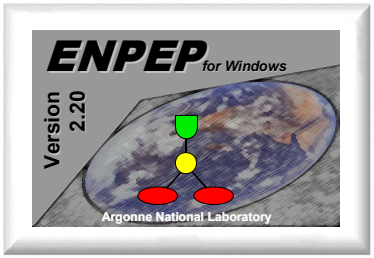
Developing an Energy Supply and Demand Network: Demand Side

ENPEP-BALANCE Training Course
Singapore
December 5-9, 2011



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ENERGY DEMAND

What is Energy Demand?

- "Energy Demand" is the amount of energy needed to meet the demand for energy-related services

- To understand energy demand, we have to analyze and understand the demand for energy services

What is Energy Demand?

- Example: User needs light to read by
  - User buys electricity to power a light bulb
- Example: User needs steam for an industrial process
  - User buys fuel oil to burn in a boiler to generate steam
- Example: User wants to travel from one place to another
  - User buys gasoline to put in an automobile

The Service Need Creates the Demand for Energy: The Service is what People Want, NOT the Fuel

Cooking

Air Conditioning

Space heating

Water heating

Lighting

Appliances

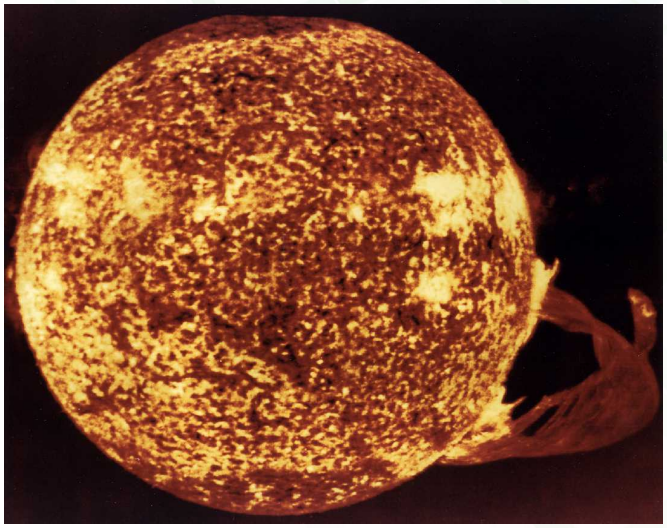
Example for a Current Energy Service Need: Transportation

In one year, what distance did all people in the U.S. combined travel by car in 2004?

2.652 trillion miles or 4.267 trillion km[1]

Equal to about 107 million trips around the world

Equal to about 8,890 roundtrips from the earth to the sun and back



[1] Source: DOE-EIA, AEO 2006

The Consumer Makes a Different Energy Demand Choices

- How much service will I use?
  - How much cooking will I do
  - How much hot water will I use
  - How warm (cool) will I make my home

- What will I use to provide the service?
  - Kerosene, gas, or electric stove
  - Oil, gas, or electric space heater
  - High or low efficiency equipment

There are Many Factors That Determine the Choices Made by Consumers

- Cost of service
- Cost of equipment (capital, operating)
- Availability of alternatives
- Convenience
- Personal preference

Important: Not all consumers make the same choice!!

An Energy Demand Network Must Do the Following

- Display the choices that consumers have made today
- Display the possible choices they may have in the future
- ***ENERGY CONSUMPTION*** is the energy purchased by consumers
  - measured in physical units: tonnes of coal, liters of gasoline, cubic meters of natural gas, kilowatt-hours of electricity
- ***USEFUL ENERGY DEMAND*** is the energy service that the consumer receives
  - residential space heat, industrial process steam, passenger-km traveled

Useful Energy Demand in Residential Sector

Useful energy demand
34.2 GJ low-temperature heat

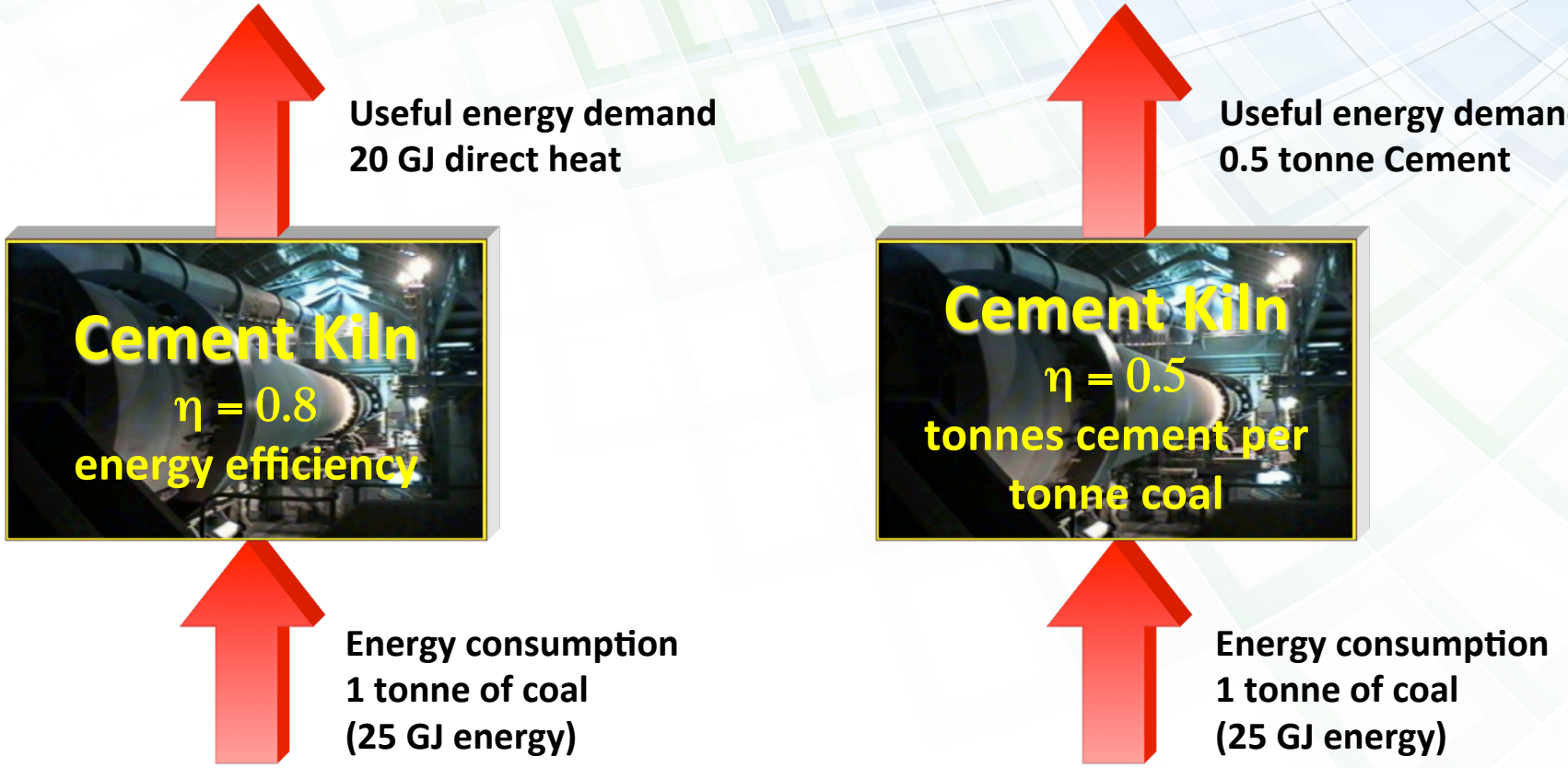
Energy consumption
1 m^3 of natural gas
(38 MJ energy)

Useful Energy Demand in Transportation Sector: UED May not Be an Energy Unit

Useful energy demand
150 km of travel
(with 4 people in the car, you would have 600 passenger-km)

Energy consumption
10 liters of gasoline
(300 MJ energy)

Useful Energy Demand in Industry: In Some Representations, UED May not be an Energy Unit



The First Step in Developing a Demand Network is to Select the Demand Sectors

The Consumption by Each Sector Must be Shown, Including Base Year Energy Flows and Prices

600

400

500

1100

1400

2000

Note: Energy Units Are User-Defined (can be any unit)

$80/boe

1000 kboe

Electricity

$60/boe

3000 kboe

Diesel

$75/boe

2000 kboe

Jet Fuel

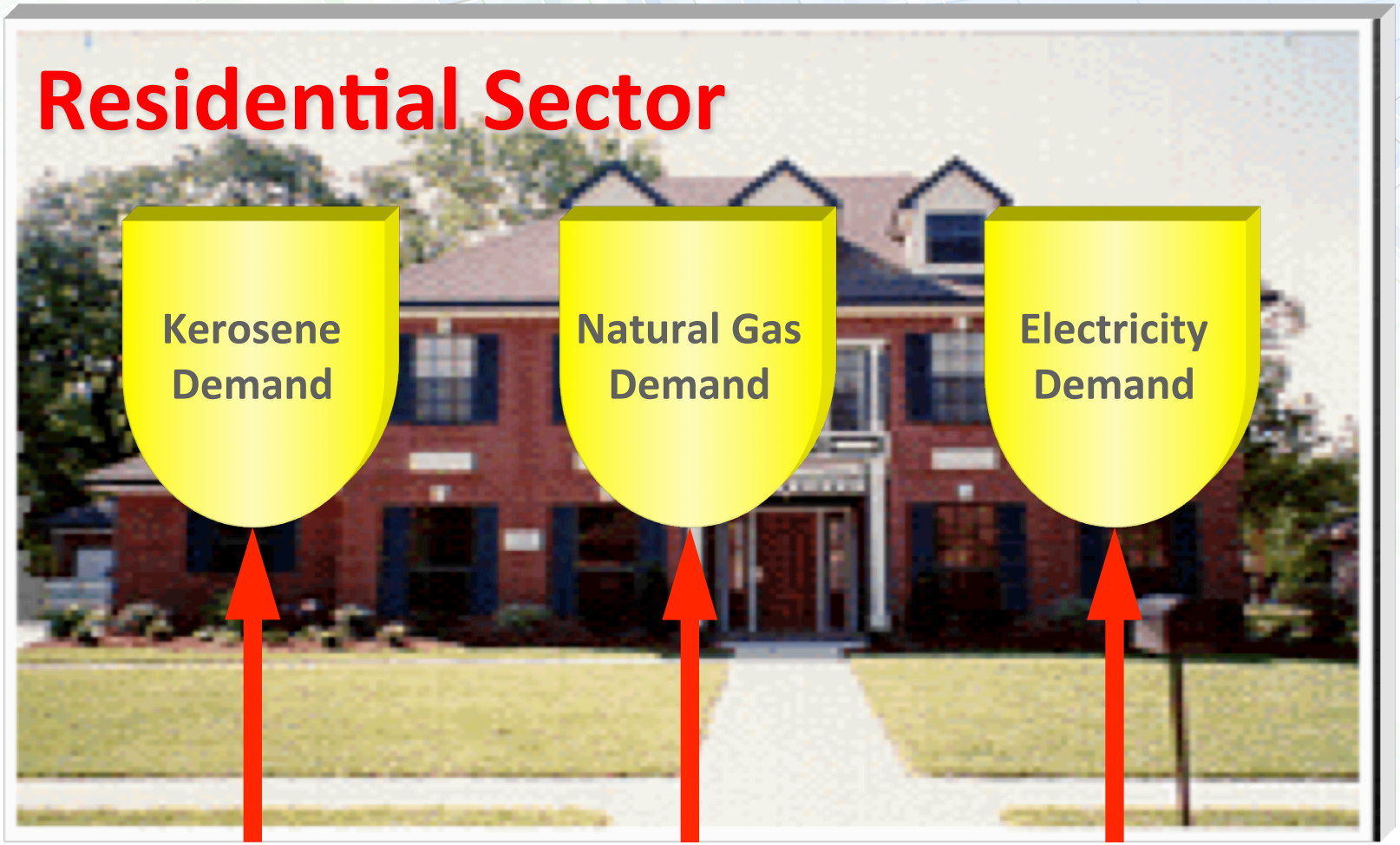
The Next Step is to Develop the Demand Structure for Each End Use Sector

