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# Energy Modeling in GaBi – 2021 Edition

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# Agenda

- Overview Electricity Model
- Individual Modules – Energy Carriers
- Individual Modules – Energy Conversion
- Electricity Mixes

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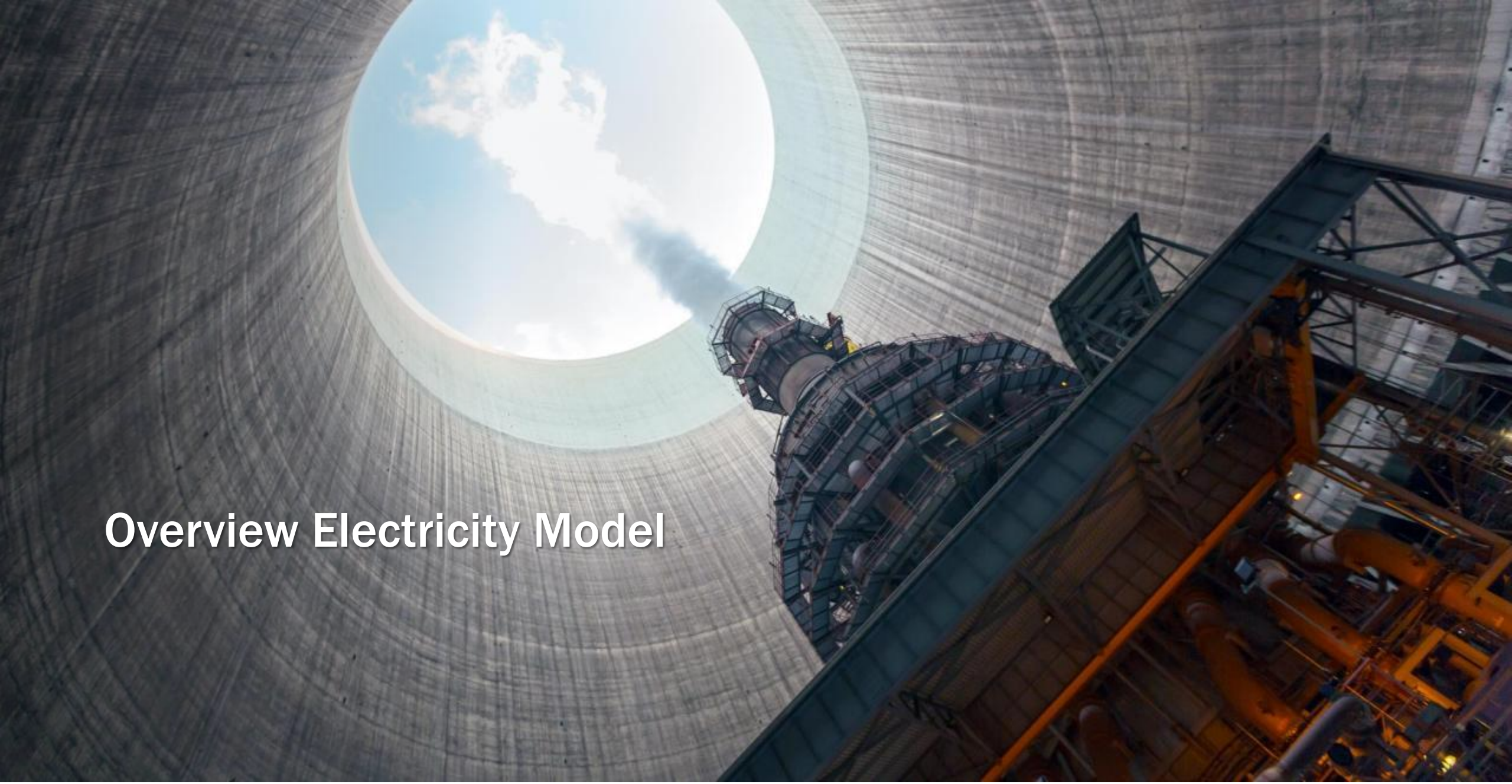

