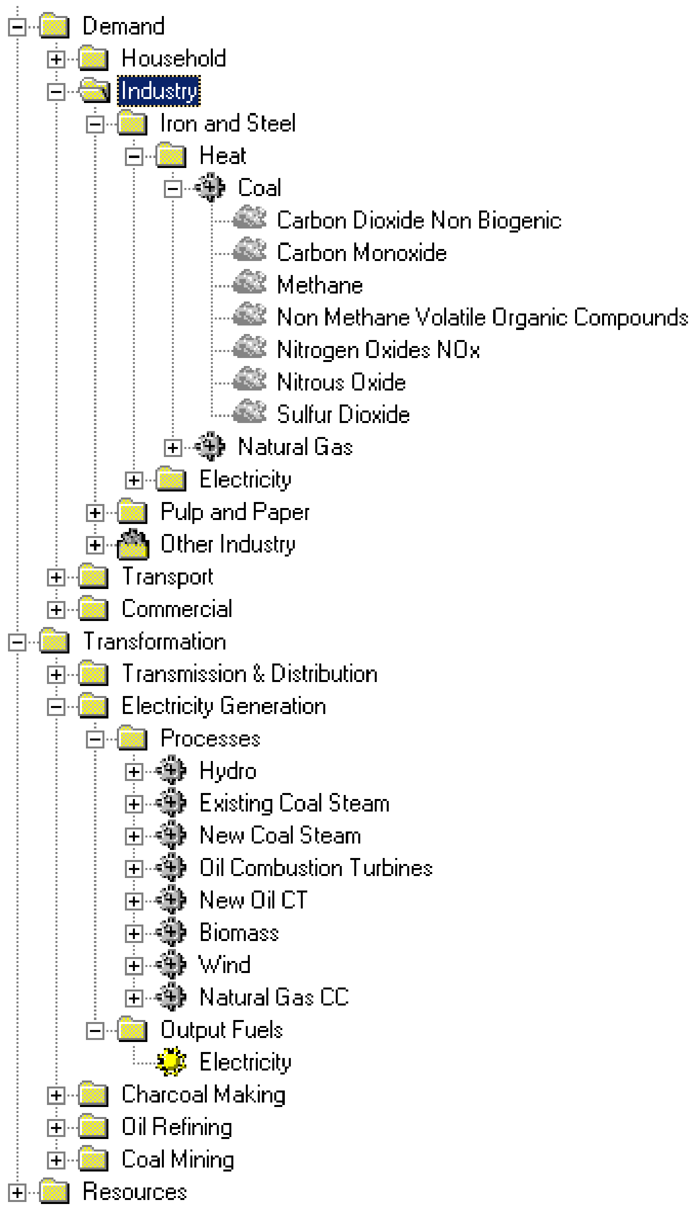
Summary View: cost-benefit comparisons of scenarios and other customized tabular reports.

Overviews: where you group together multiple “favorite” charts for presentation purposes.

TED: Technology and Environmental Database – technology characteristics, costs, and environmental impacts of apx. 1000 energy technologies.

Notes: where you document and reference your data and models.

The Tree



- The main data structure used for organizing data and models, and reviewing results
- Icons indicate types of data (e.g., categories, technologies, fuels and effects)
- User can edit data structure.
- Supports standard editing functions (copying, pasting, drag & drop of groups of branches)

Modeling at Two levels

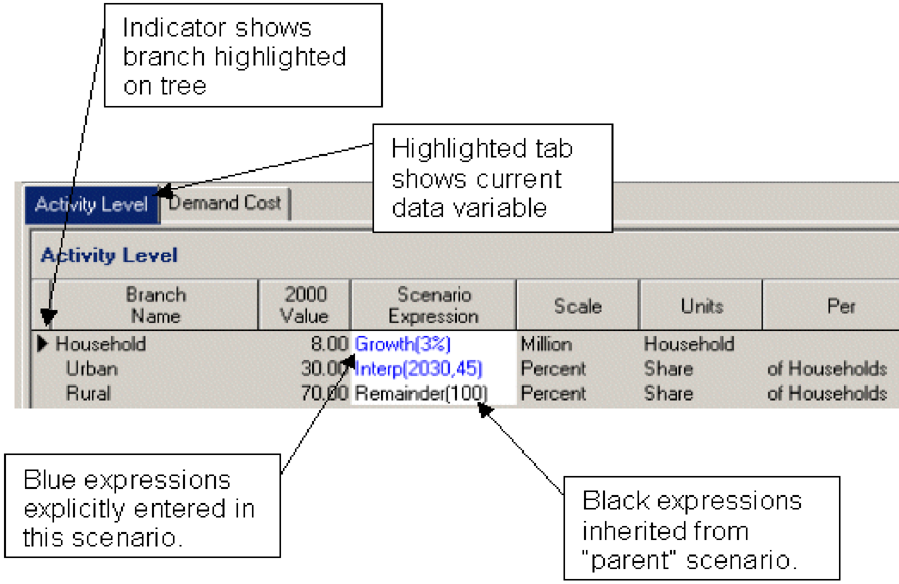
1. Basic physical accounting calculations handled internally within software (stock turnover, energy demand and supply, electric dispatch and capacity expansion, resource requirements, costing, pollutant emissions, etc.).
2. Additional modeling can be added by the user (e.g. user might specify market penetration as a function of prices, income level and policy variables).
   - Users can specify spreadsheet-like expressions that define data and models, describing how variables change over time in scenarios:
   - Expressions can range from simple numeric values to complex mathematical formulae. Each can make use of
     1. math functions,
     2. values of other variables,
     3. functions for specifying how a variable changes over time, or
     4. links to external spreadsheets.

