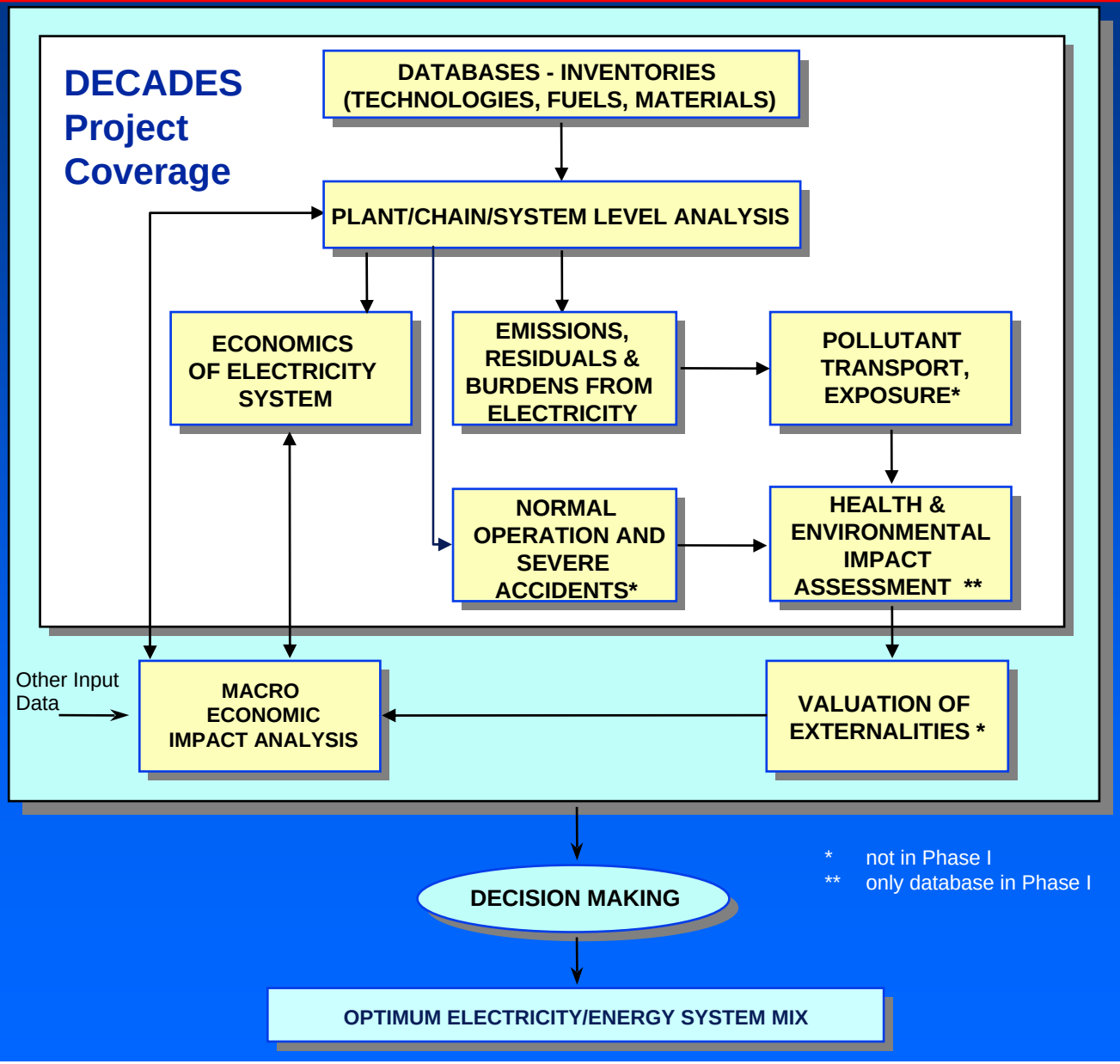
Overall Framework of Comparative Assessment for Decision Making in Electricity Sector



DECADES Project

Inter-Agency Joint Project on Databases and mEthodologies for Comparative Assessment of Different Energy Sources for electricity generation (DECADES)

Initiated in 1992 by the Agency, in co-operation with eight international organizations (EC, ESCAP, IBRD, IIASA, OECD/NEA, OPEC, UNIDO, WMO)

Objective To enhance capabilities, particularly in developing countries, for comparative assessment of different energy sources in the process of planning and decision-making for the electricity sector.

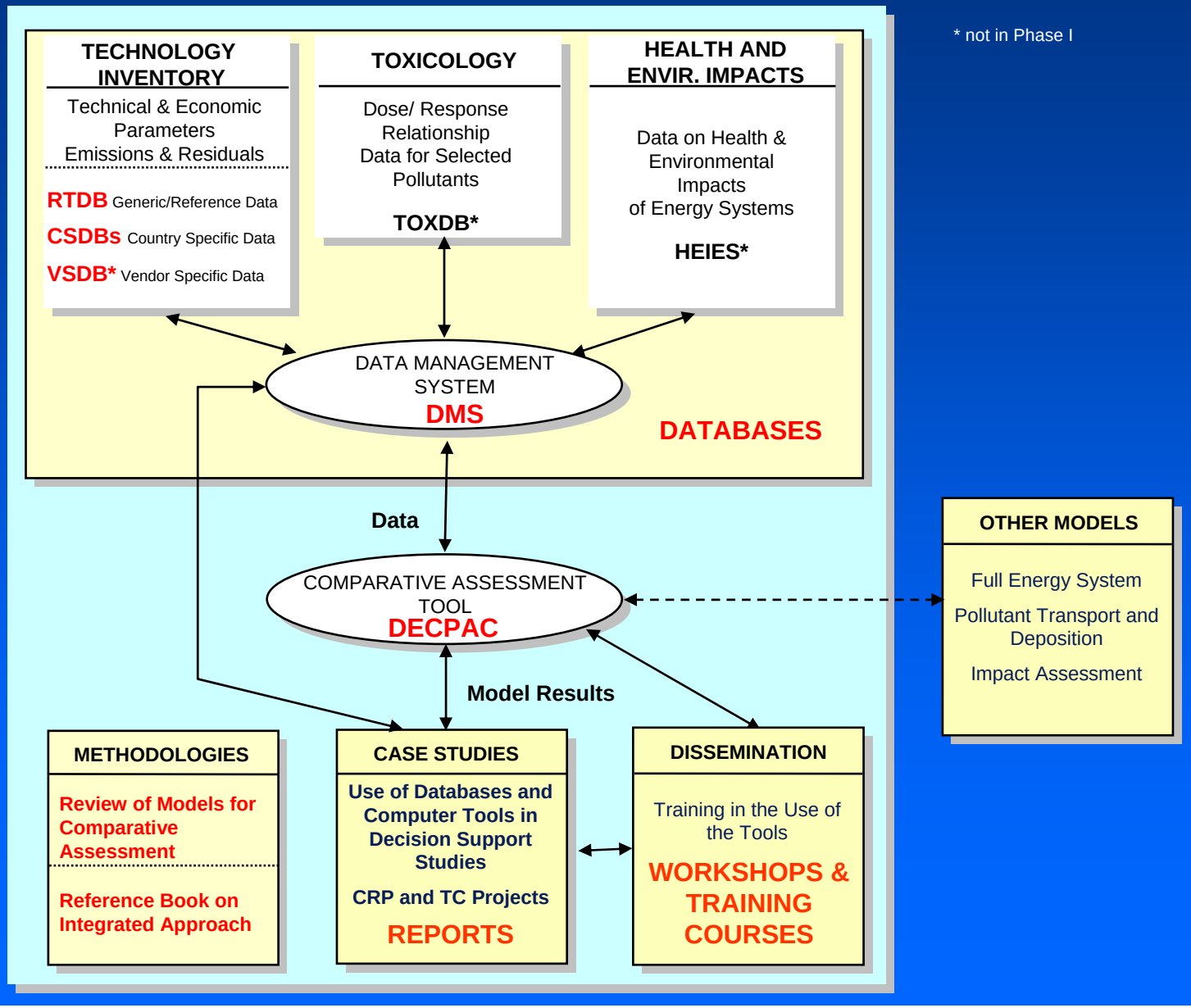
- **Broad range of expertise and viewpoints**
- **Sharing and exchanging of information**
- **Improved credibility, since all organizations are identified with the outcomes (special series of publications for DECADES project)**

Not aiming towards an overall ranking of energy options, since results are country specific.

DECADES Project Participation

- 9 International Organizations formally participating (letters of understanding)
- Other organizations participating on an ad hoc basis (UNEP, Uranium Institute, WHO, OLADE)
- Member States - Phase I (1993-1996)
  - Argentina, Bulgaria, China, Colombia, Croatia, Egypt, France, Germany, Greece, Hungary, India, Indonesia, Korea Republic of, Macedonia FRY, Pakistan, Peru, Poland, Romania, Russia, Slovakia, Turkey, USA (22)
- New Member States - Phase II (1997-)
  - Belarus, Brazil, Cuba, Israel, Mexico, Moldova, Philippines, Portugal, Slovenia, Switzerland, Thailand, Uzbekistan and Vietnam (13)
  - Guatemala, Lithuania, Mexico, Paraguay and Sri Lanka (5)