# Overview Electricity Model

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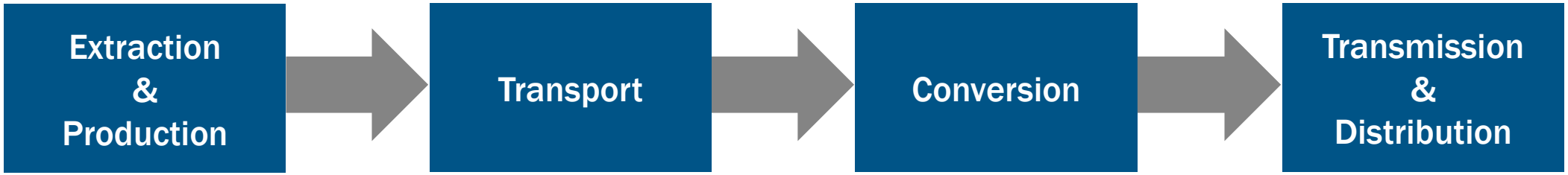
# Overview Electricity Model

## Life Cycle Assessment of Energy Supply Chains

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# Overview Electricity Model

## Energy Systems / Generic Modeling

To provide a comprehensive range of LCI data sets, a large amount of data has to be handled

How do we handle large amounts of data and generate consistent datsets?

**Challenge**

Development of a model which allows the adaptation to various country-specific and technology-specific boundary conditions

**Approach**

Generic, parameterized, adaptable models

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# Overview Electricity Model

## Energy Generation (Power Plants) – Example

**Conversion parameter**

**Energy conversion unit:**

- Plant type (direct, CHP, etc.)
- Combustion technology
- Combustion efficiency
- Type of cooling system
- Flue gas cleaning technology
- Allocation method

**Fuel parameter**

- Calorific value
- Carbon content
- Sulphur content
- etc.

**Life Cycle Inventory**

- Auxiliary materials
- Emissions ($CO_2$, $NO_x$)
- Waste heat

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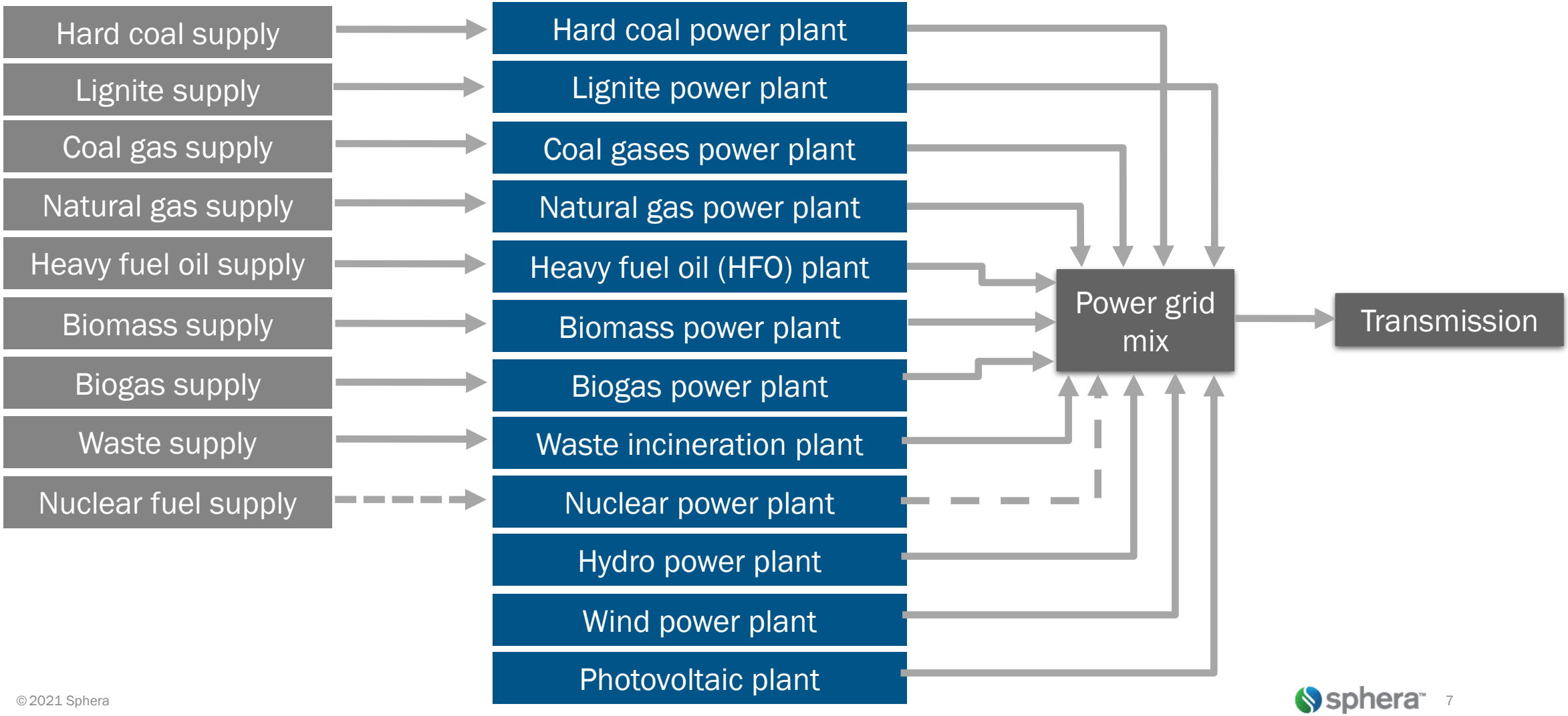
# Overview Electricity Model