Examples of Expressions

Simple Number	3.1415927
Growth Rate	Growth(3%) Growth(3%, 2010, 2%)
Interpolation: straight-line changes between pairs of data years and values.	Interp(2000, 100, 2010, 120, 2020, 200)
Step: discrete changes between pairs of data years and values.	Step(2000, 100, 2010, 120, 2020, 200)
Remainder: calculates remaining balance between parameter and values of neighboring branches.	Remainder(100)

Editing of Expressions

- Four ways to edit expressions:
  - **Typing** directly in the expression fields in the Analysis View (see right).
  - **Selecting a function** (*Interp*, *Growth*, *Remainder,* etc.*)* from pop-ups attached to expressions.
  - **Using the Time-Series Wizard** to graphically enter time-series functions or link to Excel sheets.
  - **Using the Expression Builder**: a general purpose drag & drop tool for creating expressions.

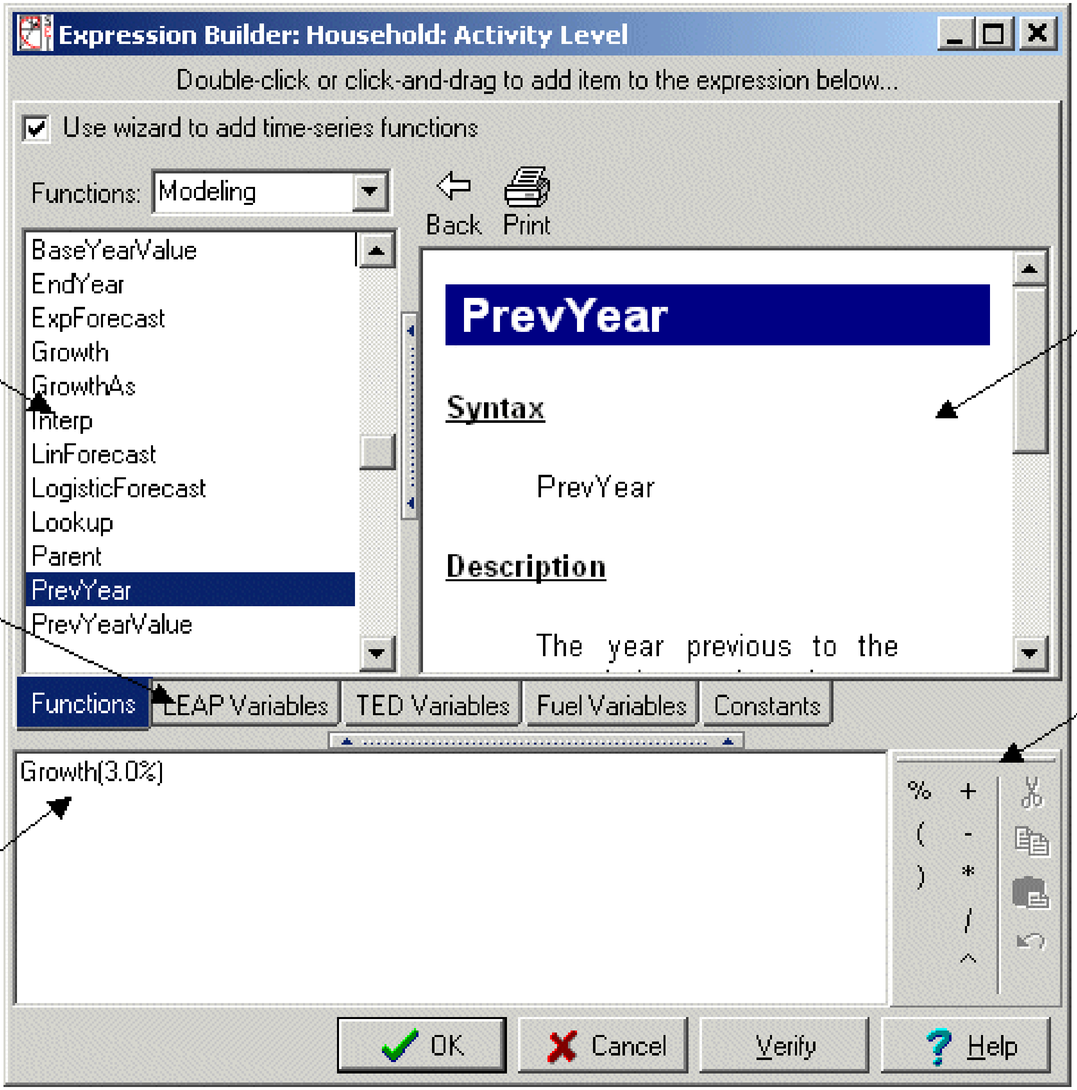


The Expression Builder

Double-click here or drag-and-drop to add a function to the edit box

Click tabs to show functions, variables, constants and other items that can be included in expressions