- Varies from sector to sector
  - depending on issues to be analyzed
    - GHG mitigation focussed on transport sector
    - natural gas penetration in residential sector
  - depending on data availability
    - data for enduse sectors are hard to find
    - usually obtained via sectoral surveys

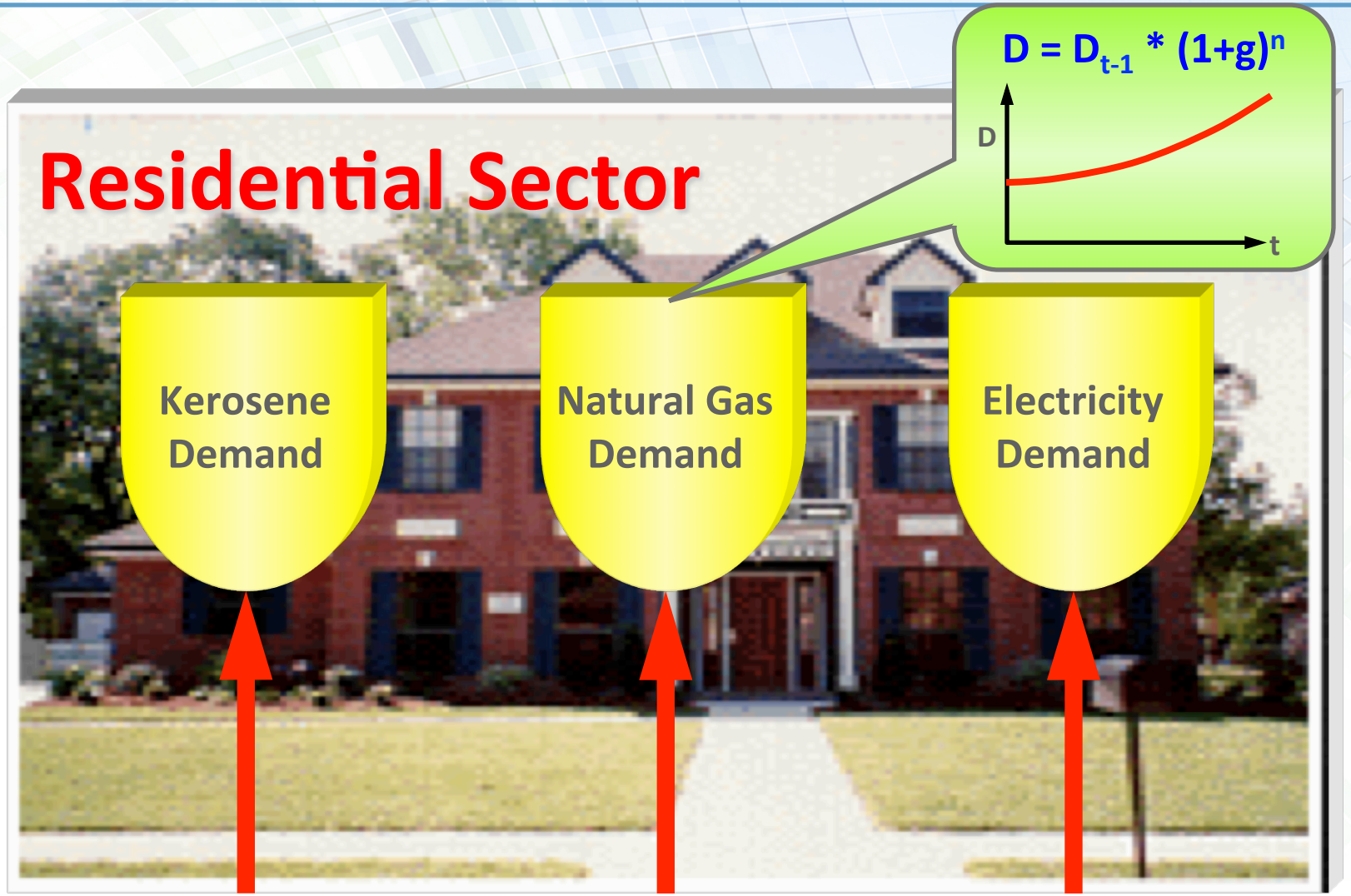
- May be done at different levels of detail
  - one sector can be very detailed (useful energy demand)
  - others can be less detailed (final energy demand)

- As part of the training course, please represent at least ONE SECTOR in useful energy demand
  - if you don't have the data, use best guess and examples from other networks
  - this will allow you to analyze GHG mitigation in at least one enduse sector