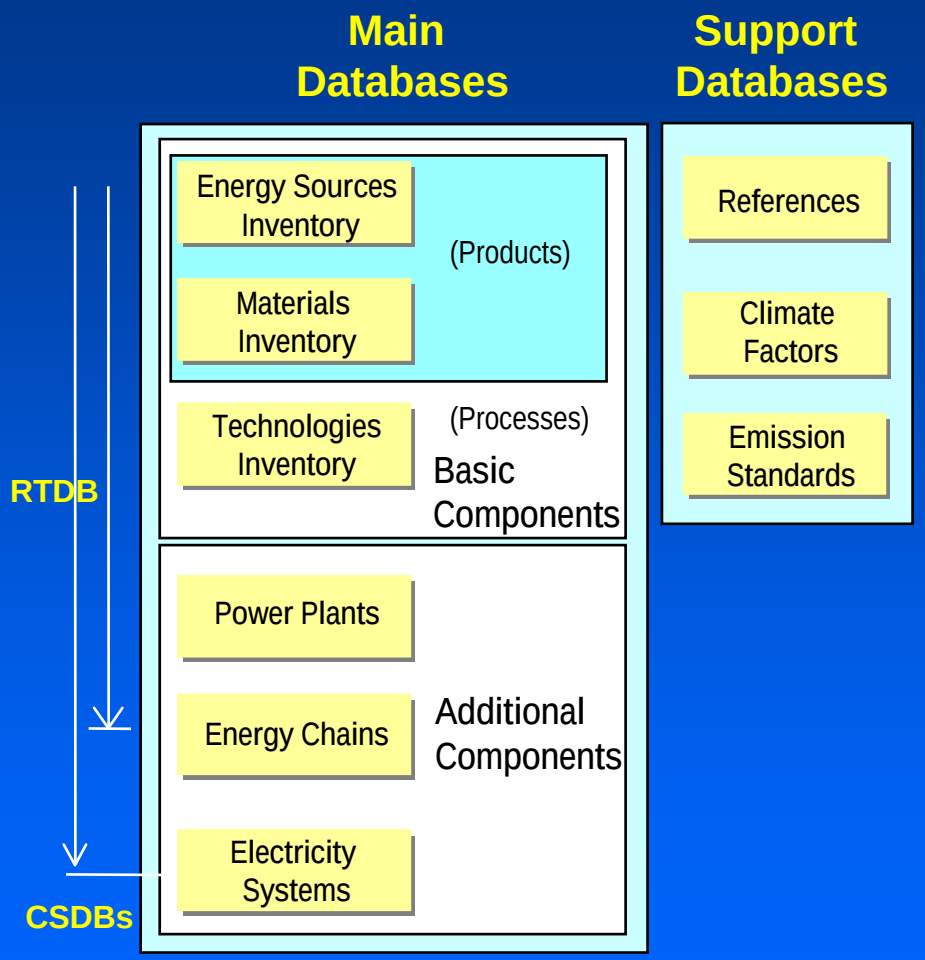
The DECADES Project Structure



* not in Phase I

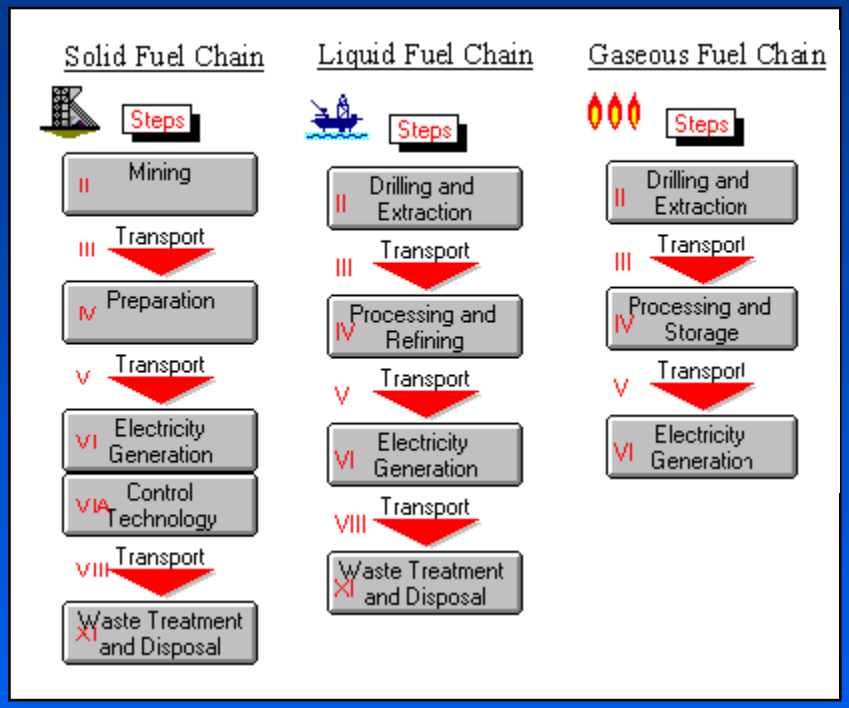
RTDB/CSDBs - Content and Structure

- **Reference Technology Data Base (RTDB)** is a generic database which provides a comprehensive, harmonized set of technical, economic and environmental data for energy chains that use fossil fuels, nuclear power, and renewable energy sources for electricity generation. RTDB follows the concept of the fuel chain analysis and addresses all stages of the chain, from energy source extraction to waste disposal.
- **Country Specific Data Bases (CSDBs)** store data on electricity generation technologies for various countries or regions for the purpose of carrying out case studies with the DECADES analytical software or other national planning tools. The CSDBs accommodates site-specific data which are not stored in the RTDB. Some thirty countries have developed CSDB, containing a total of more than 3,500 technologies.

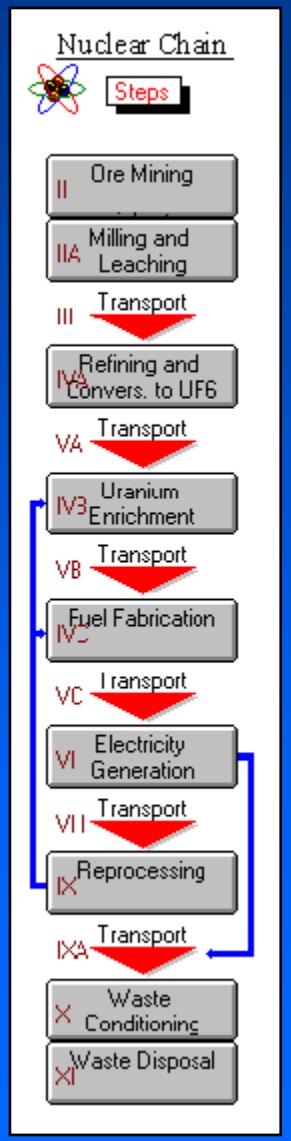


RTDB/CDSBs - Coverage

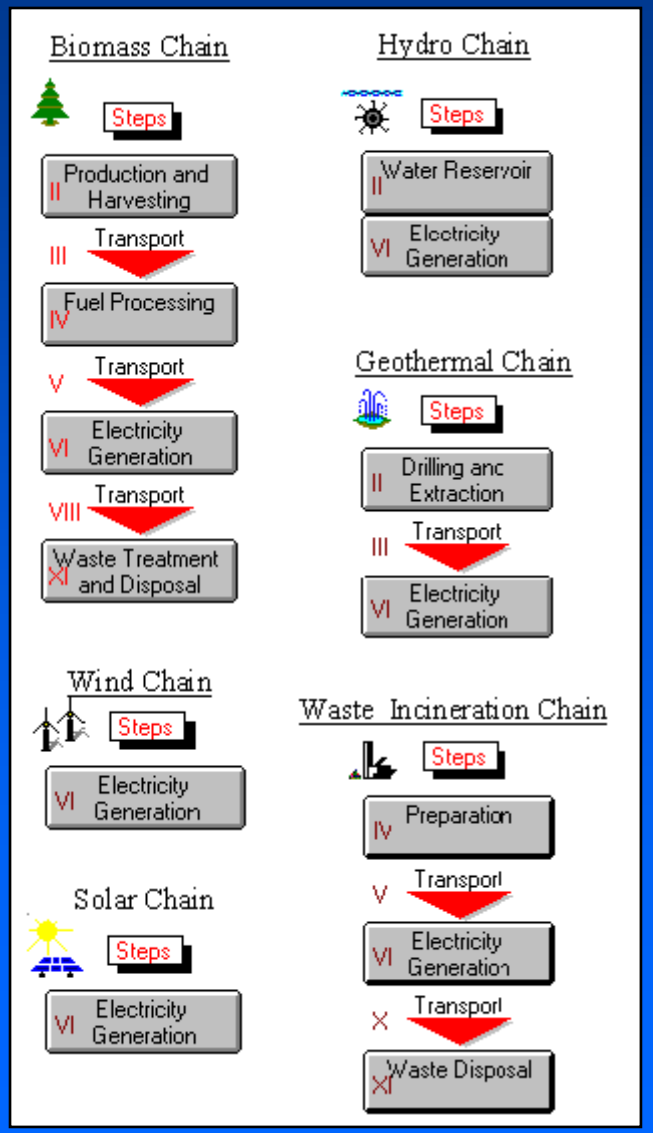
Fossil Fuels



Nuclear



Renewable



- **RTDB/CSDBs cover all the steps in the energy chain, from fuel extraction to waste disposal;**
- **Contains information on energy supply technology presently available or and expected to come into operation in the next two to three decades.**

RTDB/CSDB - Facilities Characterization

Facility Data

Numerical

- Technical
- Economic
- Environmental

Descriptive

- Textual
- Schematic
- Pictorial

Gaseous Fuel Chain
Level VI Electricity Generation — **Simple Cycle Heavy Duty**

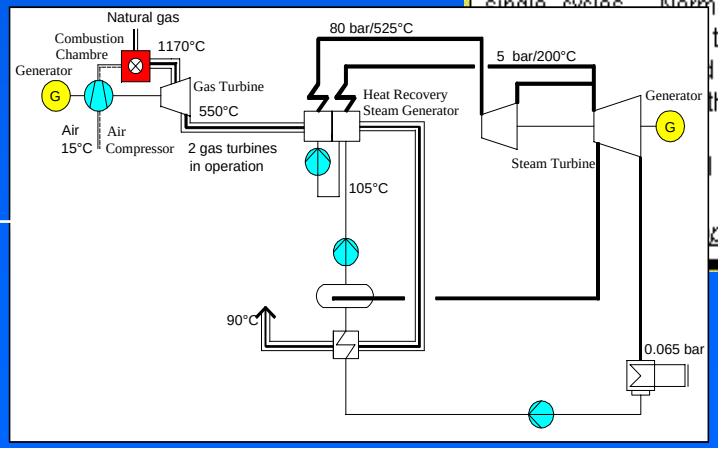
		CT100-R	CT100-U	CT135	CT150-R
1. Technical					
Output Capacity (Gross)	MWe	107	100	135	150
Output Capacity (Net)	MWe	104	95	122	146
Output Capacity (Min)	MWe	104	95	122	146
Equivalent Full Power	h/yr	750	1000	1022	750
Forced Outage Rate	%	88.3	88.3	88.3	
Scheduled Maintenance	days/yr				
Gross Efficiency (on LHV basis)	%				
Net Efficiency (LHV)	%				
Heat Rate - Full Load	kcal/kWh				
Heat Rate - Average Incr.	kcal/kWh				
Heat Rate - Base Load	kcal/kWh				
Plant Technical Lifetime	yr				

1. Natural Gas Fired Combined Cycle with Heat Recovery

The plant is using a North Sea natural gas being burnt in a modern combined cycle power station, equipped with two gas turbines, two heat recovery steam generators (HSRG) and one steam turbine, illustrated in Fig1 . Steam is generated at two pressure levels.