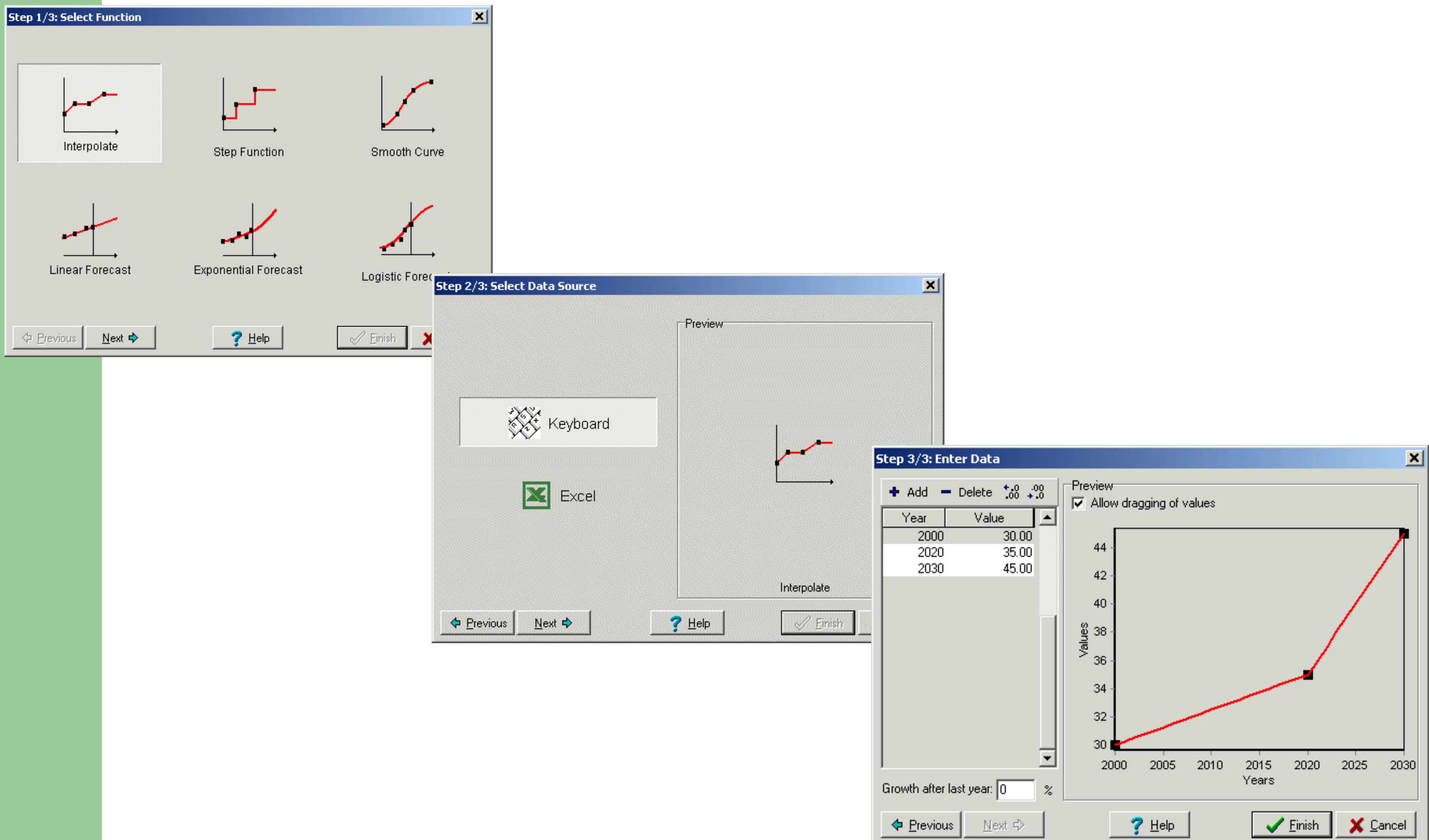
Type here to edit an expression



Each function is documented

Toolbar gives quick access to math operators and clipboard functions

The Time-Series Wizard

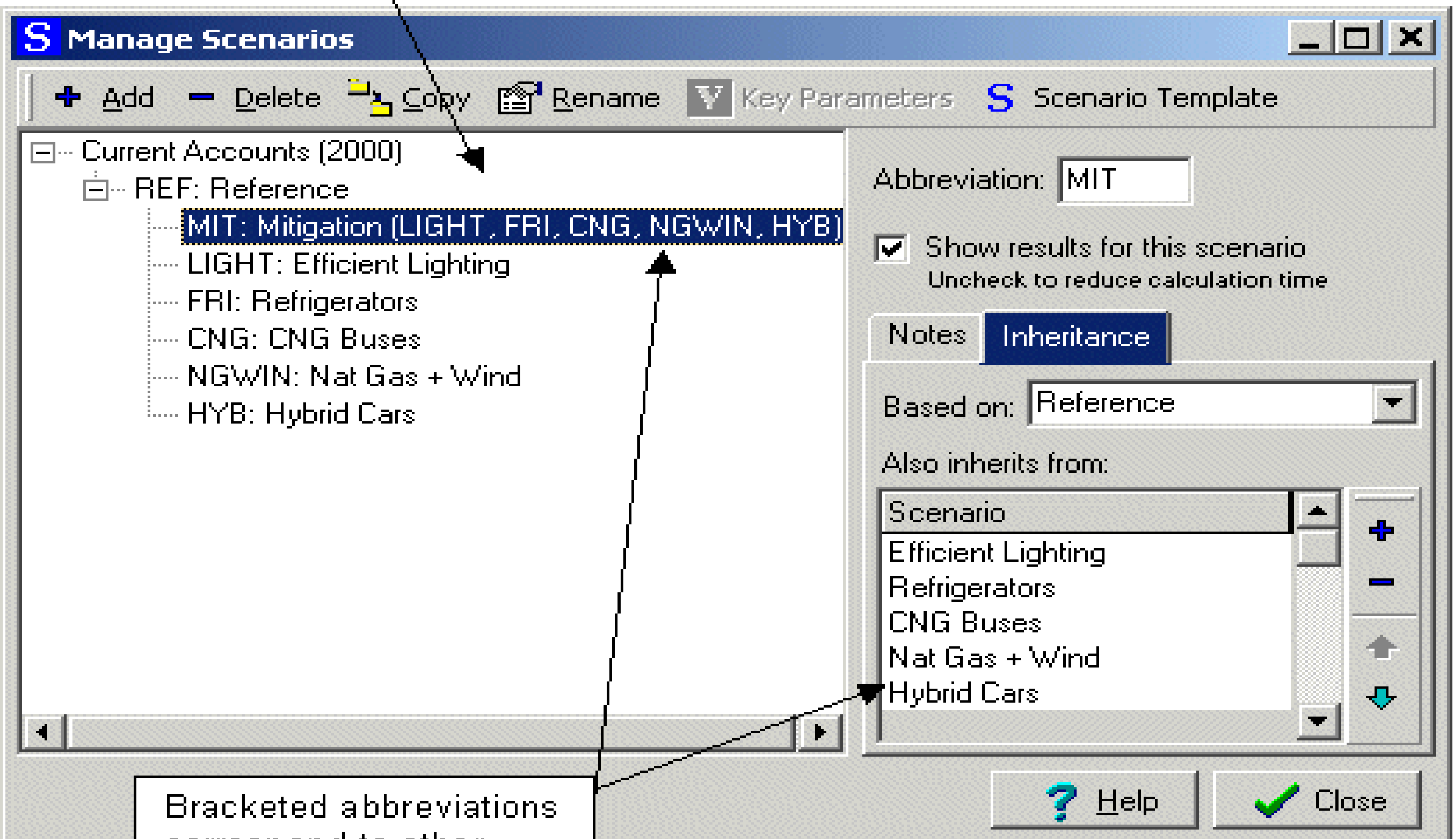


Scenarios in LEAP

- Self-consistent story-lines of how an energy system might evolve over time in a particular socio-economic setting and under a particular set of policy conditions.
- *Inheritance* allows you to create hierarchies of scenarios that inherit default expressions from their parent scenario.
- All scenarios ultimately inherit from *Current Accounts* minimizing data entry and allows common assumptions in families of scenarios to be edited in one place.
- *Multiple inheritance* allows scenarios to inherit expressions from more than parent scenario. Useful for examining individual policy measures, which can then be combined to create integrated scenarios.
- The LEAP Scenario Manager is used to organize scenarios and specify multiple inheritance.
- In the Analysis View, expressions are color coded to show which expressions have been entered explicitly in a scenario (blue), and which are inherited from a parent scenario (black).