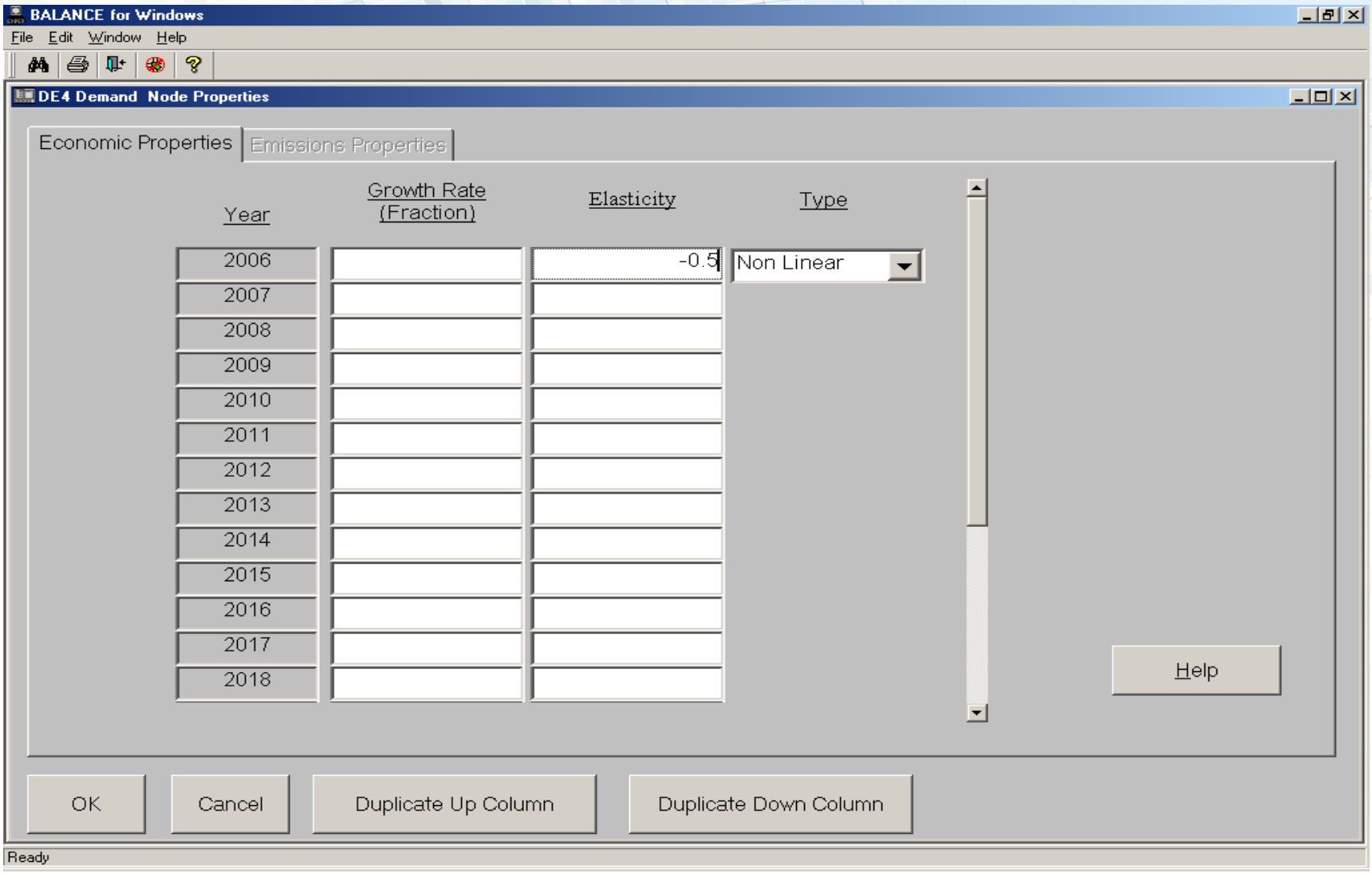
LEVEL 1 is the Simplest Approach



Projections of Fuel Demand Are Straightforward



Demand Elasticity with Respect to Prices



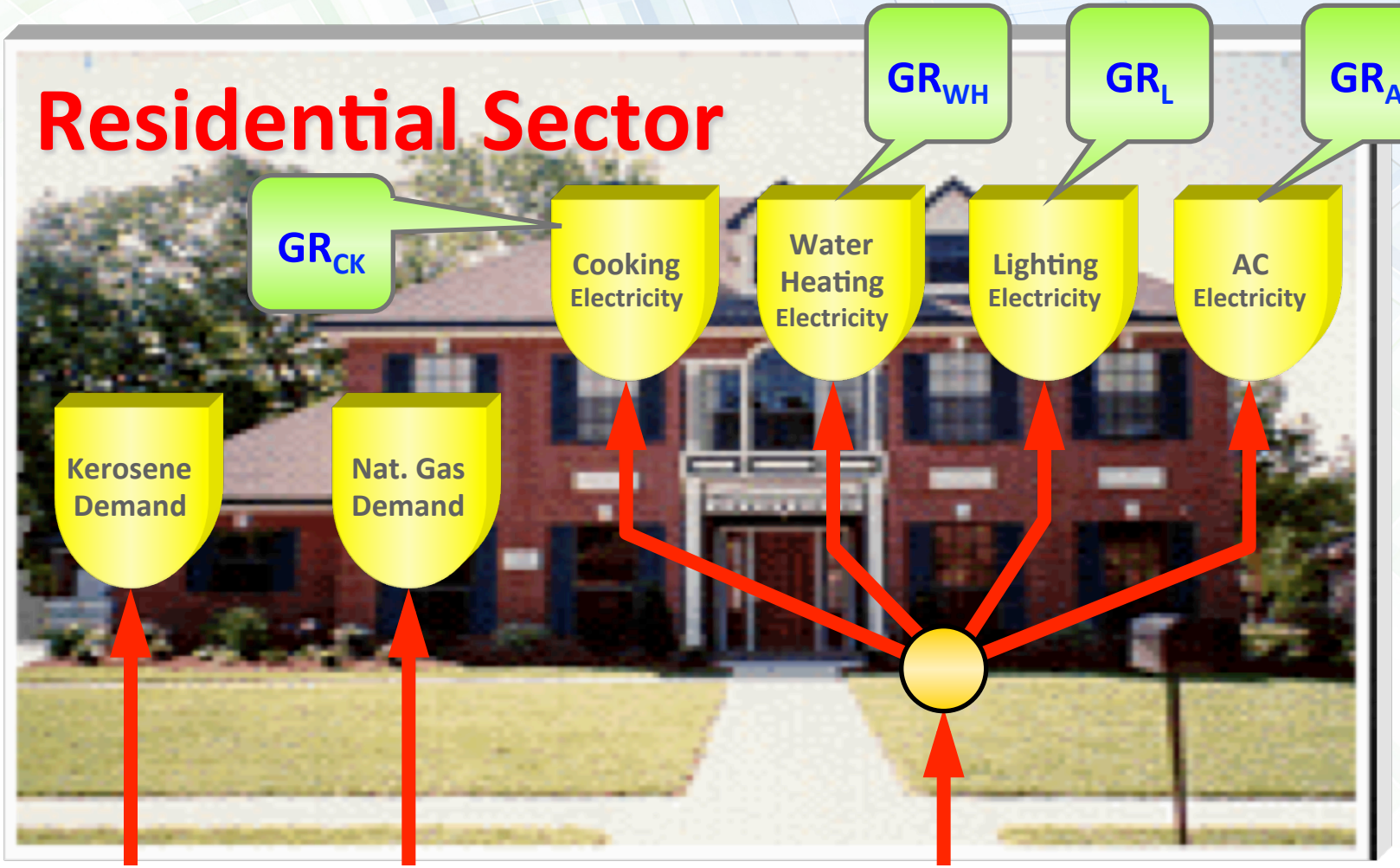
Demand Elasticity with Respect to Prices

Summary of the Level 1 Structure

- Advantages
  - Easy to implement
  - Minimum data requirements

- Disadvantages
  - Weak projection technique
  - Unable to address energy conservation directly
  - Unable to address fuel switching directly
  - No price sensitivity

A *LEVEL 2* Structure Adds More Detail: Different Growth Rates for Different Demands

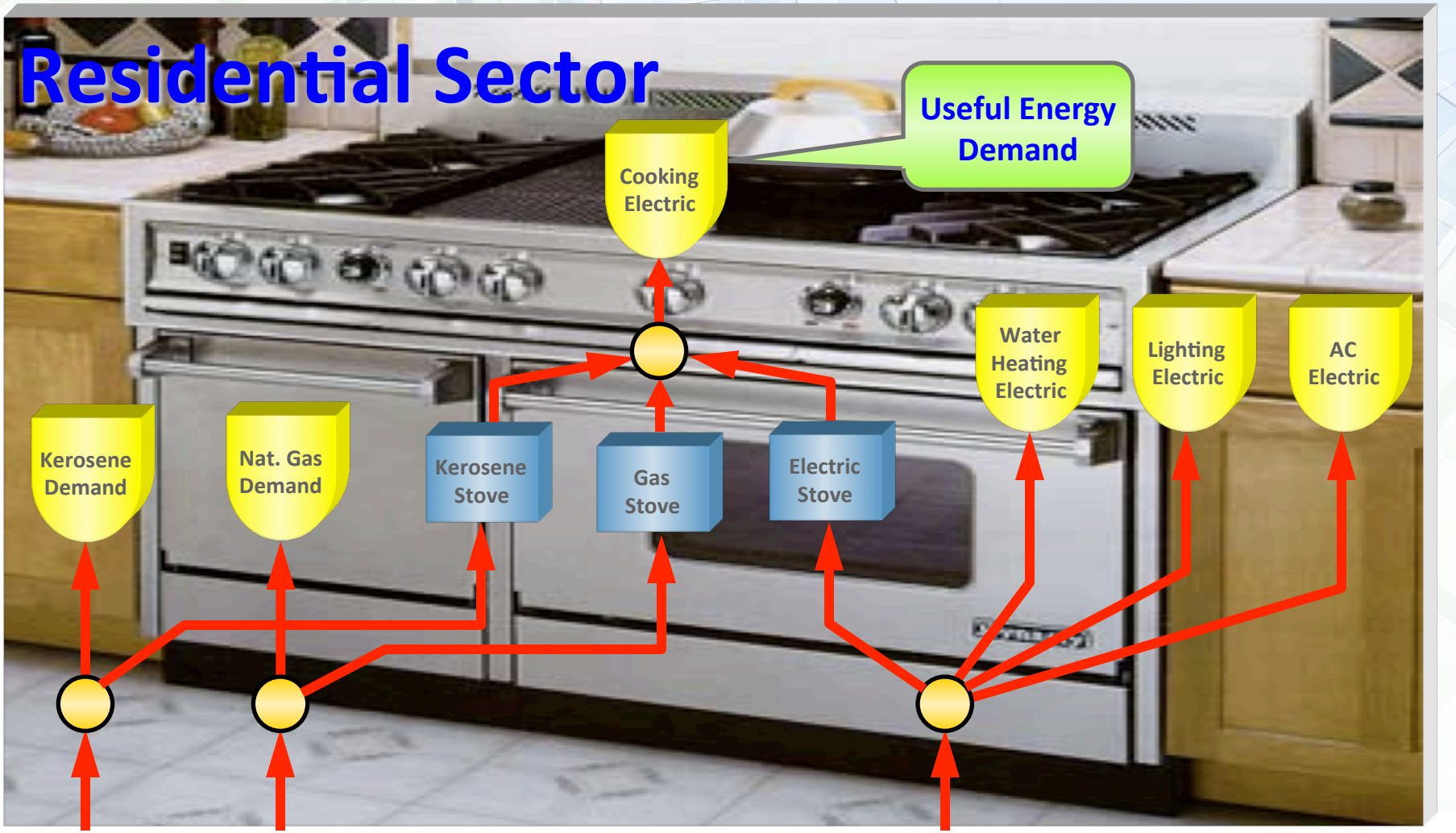


Summary of the Level 2 Structure

- Advantages
  - Allows for more detailed growth projections

- Disadvantages
  - Must know the split of each type of energy
  - No efficiency/conservation effects
  - No price effects
  - No fuel switching