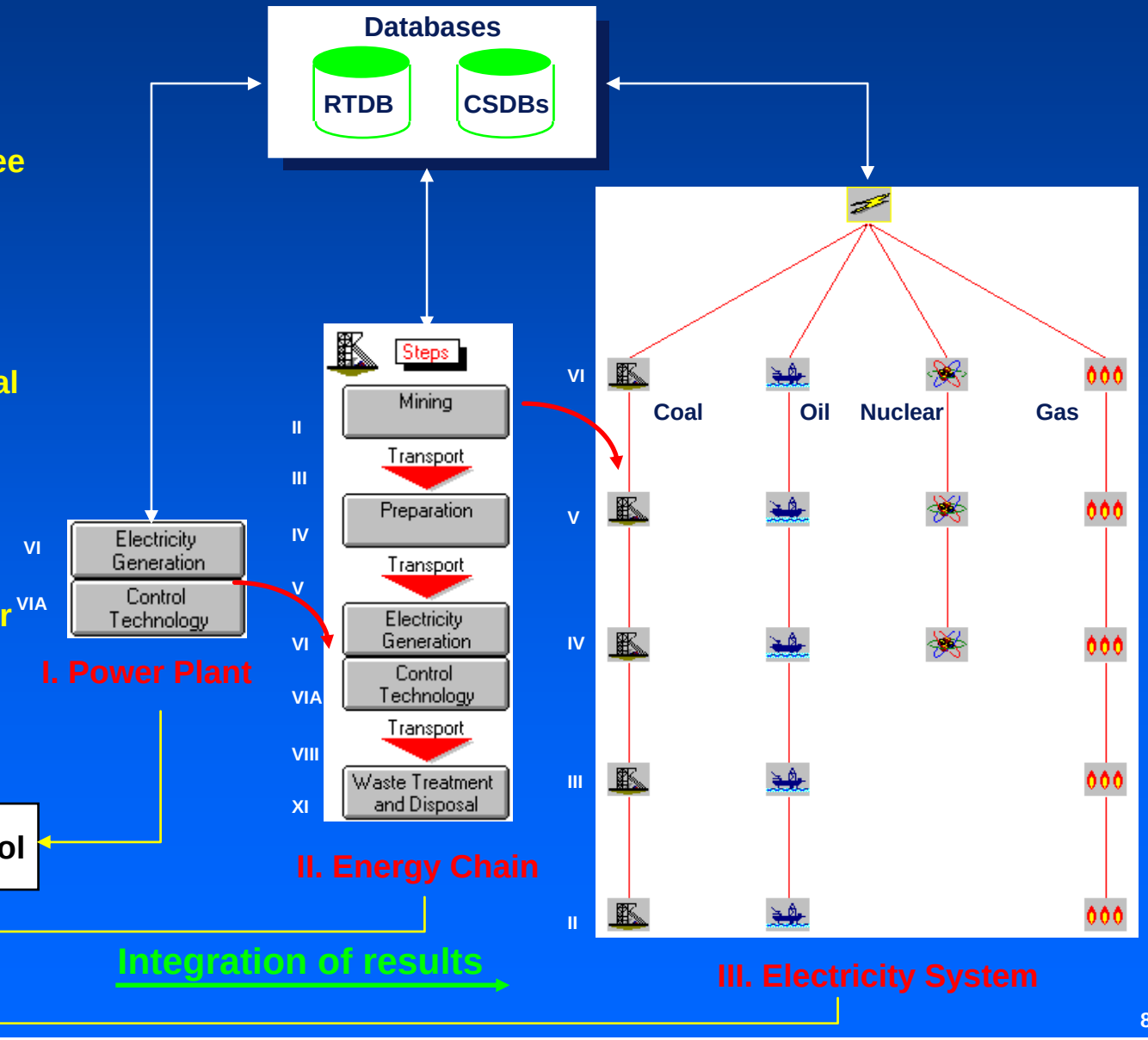
A combined cycle is a combination of two or more thermal cycles within a single power plant, where the intention is to increase the efficiency over that of the single cycles. Normally the cycles can be termed as "topping" cycle and to temperature level at which the cycles operates. Most of to the "topping" cycle which operates at rather high the "bottoming" cycle utilizes the heat rejected from the cycles are usually coupled in a heat exchanger. The gas is given in Table 1.

position (no clean up) of a typical North Sea"Brent" natural



DECPAC - Main Characteristics

- Integration with DECADES Databases
- Modular approach with three levels of comparative assessment support
- Single modeling framework which integrates technical, economic and environmental aspects
- Present model results intuitively in graphical and numerical form
- User friendly interface under MS Windows™
- Decision aiding tool



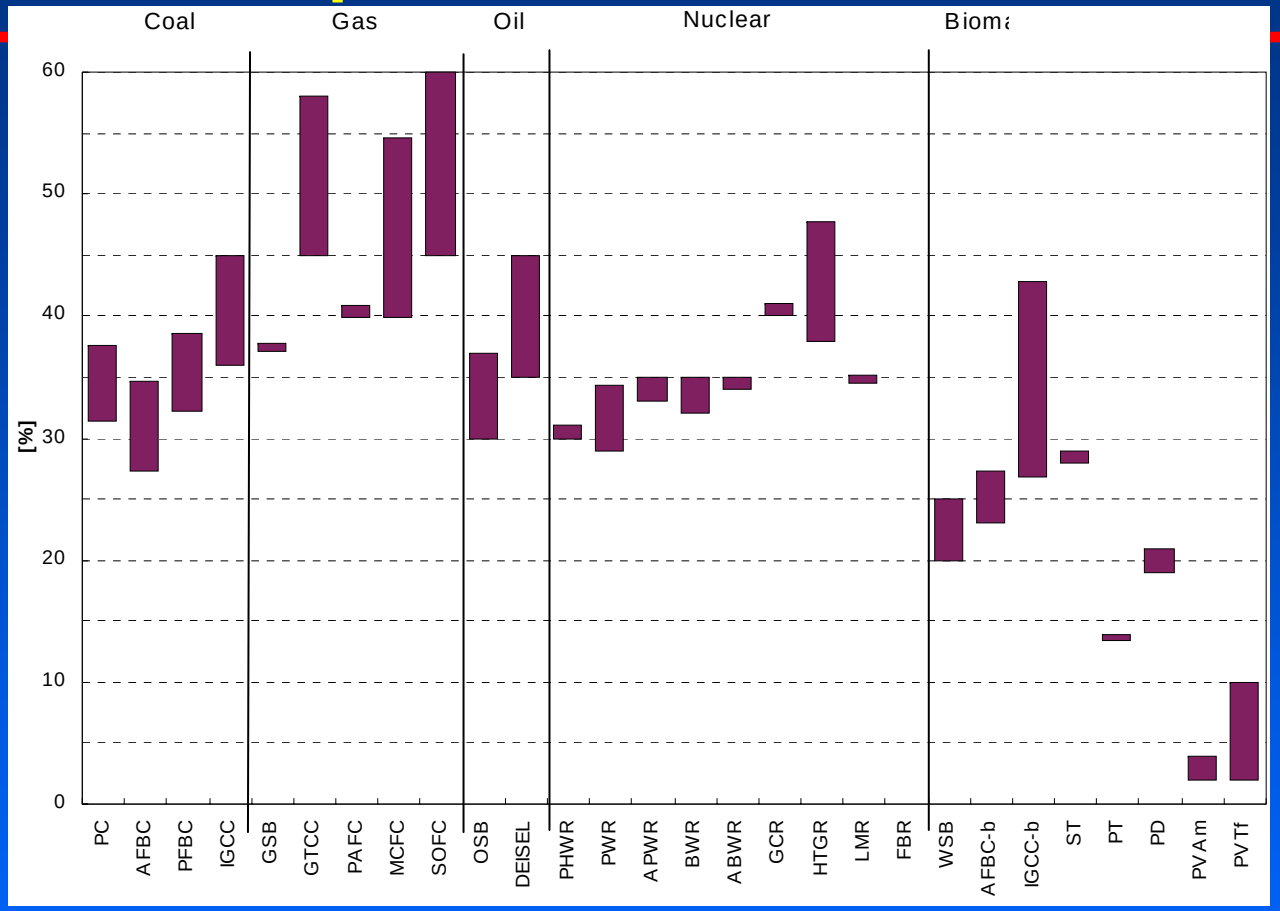
Power Plant Analysis - Main Features

The simplest level of comparisons which can be carried out using the DECADES tools is between different electricity generation plants. Although it is generally agreed that the comparisons between the generation options must be made at the full energy chain level for screening purposes the power plant comparison has its value.