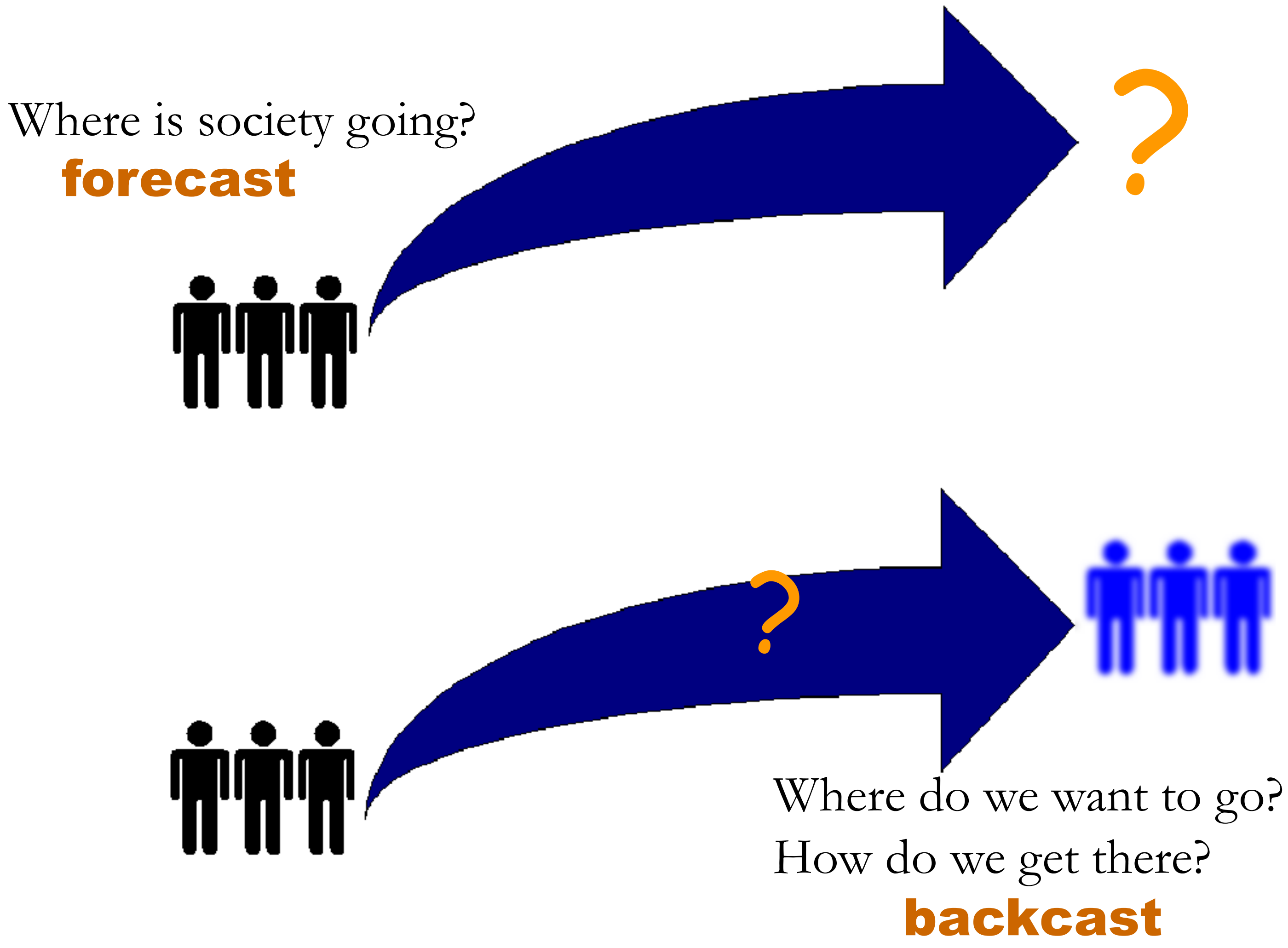
The Scenario Manager

Tree shows main scenario inheritance structure



Bracketed abbreviations correspond to other inherited scenarios.

Forecasting & Backcasting



Simple Energy Demand Analysis in LEAP

- Identify the socio-economic activities that “drive” the consumption of energy.
- Organize structure of energy consumption into a hierarchical “tree”.
    - Example: Sectors, Subsectors, End-Uses, Fuels/Device
- Typically, specify overall activity levels at top of tree.
    - Example: total number of households, industrial value added, etc.
- Disaggregate total activities down to lower levels of the tree. (e.g. 30% of households are urban, and of these 45% have refrigerators).
- At lowest levels in tree, specify the fuels consumed by each device and assign an annual energy intensity (e.g. 10 GJ/household for cooking with LPG stoves).

Demand Modeling Methodologies (1)

1. Final Energy Analysis: $e = a \times i$
   - Where e=energy demand, a=activity level, i=final energy intensity (energy consumed per unit of activity)
   - **Example:** energy demand in the cement industry can be projected based on tons of cement produced and energy used per ton. *Each can change in the future.*
2. Useful Energy Analysis: $e = a \times (u / n)$
   - Where u=useful energy intensity, n = efficiency
   - Example: energy demand in buildings will change in future as (1) more buildings are constructed [+a] (2) people get richer and heat and cool buildings more [+u], or building insulation improves [-u], or as people switch from less efficient oil boilers to electricity or natural gas [+n].