The LEVEL 3 Structure Has Even More Detail

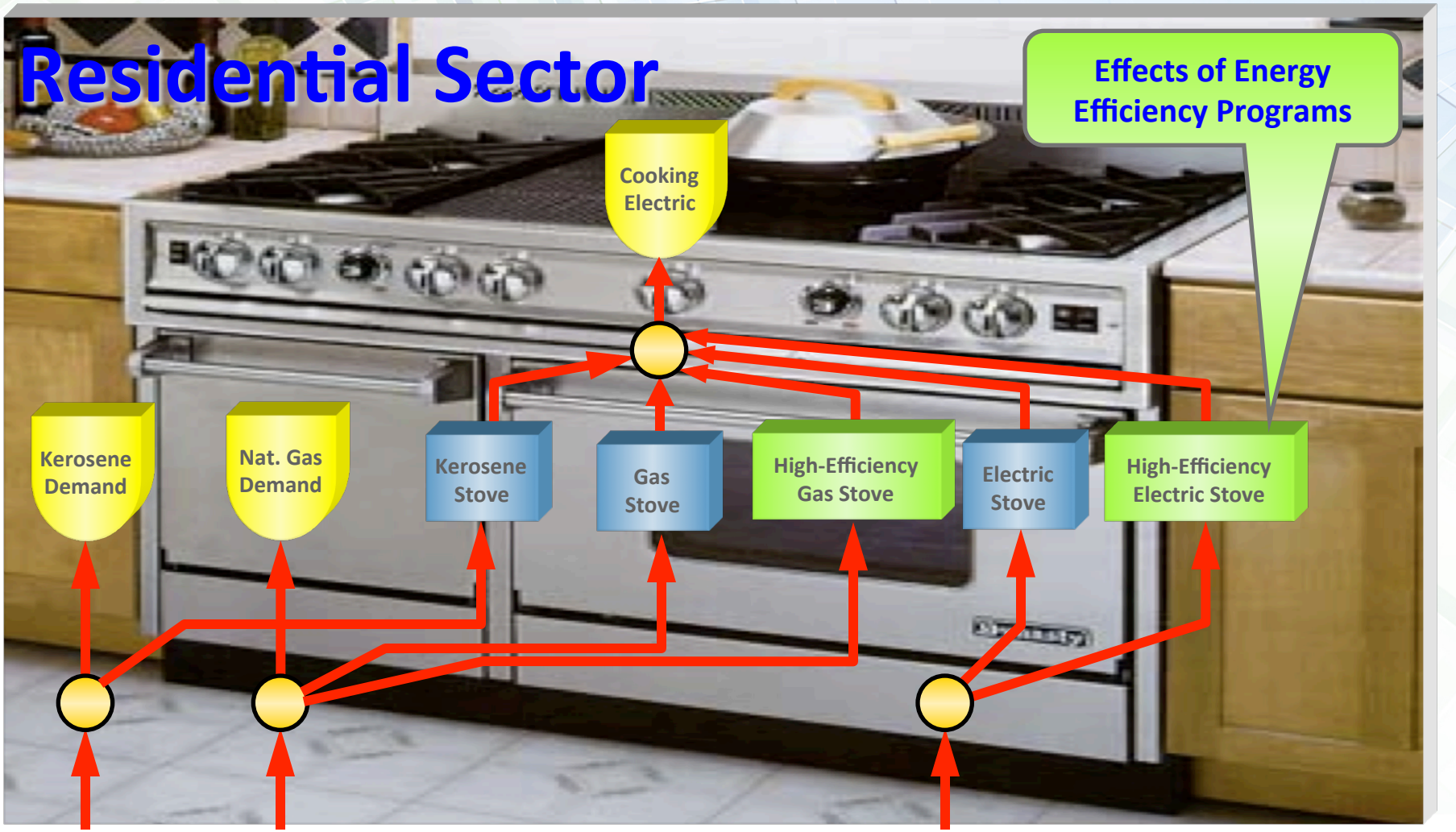


Summary of the Level 3 Structure

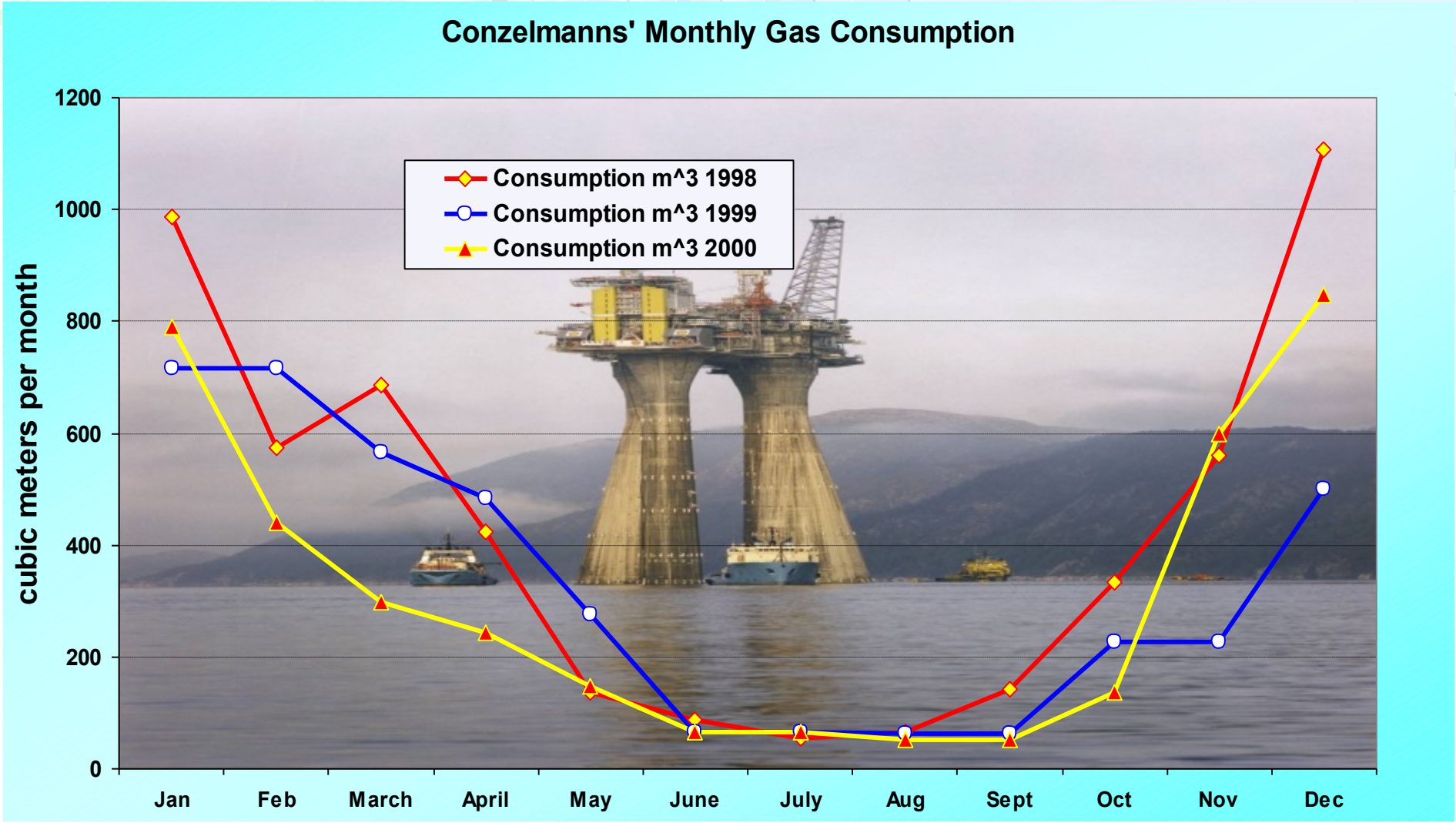
- Advantages
  - Detailed projection techniques possible
  - Direct analysis of energy efficiency/conservation
  - Fuel switching analysis
  - Price effects of alternatives

- Disadvantages
  - Requires more data

Even More Detail Can be Added



When Data is Not Available for Residential Sector, Start with your Own Personal Experience