The possibilities offered by this level of comparison includes:

- Assessment of air pollution control devices;
- Estimation of emission factors for main air pollutants for power plants using solid fuel, liquid fuels, gaseous fuels and biomass (wood or bagasse);
- Checking of environmental regulation on point emissions;
- Calculation of annual production costs;
- Calculation of levelized electricity generation costs;
- Establishment of comparison cases and graphical presentation of the results;
- Integration with a decision aiding module.

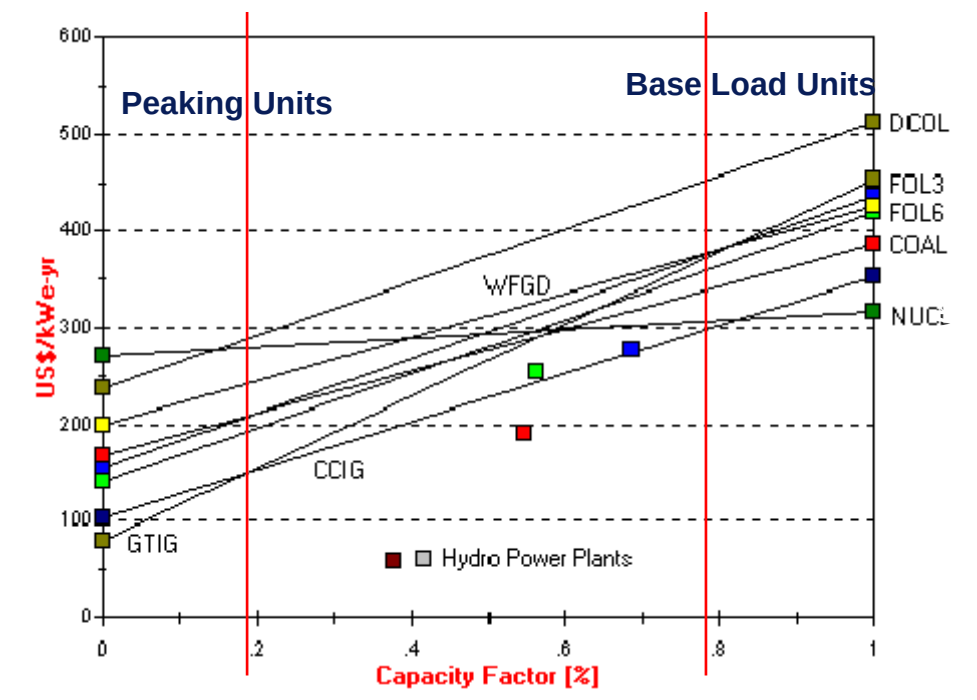
Comparison of Power Plants



Comparisons of net generating efficiency for RTDB technologies

PC- Pulverized Coal, **AFBC**- Atmospheric Fluidized Bed Combustion, **PFBC**-Pressurized Fluidized Bed Combustion, **IGCC**-Integrated Gasification Combined Cycle, **GSB**-Gas Steam Boiler, **GTCC**-Gas Turbine Combined Cycle, **PAFC**-Phosphoric Acid Fuel Cell, **MCFC**-Molten Carbonate Fuel Cell, **SOFC**-Solid Oxide Fuel Cell, **OSB**-Oils Steam Boiler, **DIESEL**- Diesel Engine, **PHWR**-Pressurized Heavy Water Reactor, **PWR**-Pressurized Water Reactor, **APWR**- Advanced PWR, **BWR**-Boiling Water Reactor, **ABWR**- Advanced BWR, **GCR**-Gas Cooled Reactor, **HGCR**-High Temperature Gas Cooled Reactor, **LMR**-Liquid Metal Reactor, **FBR**- Fast Breeder Reactor, **WSB**-Wood Steam Boiler, **AFBC-b** - Atmospheric Fluidized Bed Combustion using biomass, **IGCC-b** - Integrated Gasification Combined Cycle using biomass, **ST**-Solar Thermal, **PT**-Parabolic trough, **PD**-Parabolic dish/Sterling, **PVAm**-Photovoltaic Amorphous, **PVTf**-Photovoltaic Thin Film

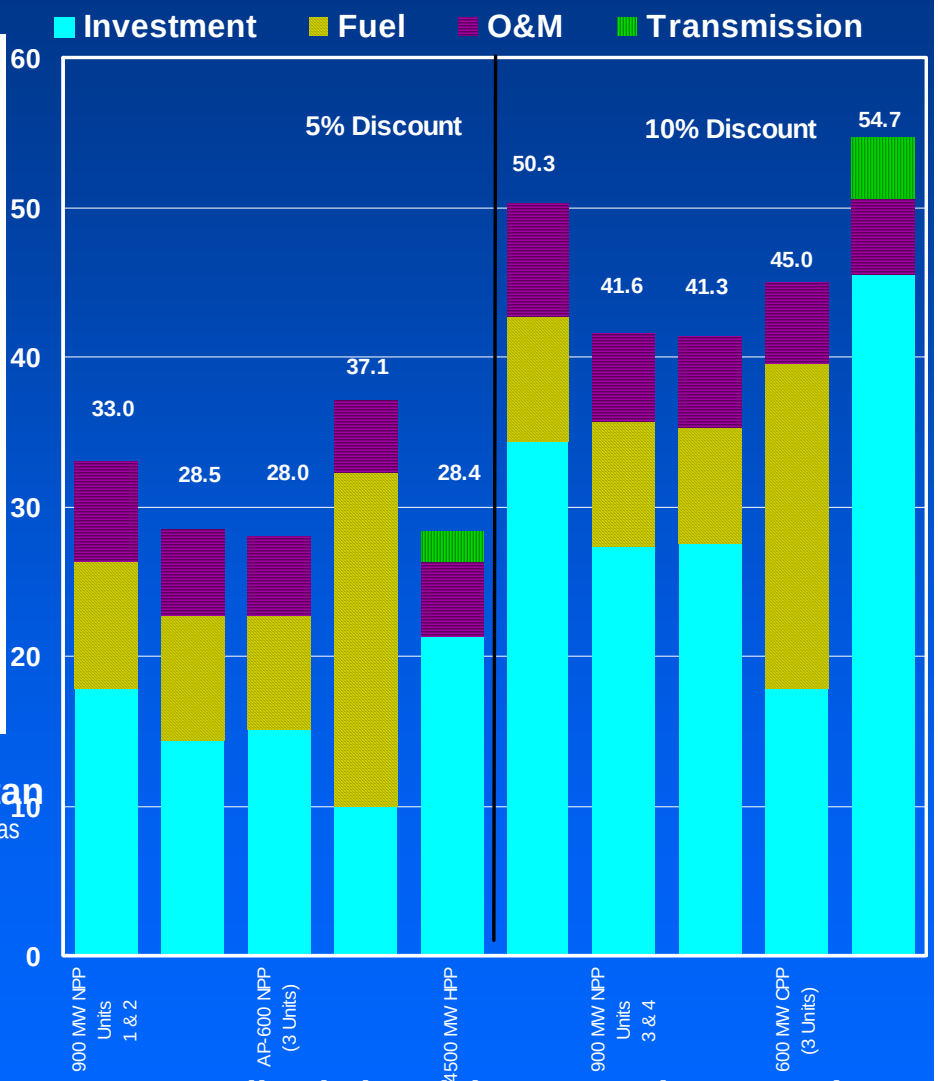
Comparison of Power Plants



Annual production costs at 10% discount rate in Pakistan

(DCOAL Domestic coal, COAL: Imported Coal; FOL3, FOL6: Fuel Oil (300 and 600 MW), GTIG: Gas Turbine, CCIG: Combined Cycle, WFGD: Pulverized Coal + Wet Scrubber, NUCL: Nuclear)

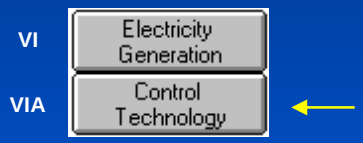
- **Rough tool for comparison of future options (consider only capital recovery factor and the values are discounted to the base year)**
  - **Levelized costs and electricity by discounting them to the base year (constant money)**



Levelized electricity generation costs in China

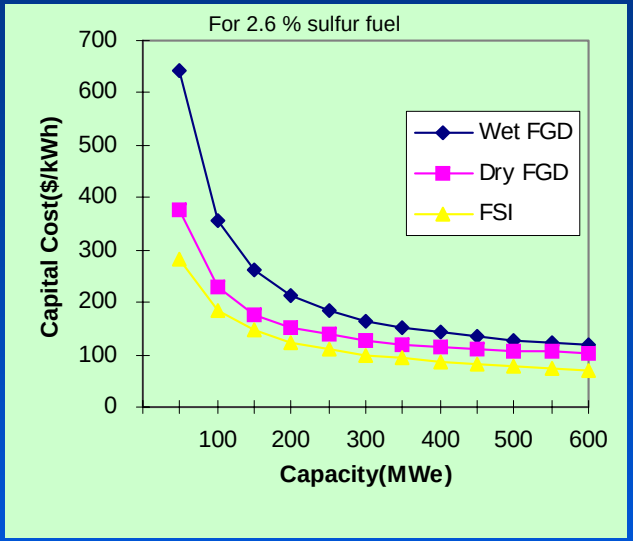
Pollution Abatement Technologies

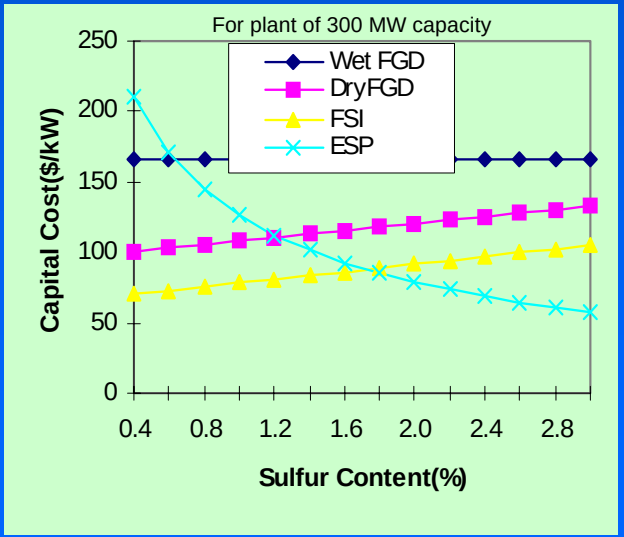
- Modular representation allows for user-specification of abatement technologies