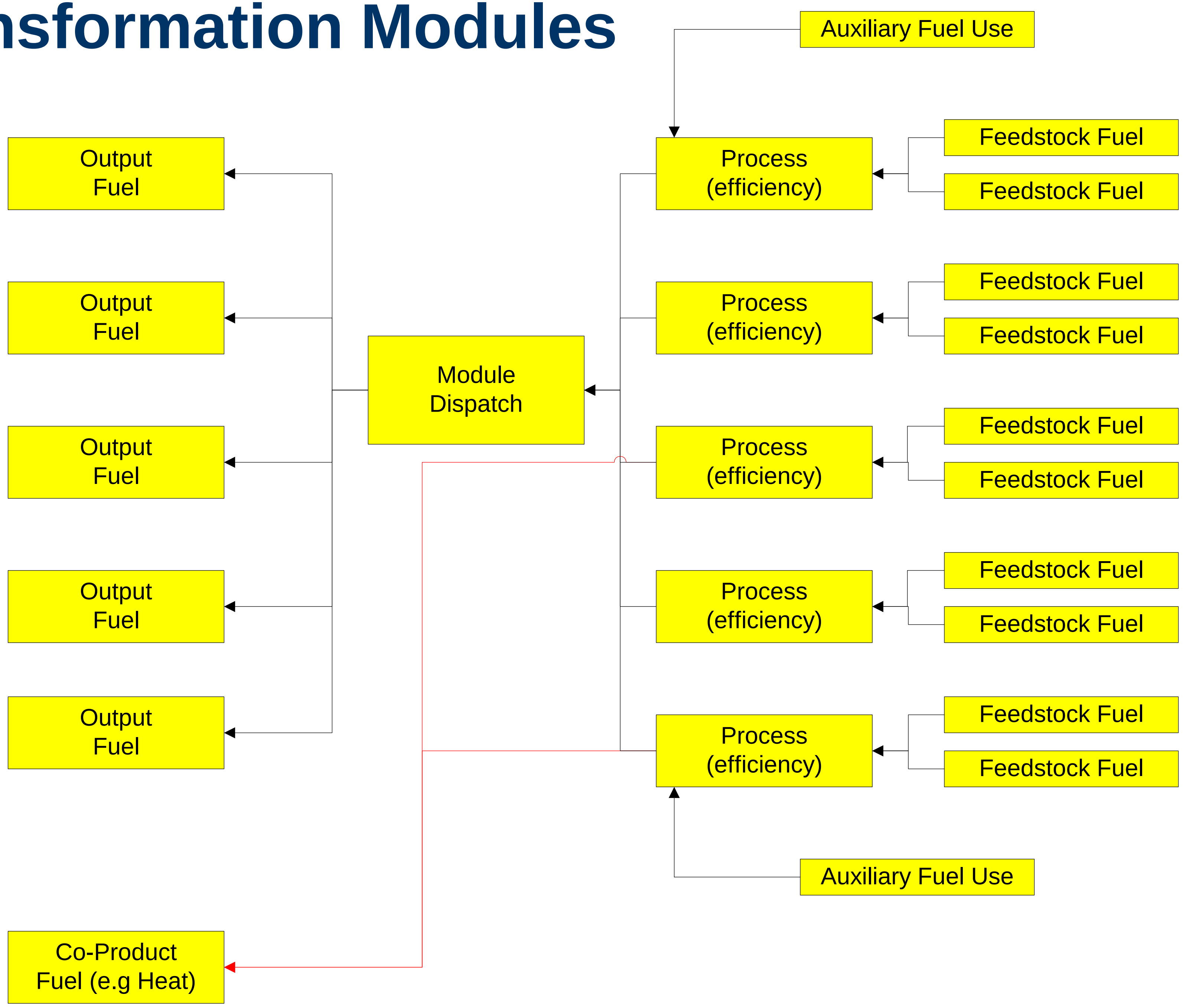
Demand Modeling Methodologies (2)

3. Stock Analysis: $e = s \times d$
   - Where s=stock, d=device intensity (energy use per device). Stock is modeled endogenously based on existing vintage of devices, sales of new devices and survival profile for devices.
   - Example: how quickly will a new energy efficiency standard for refrigerators lead to energy savings based on penetration of new devices and turnover of existing stock?
4. Transport Analysis: $e = s \times m / fe$
   - Where m = vehicle miles, fe = fuel economy (MPG)
   - Allows modeling of vehicle stock turnover.
   - Also allows pollutant emissions to be modeled as function of vehicle miles
   - Example: model impact of new vehicle fuel economy (CAFÉ) or emissions standards.