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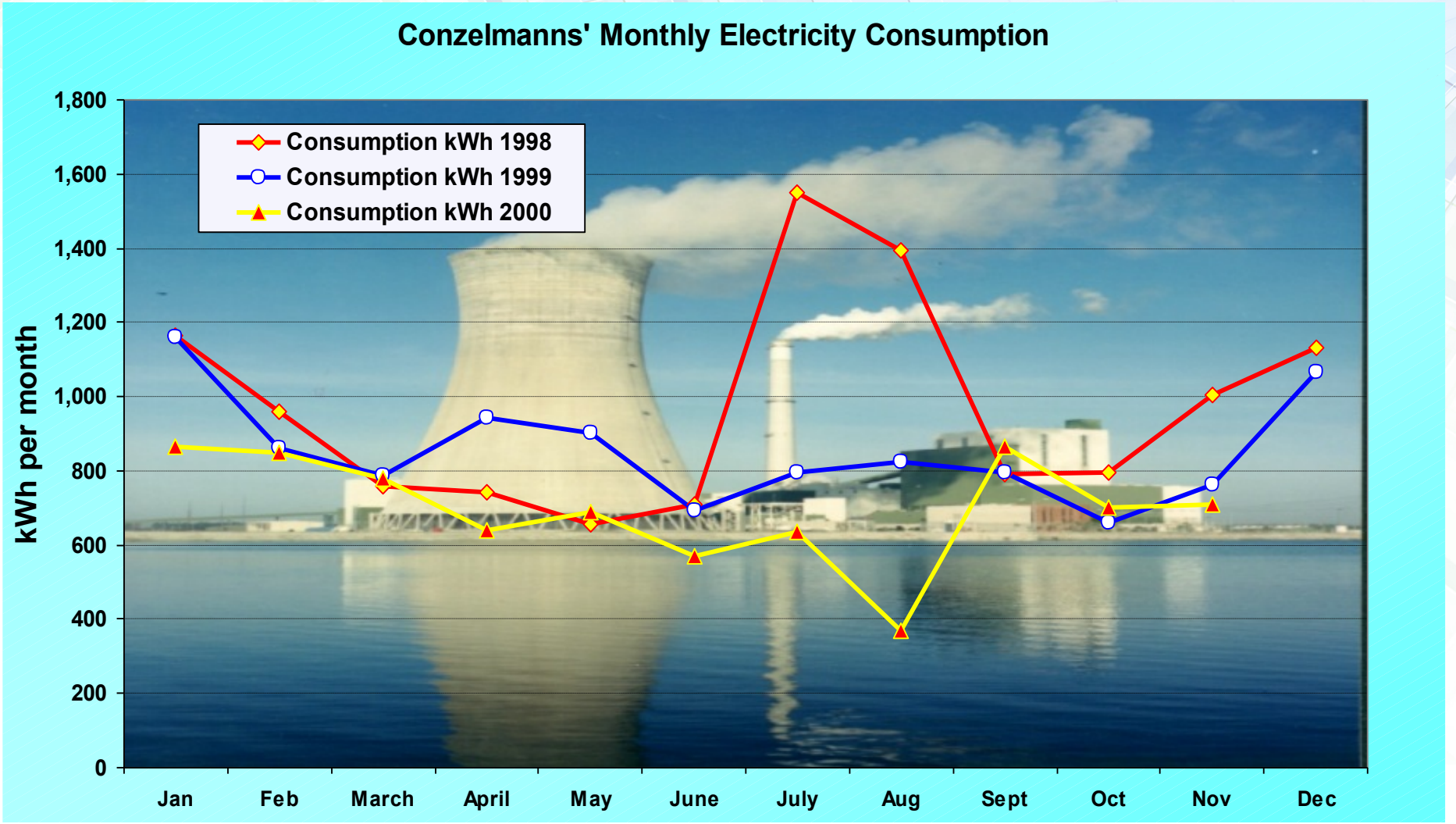
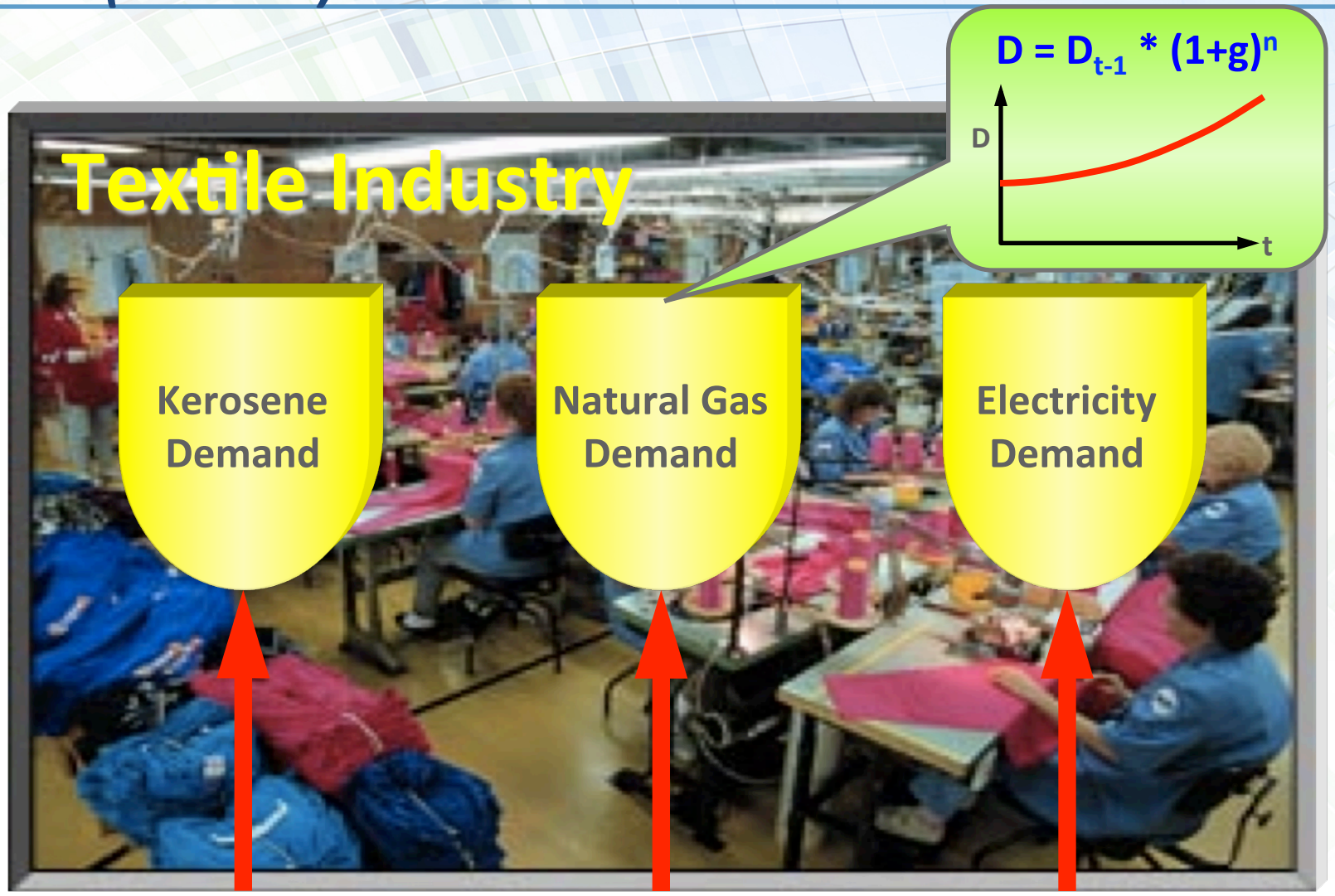
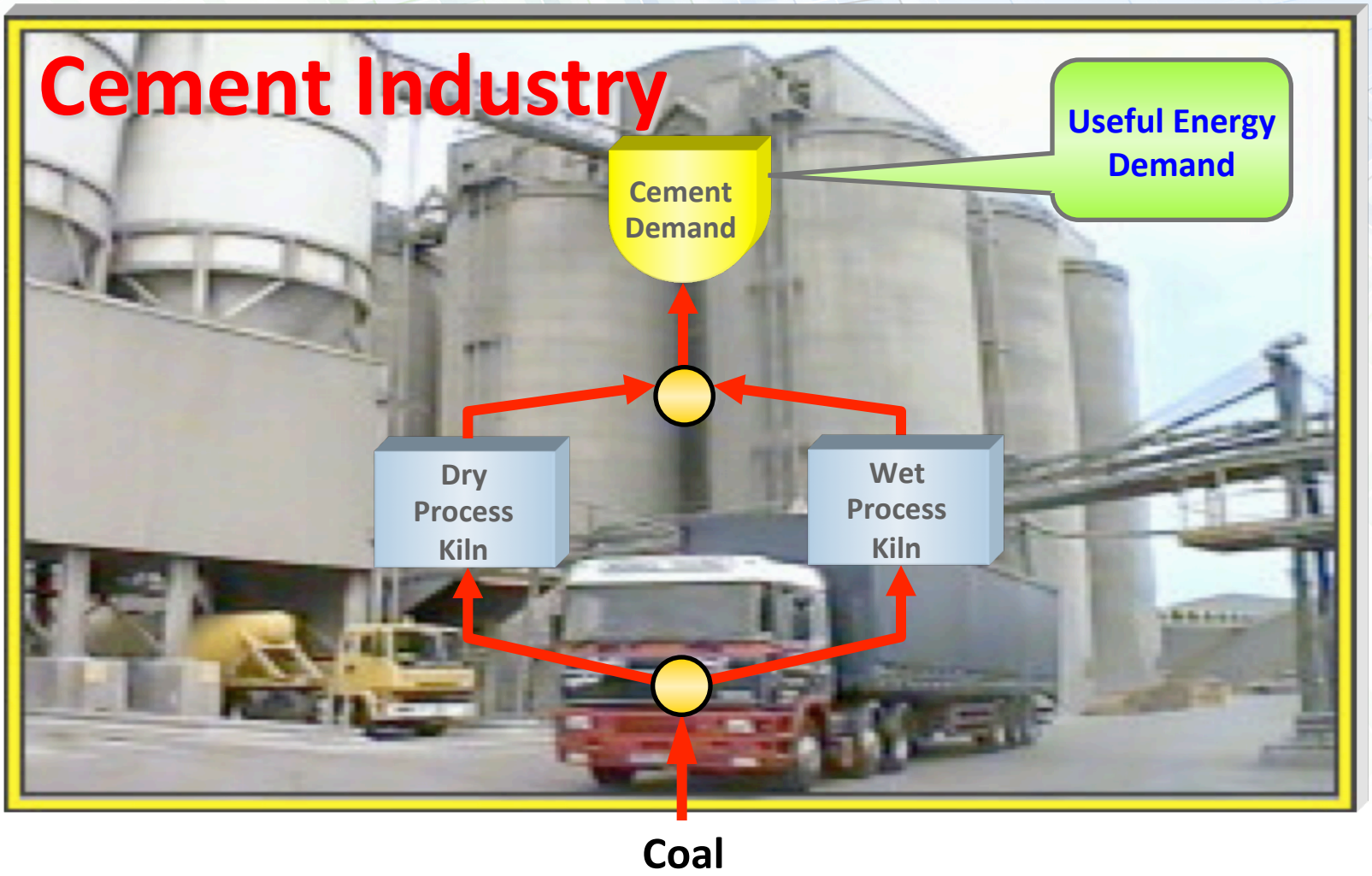


For the Industrial Sector, Levels of Detail are Also Possible (LEVEL 1)



… Industrial Sectors - LEVEL 3 …



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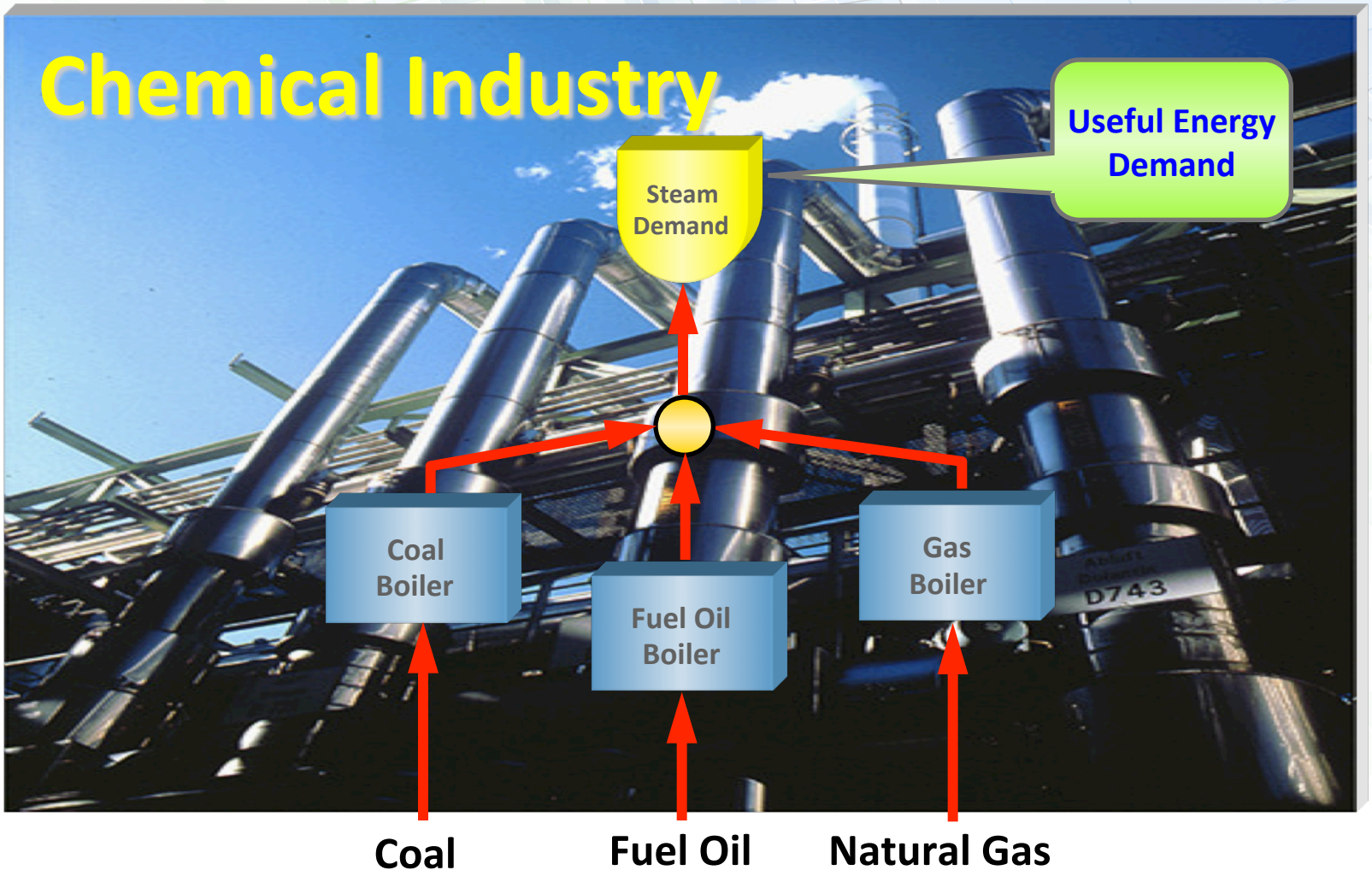
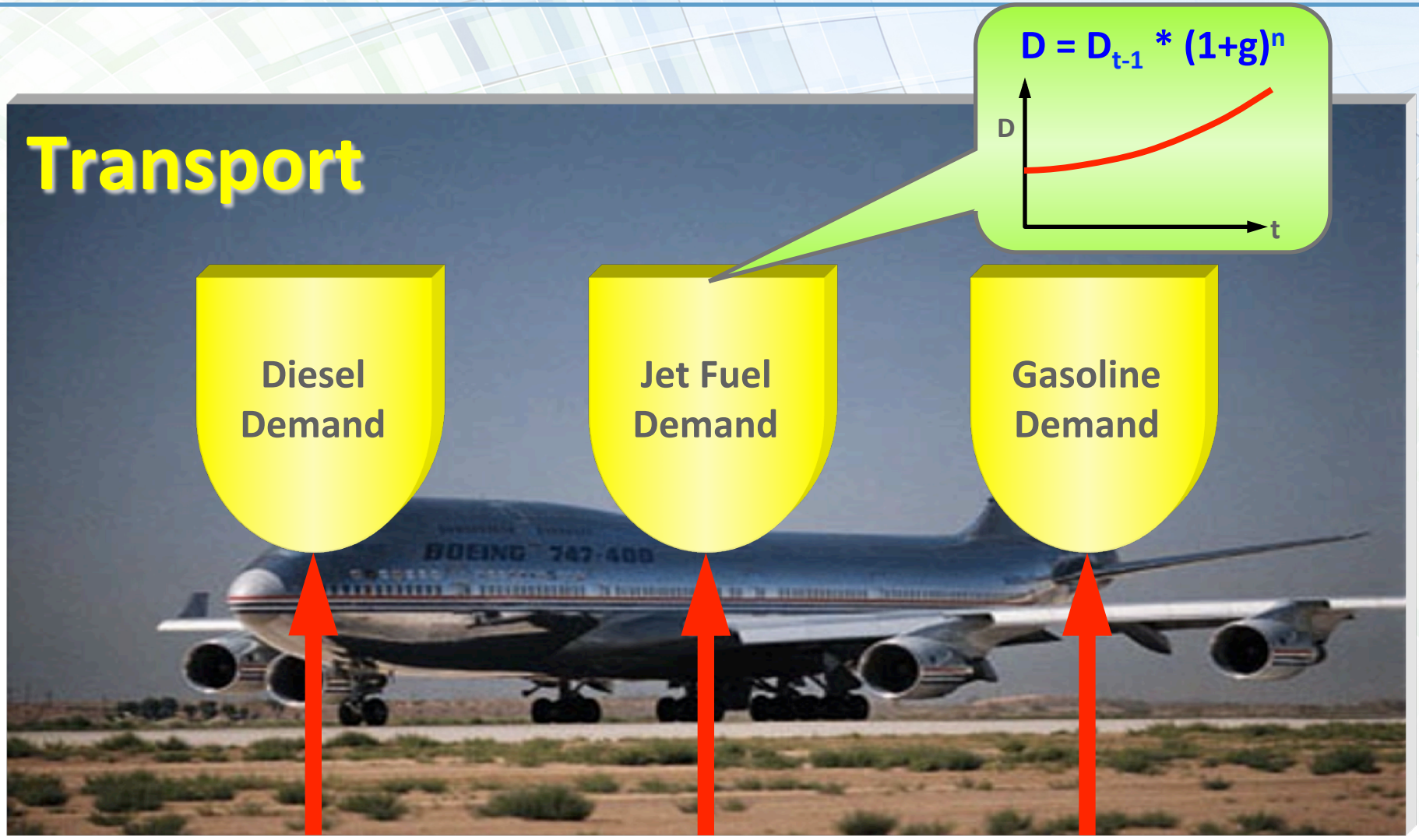