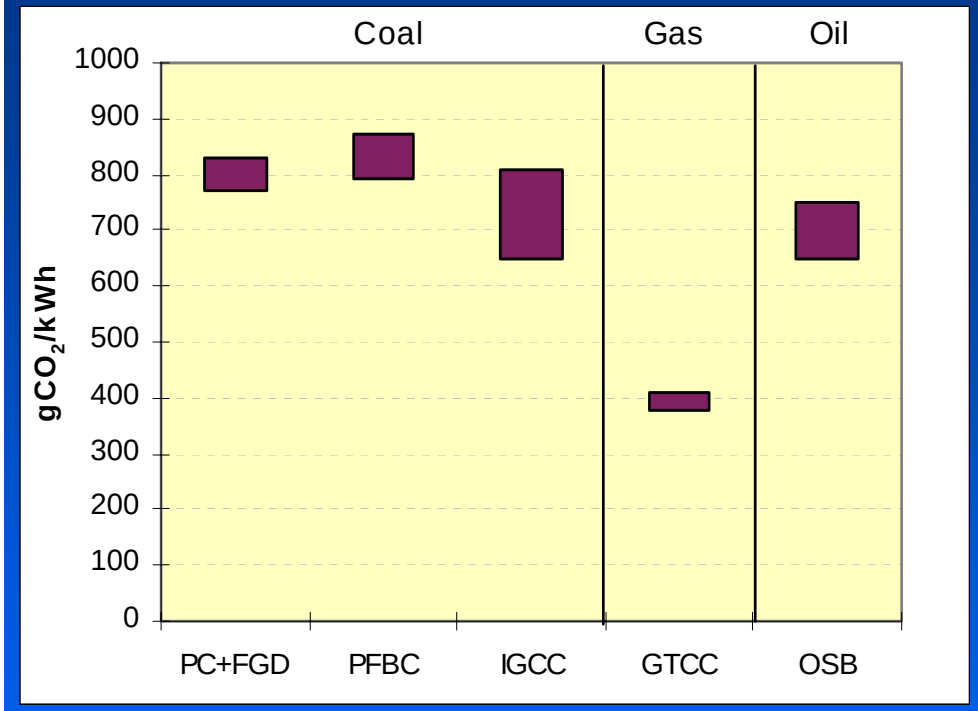
WFGD, DFGD, FSI
ESP, FF
HSCR, CSCR

- Facility characteristics are adjusted based on selected abatement technologies
- Abatement technology effects include: capital cost, fixed and variable O&M cost, plant capacity, plant efficiency, reagent consumption and waste generation
- This approach allows for calculation of cost effectiveness of pollutant abatement



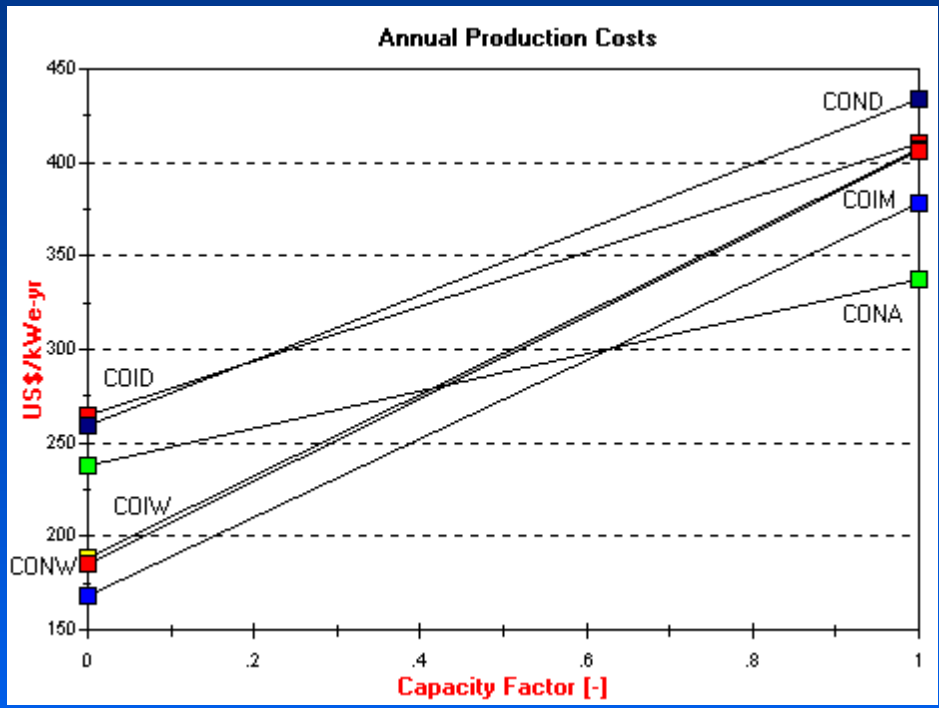


Comparison of Power Plants



CO_2 emissions

(500 MW power plants using similar fuels)



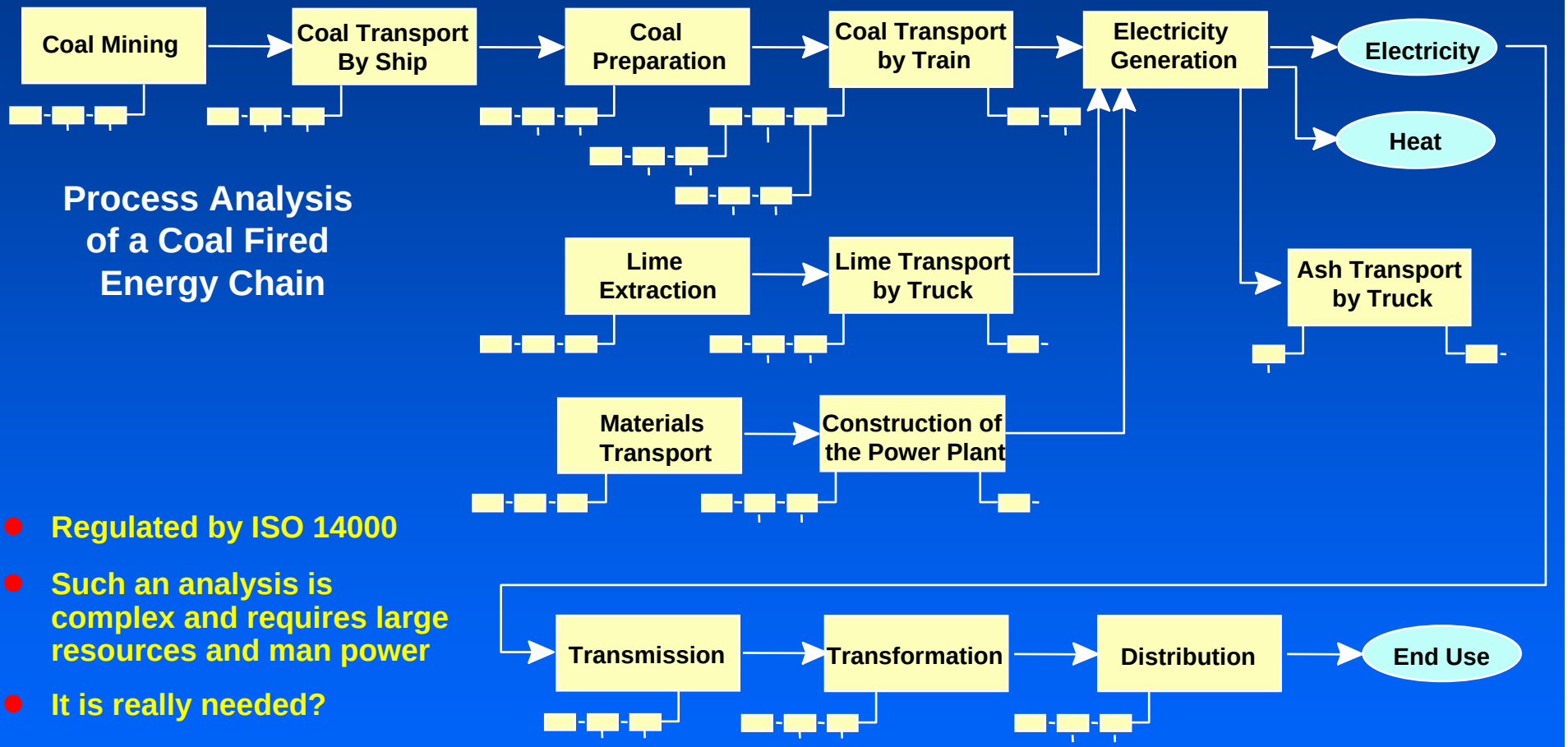
Annual production costs for coal candidates in Brazil with consideration of SO_x abatement technologies

(COIM - imported coal, CONA - domestic coal,
CONW - domestic coal with WFGD, COIW - imported coal with WFGD,
COID - domestic coal with DFGD, COND - domestic coal with DFGD)