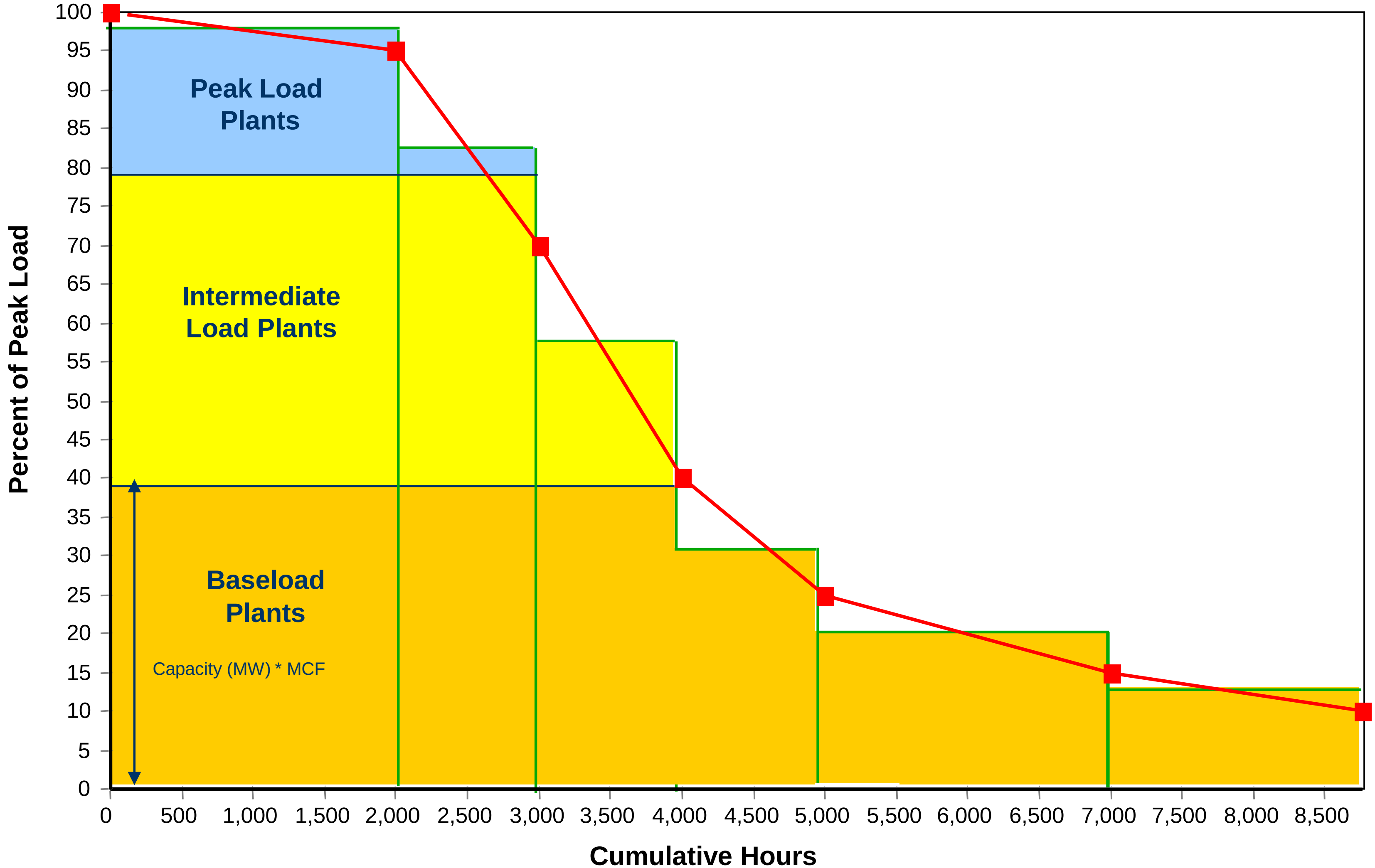
Transformation Analysis

- Scope: energy conversion, transmission and distribution, resource extraction.
- Demand-driven engineering-based simulation (no supply-demand feedback).
- Two level hierarchy: “modules” (sectors), each containing one or more “processes”.
- Optional system load data, & choice of methods for simulation of dispatch to meet peak power requirements.
- Exogenous and/or endogenous capacity expansion, Endogenous capacity added in scenarios to maintain planning reserve margin. Optional supply curves.
- Calculates imports, exports and primary resource requirements.
- Tracks costs and environmental loadings.

Transformation Modules



Load Curves and Electric Dispatch



Social Cost-Benefit Analysis in LEAP

- Societal perspective of costs and benefits (i.e. economic not financial analysis).
- Avoids double-counting by drawing boundary around analysis.
- User specifies boundary (e.g. whole system including resource costs, or partial system and costs of fuels delivered to a module).