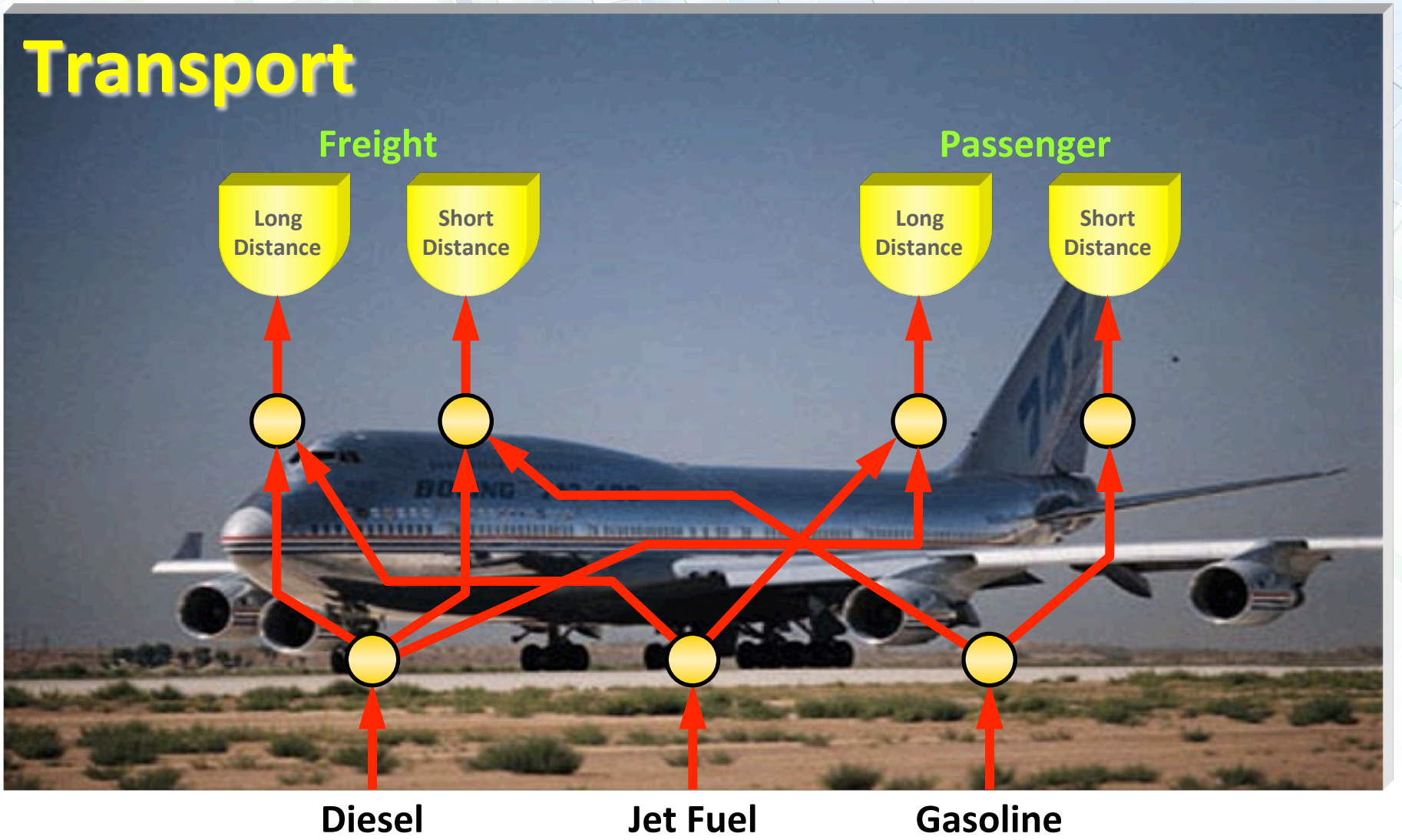
The Transportation Sector is Somewhat Different