Chain Level Analysis - Main Features

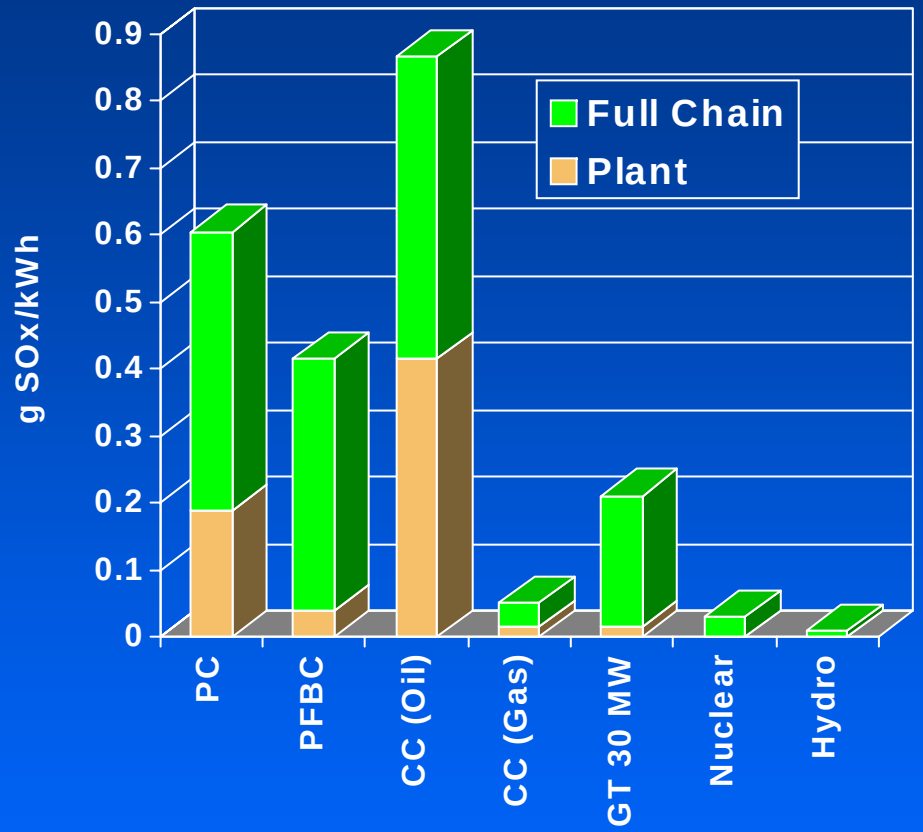
- A flexible interface which facilitates rapid construction of energy chains and ensures the validity of chain representation;
- Calculation of mass flow of fuels and waste;
- Allows installation of air pollutants control technologies;
- Track changes in fuel characteristics along the fuel chain and estimate modifications of power plant emission factors for main air pollutants and performances of abatement technology;
- Estimate direct, indirect and total emission factors and annual emissions for the full energy chain;
- Estimate aggregated emission factors (e.g., greenhouse, acidification, ozone depletion);
- Calculate fuel cost (nuclear) and levelized electricity generation costs based on the chain configuration;
- Establish and analyze comparison cases for a user-specified mix of energy chains and pre-defined electricity demand. Graphical presentation of the results;
- Analyze the results in a decision aiding module.

LCA Approach - Process Analysis

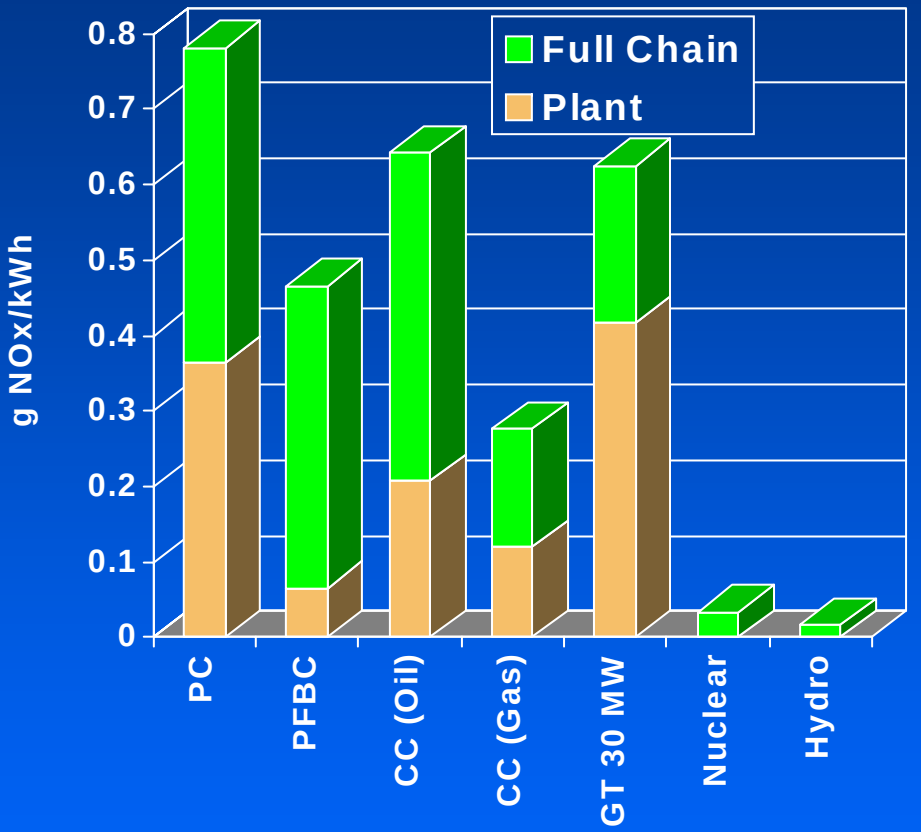


- Regulated by ISO 14000
- Such an analysis is complex and requires large resources and man power
- It is really needed?

Comparison of Chains



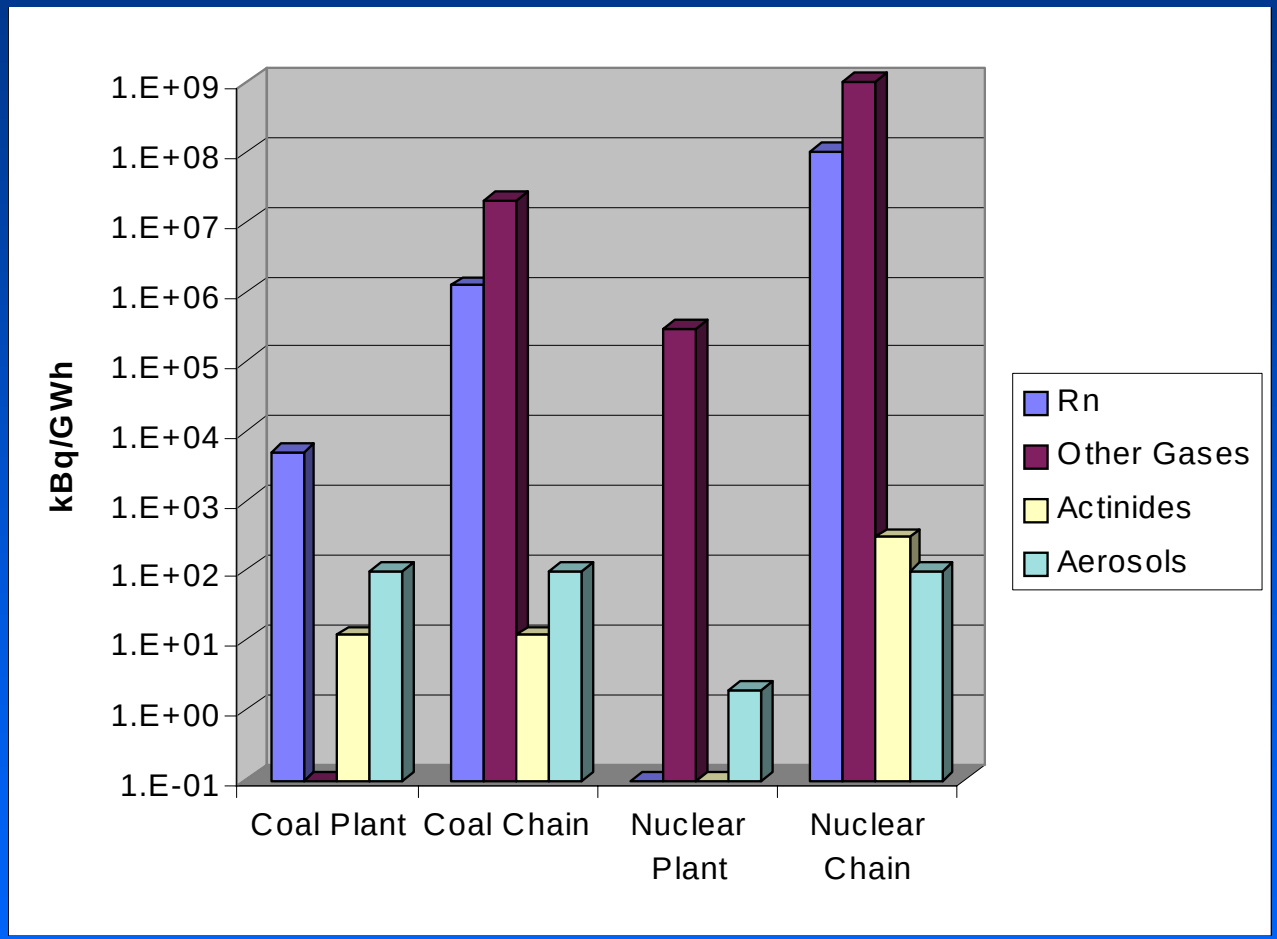
SO_x emissions - Full Chain



NO_x emissions - Full Chain

For some pollutants the main contribution comes for the other steps of the energy chain !!!