- Cost-benefit analysis calculates the Net Present Value (NPV) of the differences in costs between scenarios.
- NPV sums all costs in all years of the study discounted to a common base year.
- Optionally include externality costs.

Demand
(costs of saved energy, device costs, other non-fuel costs)

Transformation
(Capital and O&M costs)

Primary Resource Costs
or
Delivered Fuel Costs

Environmental Externality Costs

Simple Example of Cost-Benefit Analysis

Two scenarios for meeting future growth in electricity lighting demand:

1. **Base Case**
   - **Demand:** future demand met by cheap incandescent bulbs.
   - **Transformation:** growth in demand met by new fossil fired generating capacity.

2. **Alternative Case**
   - **Demand:** DSM programs increase the penetration of efficient (but more expensive) fluorescent lighting.
   - **Transformation:** Slower growth in electricity consumption and investments to reduce transmission & distribution losses mean that less generating capacity is required.

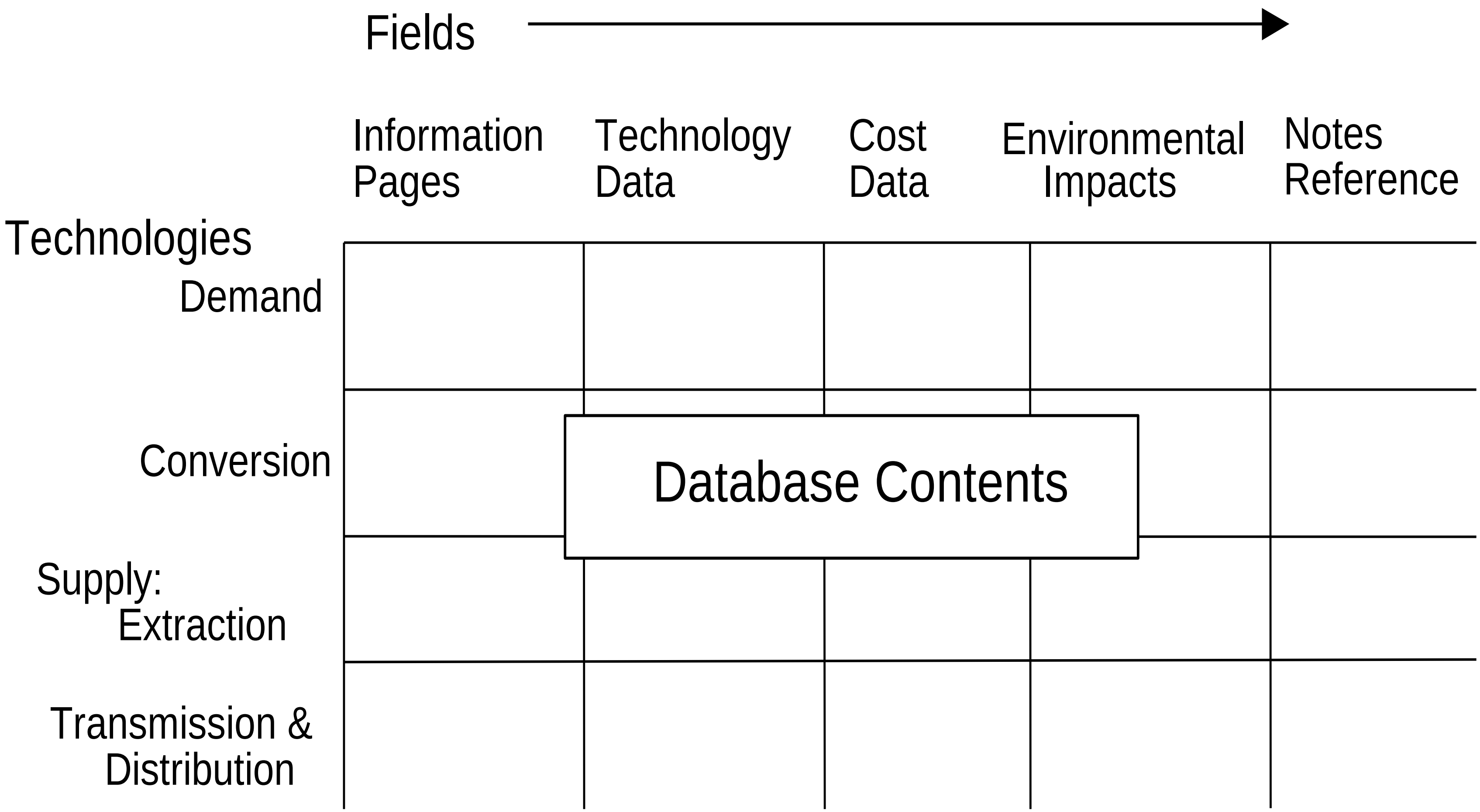
Simple Cost-Benefit Analysis (cont.)