- Type of transport
- Mode choice
- Vehicle choice

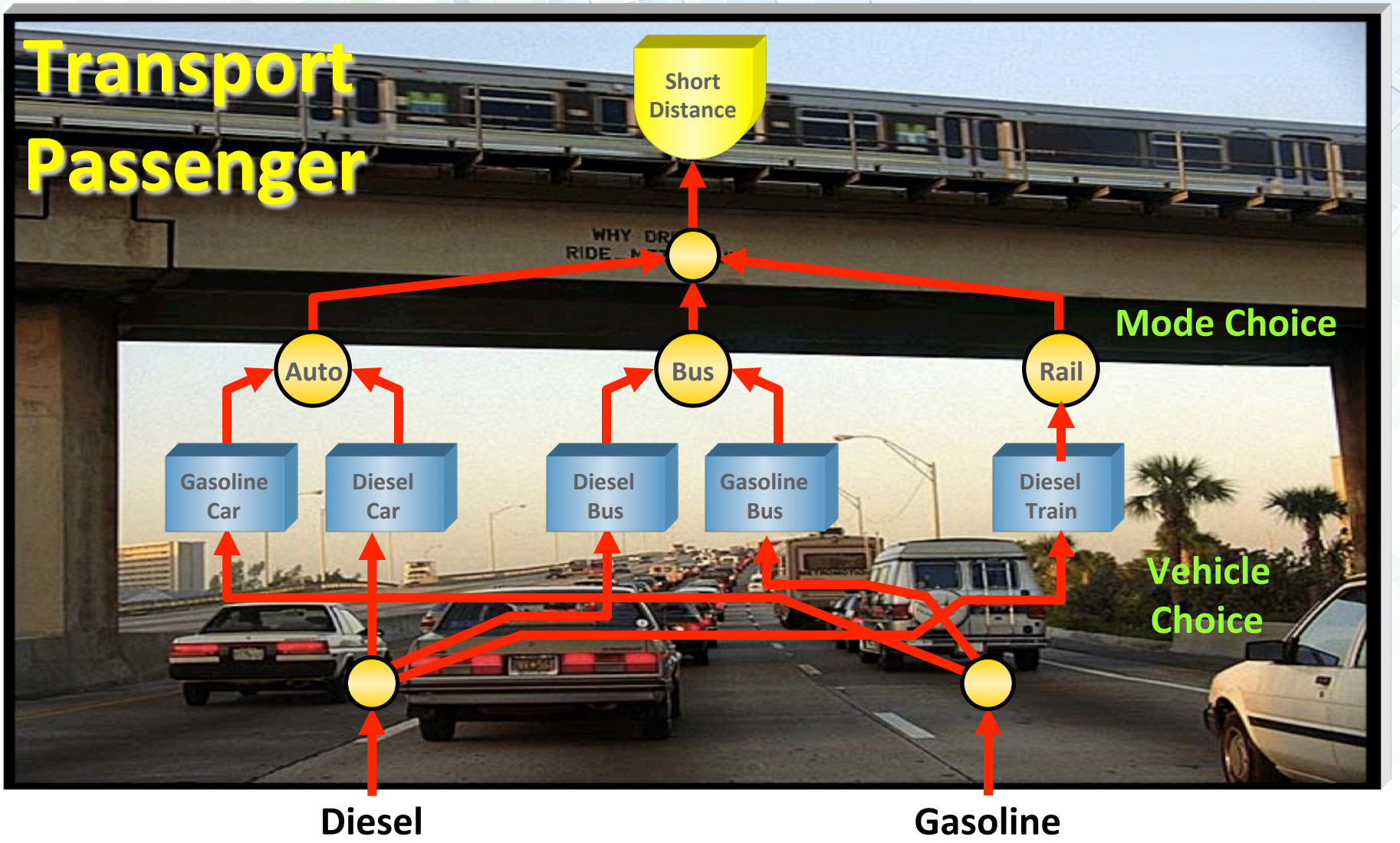
LEVEL 1 Transport Sector



LEVEL 2 Transport Sector

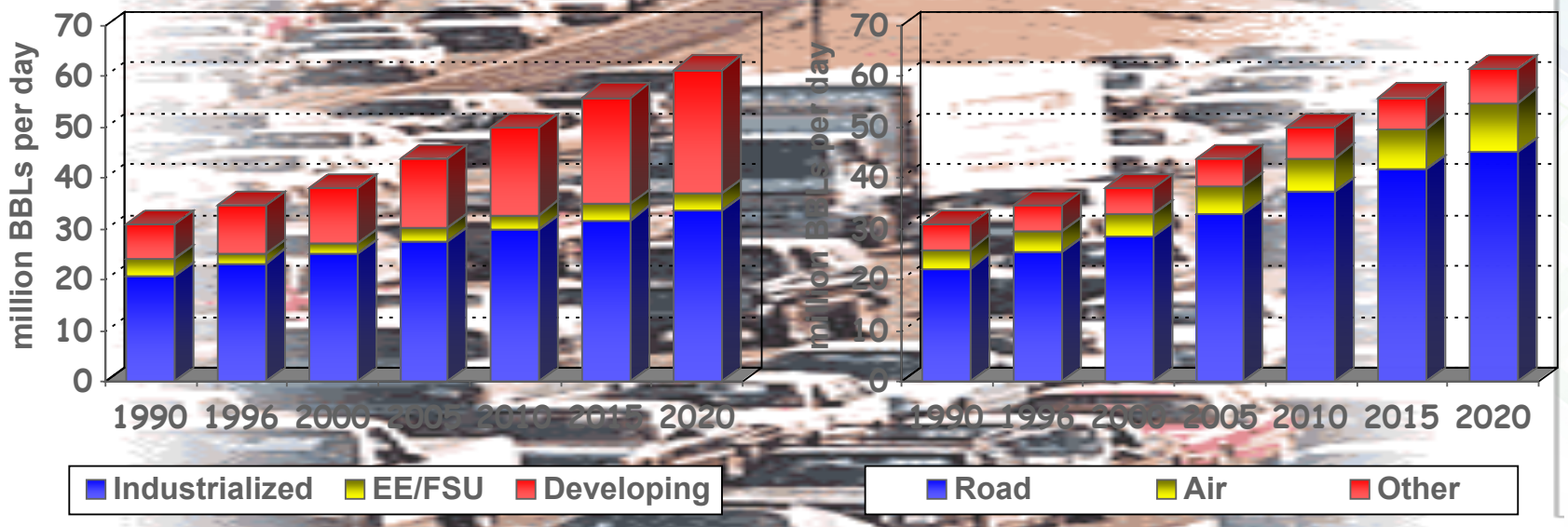


LEVEL 3 Transport Sector



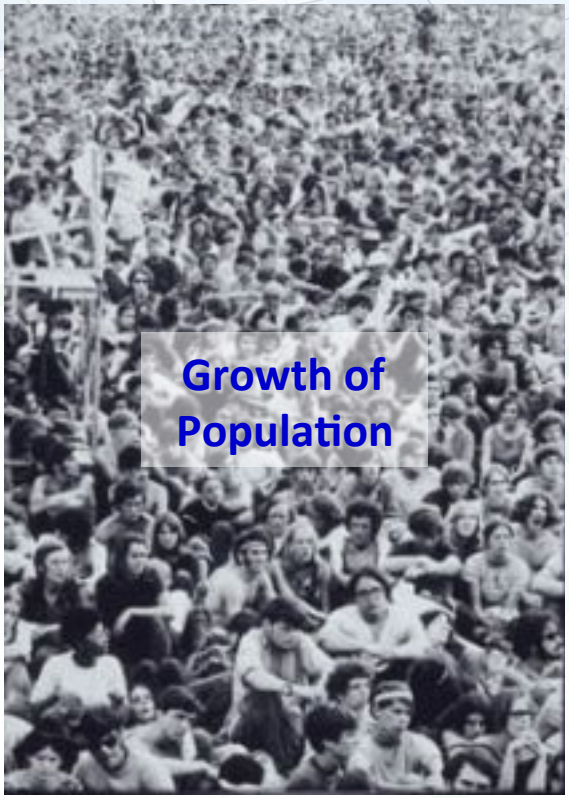
Once We Know the Current Demand Structure and Levels, We Need to Project What the Demand Will be in Future Years

EXAMPLE: GLOBAL TRANSPORTION ENERGY DEMAND



Source: EIA, 1999

To Make the Projections, We Have to Understand What Causes a Change in Energy Demand

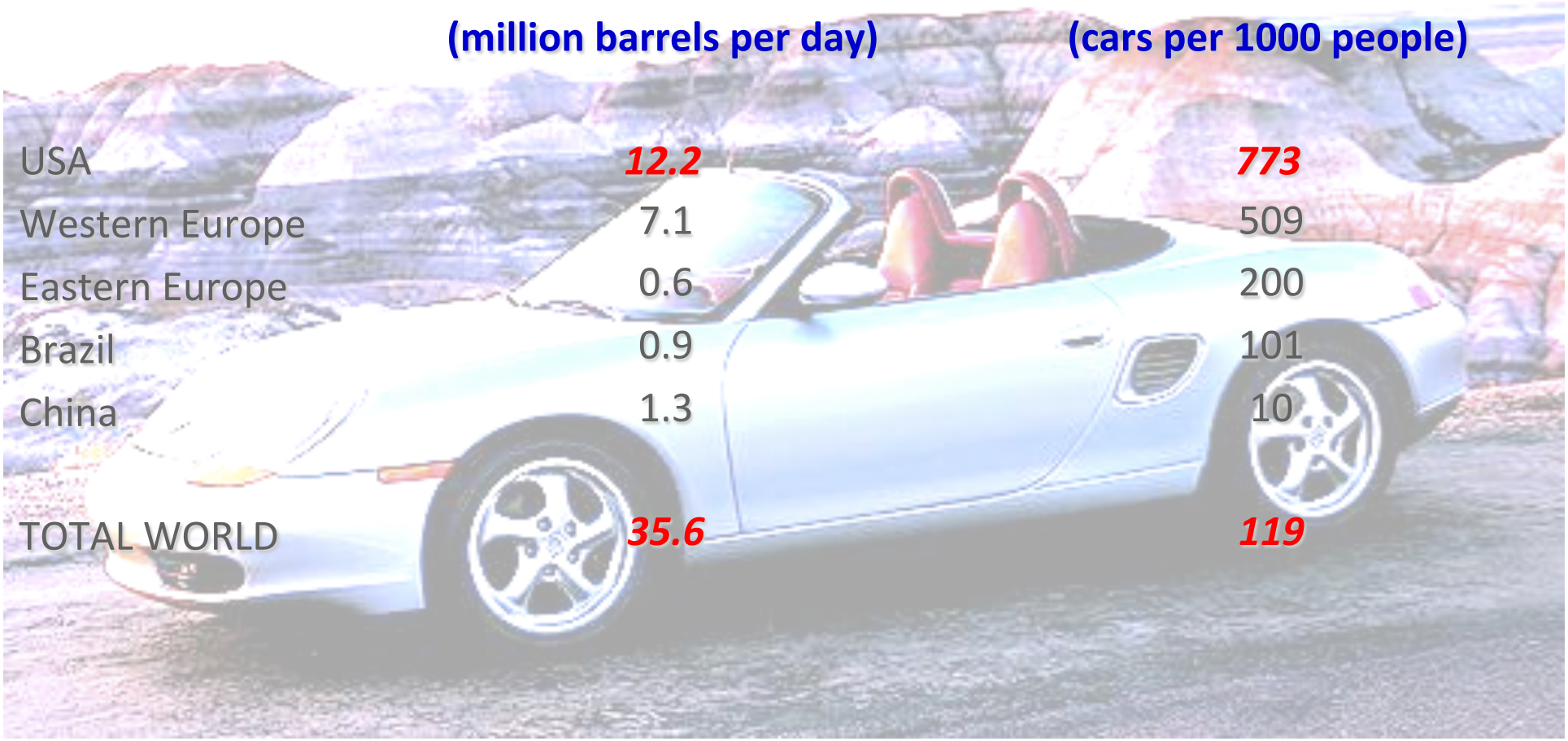


Example: Cost of Premium Gasoline on May 29, 2000 (US$ per Gallon)

- U.S. (average) 1.71
- Belgium 3.89
- France 3.94
- Germany 3.63
- Italy 3.89
- Netherlands 4.34
- U.K. 4.67

Transportation: An International Comparison

	Current Energy Consumption (million barrels per day)	Current Car Ownership (cars per 1000 people)
USA	***12.2***	***773***
Western Europe	7.1	509
Eastern Europe	0.6	200
Brazil	0.9	101
China	1.3	10
TOTAL WORLD	***35.6***	***119***



Energy Demand is Driven by a Number of Parameters

- Growth in population
  - urban and rural (shifts like urbanization)
- Economic output and structure of output as measured by GDP
  - total output (note that underground economy may be significant
  - sectoral output
  - shifts in mix (not related to efficiency)
  - income per capita
- Technological progress
  - increased efficiency lowers demand but feedbacks may reduce the overall effect (e.g. for 10% increase in fuel efficiency, car use may increase by 1-2%)
  - fuel mix for new technologies
- Other factors
  - energy prices
  - lifestyle, human behavior
  - energy and environmental policies

- **There are complex interdependencies linking these parameters**
- **How changes in these parameters affect energy demand depends on**
  - **type of energy service**
  - **stage of economic development**
  - **existing infrastructure**
  - **political system**
  - **availability of energy resources**
  - **climate and geographic conditions**
  - **culture**