Comparison of Chain



Direct radioactive emissions to air
(future power plant and full chain for future hard coal and nuclear options)

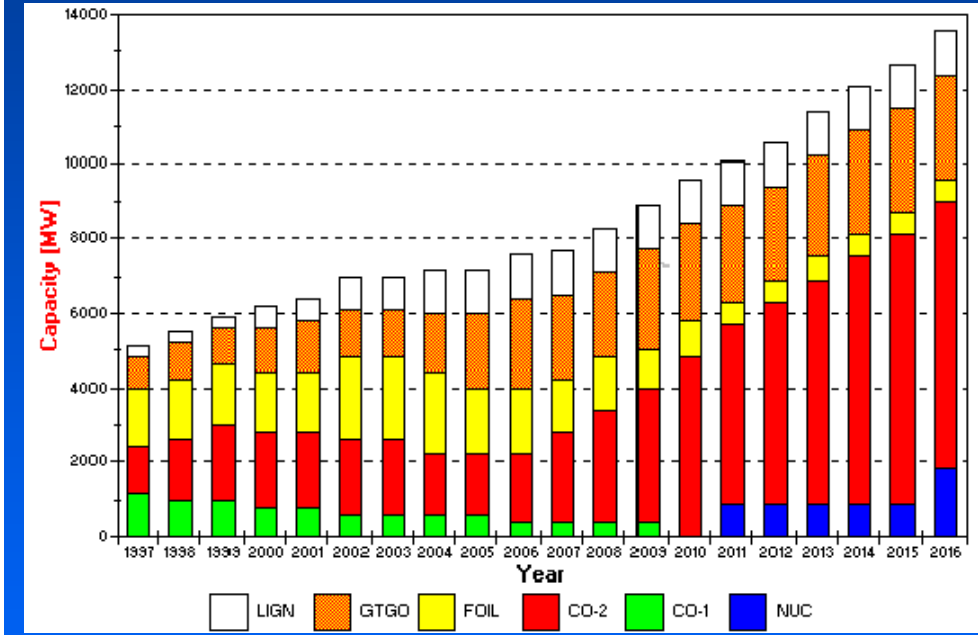
Source: GaBE project - Switzerland

System Level Analysis - Main Features

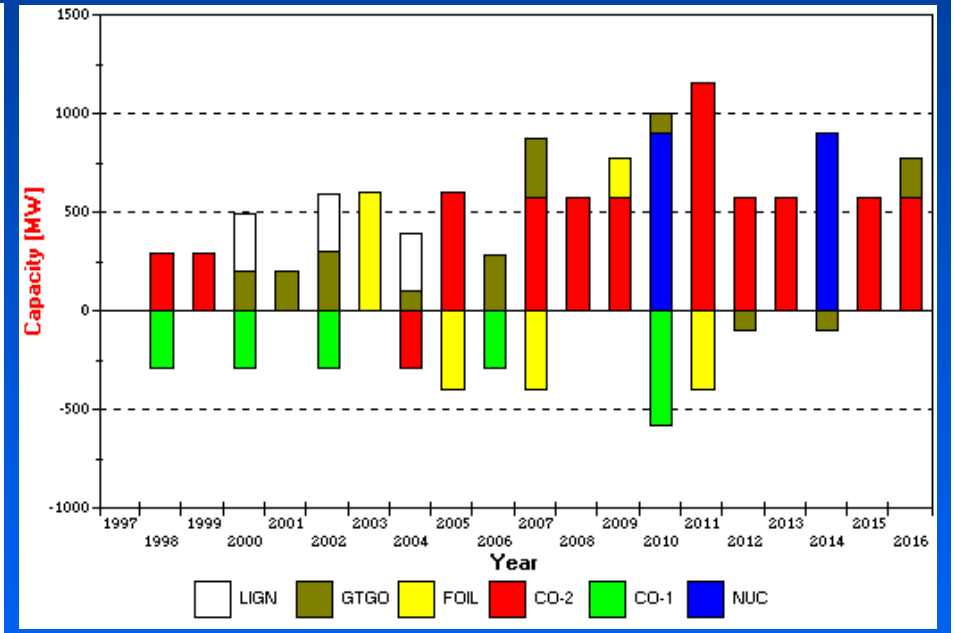
- Allows users to quickly screen electric generation system expansion strategies and to conduct comprehensive studies. It contains three electric system analysis options, ranging from preliminary analysis tools based on screening curves to sophisticated least-cost optimization with dynamic programming.
- Has core features derived from the IAEA's WASP and ENPEP models with an enhanced graphical interface, improved computation of environmental residuals (e.g., air pollutant emissions, land use and waste generation) and extensive reporting capabilities.
- The software can be used to determine environmentally sound least-cost expansion plans for electricity generation systems or to analyze whether a particular project fits into the robust long-range least-cost development plan for a country or region.

Power System Expansion - Approach

- **A least cost expansion plan is devised using probabilistic simulation methods and dynamic programming to find the optimum strategy.**



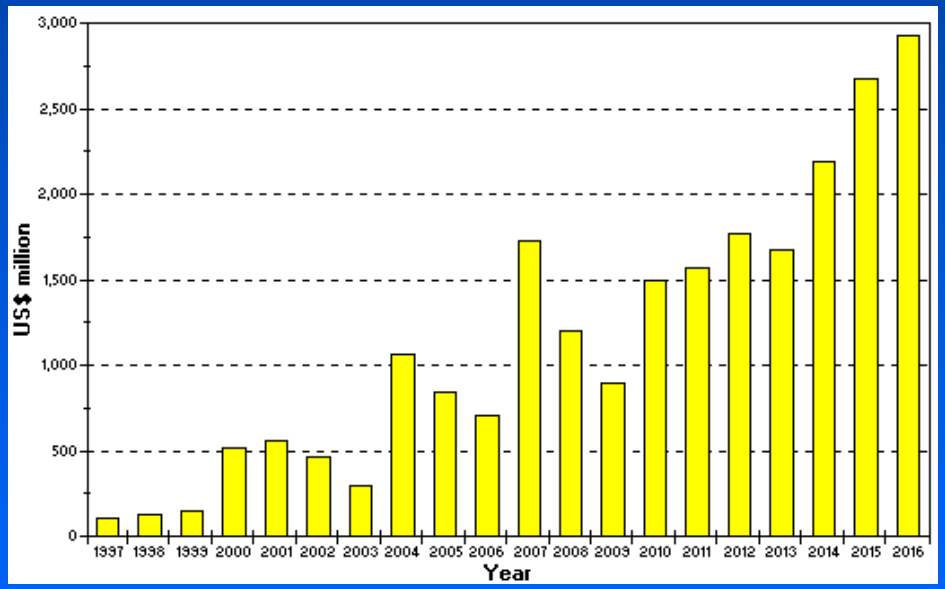
Total installed capacity in thermal system
(DECPAC optimization)
(NUC-Nuclear, CO-1-Domestic coal, CO-2-Imported coal, GTGO-Natural gas, LIGN-Lignite, IMPO-Imported electricity)



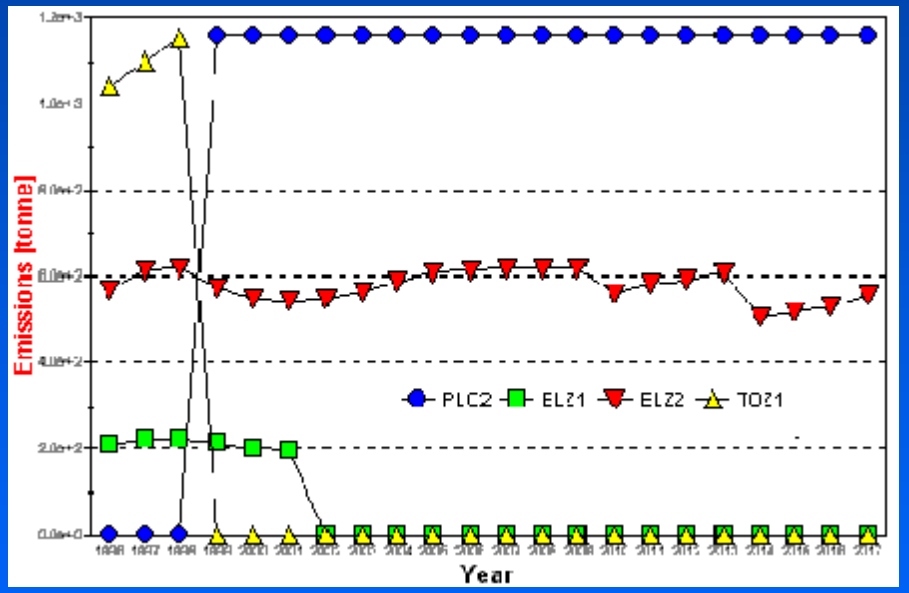
Capacity Added/Retired in Thermal System by Fuel Group

Power System Expansion - Approach

- **The optimization function is cost (including energy not served and salvage value). After optimization, the environmental burdens corresponding to the optimum expansion plan are calculated and the cost effectiveness of air pollutant abatement is estimated.**