- **<u>The Alternative Case…</u>**
- uses more expensive (but longer lived) lightbulbs.
  - *Result: depends on **costs**, lifetimes, & discount rate*
- requires extra capital and O&M investment in the electricity transmission & distribution system.
  - *Result: net cost*
- requires less generating plants to be constructed (less capital and O&M costs).
  - *Result: net benefit*
- requires less fossil fuel resources to be produced or imported.
  - *Result: net benefit*
- produces less emissions (less fuel combustion).
  - *Result: net benefit (may not be valued)*

TED: Technology and Environmental Database

- Quantitative Data: technology characteristics, costs, and environmental impacts of energy technologies.
- Qualitative Data: Guidance on matching technologies to requirements through web-based “information pages”.

TED Structure



Typical Data Requirements

<u>Macroeconomic Variables</u>	
Sectoral driving variables	GDP/value added, population, household size
More detailed driving variables	Production of energy intensive materials (tonnes or $ steel); transport needs (pass-km, tonne-km); income distribution, etc.
<u>Energy Demand Data</u>	
Sector and subsector totals	Fuel use by sector/subsector
End-use and technology characteristics by sector/subsector	a) Usage breakdown by end-use/device: new vs. existing buildings; vehicle stock by type, vintage; or simpler breakdowns; b) Technology cost and performance
Price and income response (optional)	Price and income elasticities
<u>Energy Supply Data</u>	
Characteristics of energy supply, transport, and conversion facilities	Capital and O&M costs, performance (efficiencies, capacity factors, etc.)
Energy supply plans	New capacity on-line dates, costs, characteristics;
Energy resources and prices	Reserves of fossil fuels; potential for renewable resources
<u>Technology Options</u>	
Technology costs and performance	Capital and O&M costs, foreign exchange, performance (efficiency, unit usage, capacity factor, etc.)
Penetration rates	Percent of new or existing stock replaced per year
Administrative and program costs	
Emission Factors	Emissions per unit energy consumed, produced, or transported.

Terminology

- Area: the system being studied (e.g. country or region).
- Current Accounts: the data describing the Base Year (first year) of the study period.
- Scenario: one consistent set of assumptions about the future, starting from the Current Accounts. LEAP can have any number of scenarios. Typically a study consists of one baseline scenarios (e.g. business as usual) plus various counter-factual policy scenarios.
- Tree: the main organizational data structure in LEAP – a visual tree similar to the one used in Windows Explorer.
- Branch: an item on the tree: branches can be organizing categories, technologies, modules, processes, fuels and independent “driver variables”, etc.
- Variable: data at a branch. Each branch may have multiple variables. Types of variables depend on the type of branch, and its properties.
- Disaggregation: the process of analyzing energy consumption by breaking down total demand into the various sectors, subsectors, end-uses and devices that consume energy.
- Expression: a mathematical formula that specifies the values of a variable over time at a given branch and for a given scenario. Expressions can be simple values, or mathematical formula that yield different results in different years.
- Share: (>= 0% and <= 100%). The value of neighboring demand branches with “share” units (activity share or fuel share) , which must sum to 100%.
- Saturation: (>= 0% and <= 100%). The % penetration of a particular activity. The value of neighboring demand branches with “saturation” units need not sum to 100%. (e.g. % saturation of households with a given cooking device: one household may have > 1 device)

Thank You