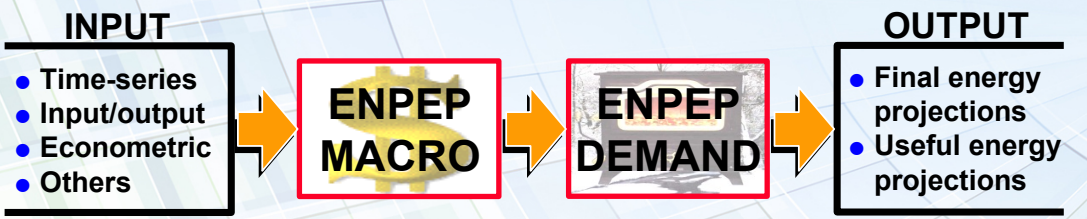
- **Understanding historical energy demand is complicated enough in stable situations, such as one country or a limited period of time**
- **It is significantly more complex when looking at long time periods and/or countries with ongoing economic reforms**

Understanding Energy Demand Drivers: Example Stage in Economic Development

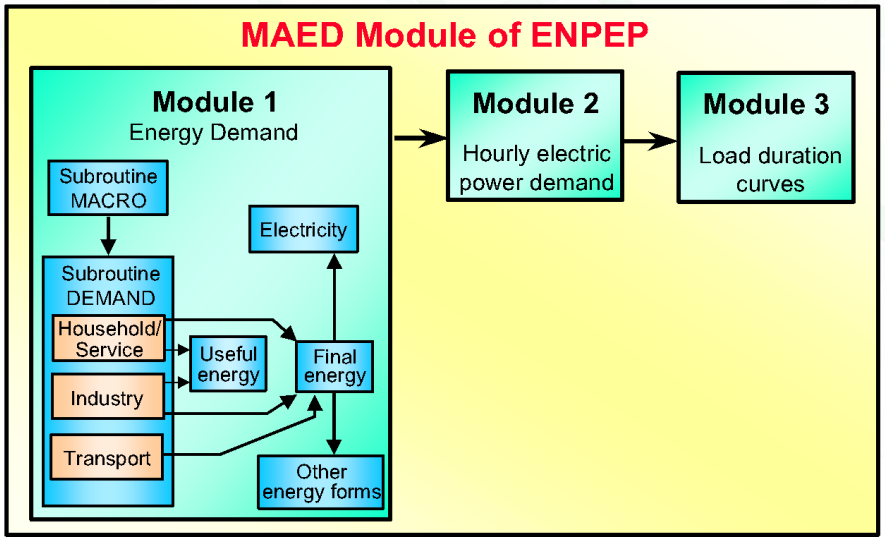
- Growth in number of cars is much higher in many LDCs/CEE/CIS countries compared to OECD countries, even relative to income
  - less saturated markets, fewer people have cars
  - suppressed demand, esp. CES/CIS
- Gasoline consumption in the Czech Republic, Hungary, Poland, Slovakia and Slovenia grew by more than 30% from 1990 to 1995
  - gasoline prices declined in real terms
  - real income growth
- CEE/CIS countries are now fastest growing new car market
  - CEE car sales increased by 35%; CIS by 13%
  - West Europe by 5% (1996)
- Similarly, residential electricity demand can be expected to grow much faster in countries with current low ownership of household appliances compared with saturated markets in OECD

There are Two Basic Methodologies to Estimate Future Energy Demand Levels

- Top-Down
  - time series of historical energy demand as a function of time
  - economometric models using historical data to determine causal relationships between energy demand and economic, technological, and demographic variables



- Bottom-Up
  - uses tools such as the Model for Analysis of Energy Demand (MAED)
  - develops demand forecasts simulating detailed scenarios about social, economic, technological developments
  - e.g., housing stock, breakdown into apartments, single family, and others, share of heated space, insulation standards, etc.



The Top-Down Approach Converts Results from Exogenous Economic Growth Analyses into Energy Demand Projections

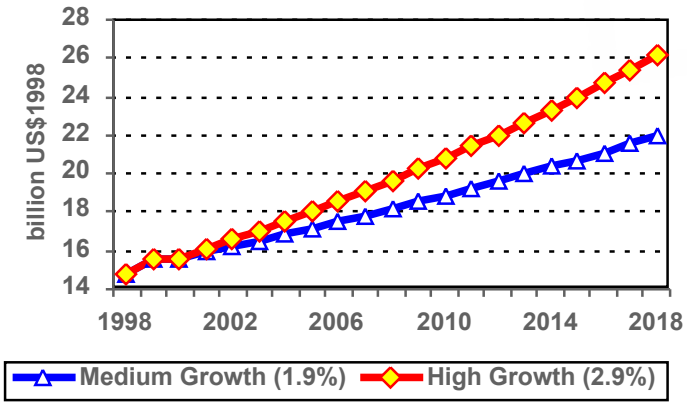
Macro-Economic Information

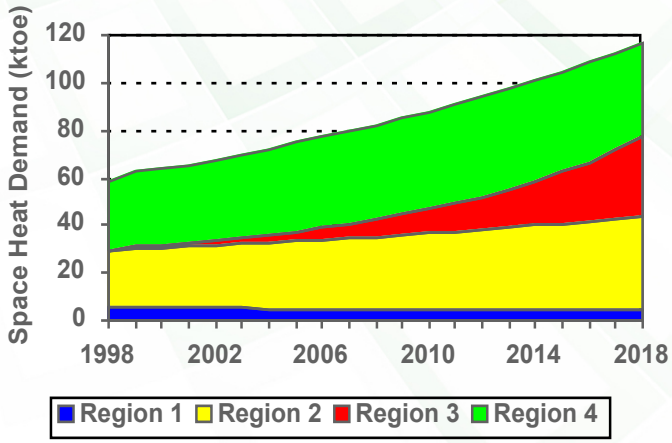
Time-series extrapolation

Input/output model

Econometric model

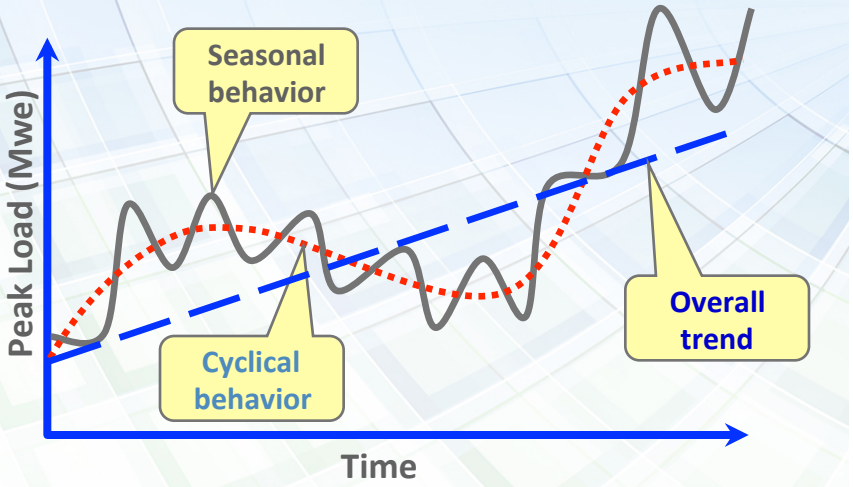
Other models





Time Series Analysis Searches for Systematic and Recurrent Relationships Between Energy Demands at Different Points in Time

- Time series is different from trend analysis in that it tries to decompose the data into at least three systematic components
  - Seasonal variations: recurring pattern between seasons, e.g., increased air-conditioning in Chicago leads to peak load in summer
  - Cyclical variations: recurring pattern over many years, e.g., 5-7 year business cycles
  - Trend: relatively consistent pattern that remains after filtering out the first two components



- Time is the only variable; minimal data collection
- Best suited for relatively large and stable systems for short term forecasting (months to a few years) as it may miss "turning points" in long-term trends (significant social or economic events)
- Choosing the most appropriate historical data sample (time period) is critical

Econometric Models Use Historical Data but Also Try to Explain the Causes of Trends

- Postulate explicit causal relationships between energy demand and a variety of variables (social, economic, technological, etc.)
- Can be simple linear models (univariate such as GDP and energy growth)
- Can be more complex, refined, and detailed
  - GDP by sector, growth in energy demand by sector
  - multiple equations
  - non-linear and dynamic
- Causality is not easy to determine
- Identifying the explanatory (dependent) variables and the functions by which they are related to energy demand is the most difficult part (often relies on experience and expert judgement)
- Preferred over time series
- Data intensive
- In general, good for short to medium term forecasts

Example for a More Complex Econometric Model Used by a U.S. Electric Utility to Project Residential Electricity Consumption

$$RC_t = 1.136 * RC_{t-1} - 0.341 * P_{elec} + 0.021 * THI + 0.115 * IPC$$

- RCt: Consumption in MWh per residential customer in period t
- RCt-1: Consumption in MWh per residential customer in time period t-1
- Pelec: Residential price of electricity
- THI: Temperature-humidity index
- IPC: Total income per capita

Examples for Simpler Relationships between Macroeconomic Parameters and Energy Demand

- Residential sector energy demand growth rate (GRResidential)
  - GRResidential = (1 + GRPOP) * (1 + GRGDP per capita) e * (1 + GRAutonomous) - 1
- Transportation sector demand growth rate (GRTransport)
  - GRTransport = (1 + GRGDP per capita) e - 1
- Industrial sector demand growth rate (GRIndustry)
  - GRIndustry = (1 + GRGDP Industry) e * (1 + GRAutonomous) - 1
- Service sector demand growth rate (GRService)
  - GRService = (1 + GRGDP Service) e * (1 + GRAutonomous) - 1
    - GRAutonomous: independent growth rate
    - e: income or output elasticity

Establishing the Relationships is not an Easy Task: Countries with 'Stable' Economies

- Use date from your country and analyze historical trends (5, 10, 20 years)
- Try to determine the mathematical relationships that describe the observed historical trends; conduct regression analysis (uni- or multivariate) with
  - GDP, population, incomes, etc. as the independent variable
  - energy demand as the dependent variable
- Modify the results of the regression analysis based on "expert judgement" to account for perceived future changes in "extrapolated trends"

Establishing the Relationships is not an Easy Task: Countries with Economies in Transition

- Historical country data is inadequate

- Conduct regression analysis for ***historical time series sample*** from another country (or set of countries) that, at a given point in time, was at the same stage of economic development as your country (analogue country approach)
  - example: you may use GDP and energy demand data from Germany for 1973 to 1992 to establish GDP-to-Demand relationships

- Conduct regression analysis for ***cross-section sample of countries*** (at different stages of development) using GDP and energy data from one year
  - example: you may use GDP and energy data from Portugal, Greece, France, Germany for 1996 to determine GDP-to-Demand relationships

- Again, modify results using "expert judgement"