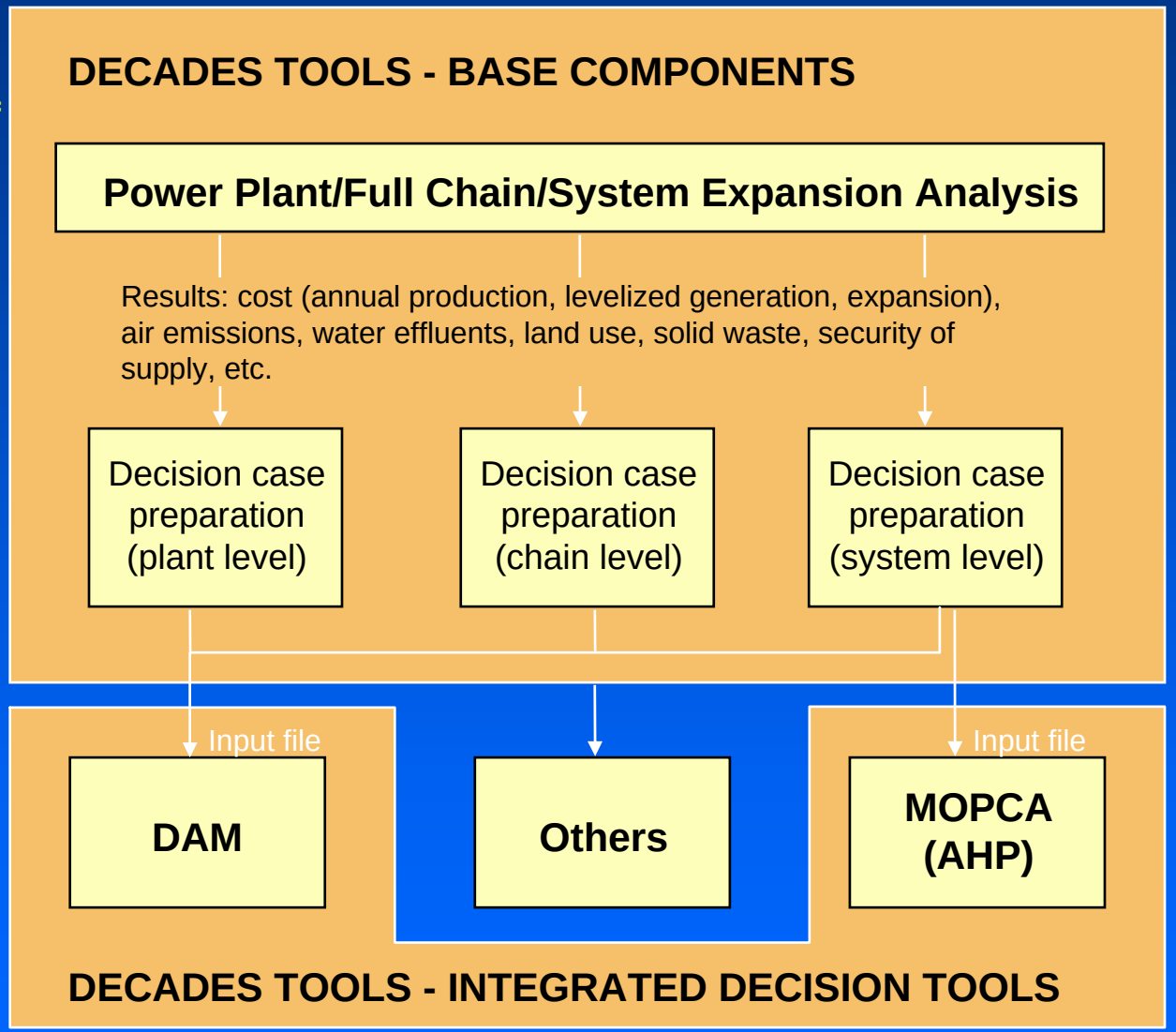
Total system cost (constant 1997 price)



SO_x emissions in Croatia (full energy chain)
(PLO2 - imported coal candidate power plant, ELZ1, ELZ2, TZO1 - existing coal power plants)

Decision Aiding Tools - Approach

- The DECADES tools have the potential to provide the decision-maker with a wealth of valuable information about costs and impacts at the power plant, full energy chain and electricity system levels, which, can be overwhelming. Therefore, a decision aiding tools is needed.
- A modular approach was adopted. In this approach, the base components of the DECADES Tools are used to define and assess comparison cases, at power plant, full energy chain and electricity expansion system. The results of these cases are exported to decision aiding tools.
- It was decided to select two methodologies and tools to be integrated in the DECADES software: the DAM and MOPCA



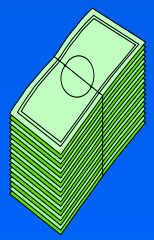
DAM - Decision Aiding Module (interval decision). MOPCA - Models of power system planning and comprehensive assessment

The Decision Aiding Module - DAM

Was developed and integrated in the DECADES Tools to help the analyst to:

- **identify candidate solutions (optimal alternatives) to the problem using different optimality concepts,**
- **understand why the identified alternatives are optimal,**
- **test the sensitivity of candidate solutions to the data used in the analysis,**
- **present the results of analysis in graphical and numerical formats.**

DAM uses unit damage costs as weights to calculate the total cost associated with a decision alternative.



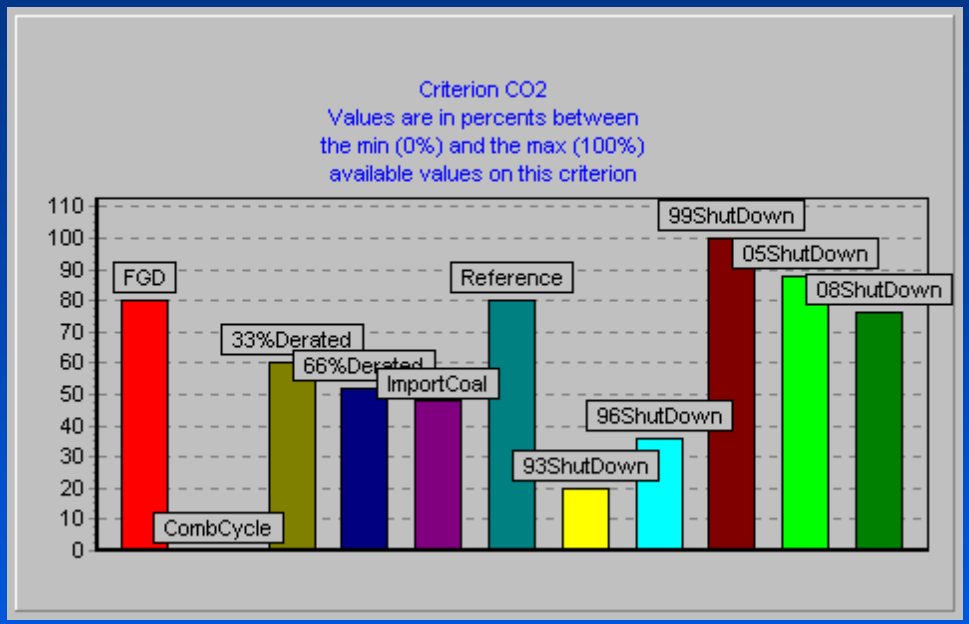
Total Cost = System Expansion Cost +

+ *a* x Cost of Imports + *b* x SO_2 emissions +

+ *c* x NO_X emissions + etc.

a,b,c are unit damage costs

DAM - Example of Use



Comparison on one criterion (CO_2 emissions)

FDG and combined cycle alternatives are the potential optimal decisions

Alternative	Potential Optimality
FGD	potentially optimal
CombCycle	potentially optimal
33%Derated	not potentially optimal
66%Derated	not potentially optimal
ImportCoal	not potentially optimal

Table of Potential Optimality
Source of trade-offs:
Table of Trade-offs

Criterion 1	Criterion 2	Trade-offs
Particulates	Cost	60
SO2	Cost	360
NOX	Cost	150
CO	Cost	50
NMVOC	Cost	800

Trade-offs rendering alternative
FGD optimal

Reference Book on Integrated Approach

- The draft of the book was prepared in 1994 - 1996. The final draft was prepared by an external consultant and reviewed by PESS in 1997-1998;

- The objective of the book is to provide state-of-the-art information on enhanced electricity planning;

- The enhanced electricity planning, as described in the book:
  - → incorporates classic IRP with comprehensive assessment of full energy supply system;
  - → is not bounded to national borders and covers the costs and impacts to the entire energy system (inside and outside the country were the energy is consumed);
  - → integrates the precautionary principle (reflects the willingness to avoid an activity which that likely would results in negative effects).

Review of Methodologies and Tools for Comparative Assessment

- A document entitled: "Computer Tools for Comparative Assessment of Electricity Generation Options and Strategies" was prepared.
- Selection Criteria for inclusion in the document:
  - → Capability of addressing the main elements of comparative assessment of different electricity generation options, in particular from economic and environmental standpoint;
  - → The availability of tools at low or no cost; and
  - → The applicability of tools on Personal Computers (PCs).
- Tools classification:

Main Tools:

- → Energy Information Systems
- → Energy System Models
- → Modular Packages
- → Integrated Models

Additional Tools:

- → Tools under Development
- → Country Specific Tools
- → Issue Specific Tools

DECADES CRPs

- The Co-ordinated Research Programmes (CRP) are designed to obtain new knowledge and better understanding or resolution of scientific and technical problems directly relevant to specific programmatic objectives outlined in the Agency's Programme;
- In a larger context, such co-ordinated research enhances the practical application of atomic energy for peaceful purposes through the world;
- Typically, Research Contracts of US$ 3,000 to US$ 5,000 are awarded and support is provided for participation to Research Co-ordination Meetings (RCMs).

DECADES CRPs

- **CRP I1.40.01 on Case Studies to Assess and Compare the Potential Role of Nuclear Power and Other Options in Reducing the Emissions and Residuals from Electricity Generation (1994-1996).**
- **CRP I1.40.02 on Case studies to assess and compare different energy sources in sustainable energy and electricity supply strategies (1997-1999).**
  - **The objective of the CRP is to enhance the capabilities of the Member States, particularly in the developing countries, to perform studies on comparative assessment of different options and strategies for electricity supply in conformity with sustainable developments and to test and demonstrate the use of approaches, databases and tools, established and reviewed within the DECADES project, in the planning and decision making process for the electricity sector.**
- **31 Member States are participating.**

Example of Reports

- Least cost electricity system expansion in Russia (central and north-west regions) and China (Fujian and Shandong provinces);
- CO_2 taxation (Hungary, Croatia and Romania);
- Selected issues on the changing structure of the electric power industry in USA;
- Assessment of the potential of wind and solar in Greece. Optimization of interconnected systems (Greece, Bulgaria and Italy);
- GHG mitigation in Egypt. Estimation of the atmospheric emissions associated to hydro power plants;
- Sustainable energy and electricity supply strategies in Switzerland;
- Impact of privatization on Argentina generation mix.