## Parameterized Models – Electricity Grid Mix

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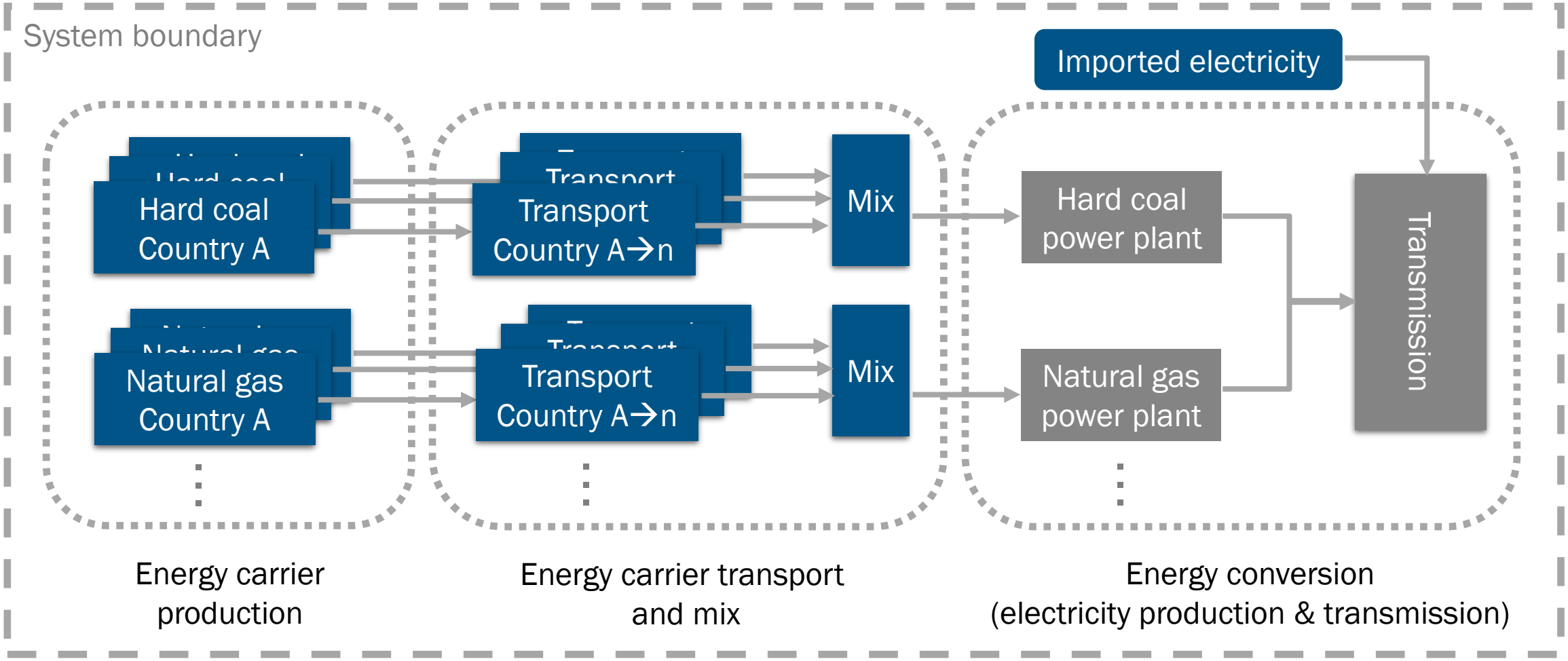
# Overview Electricity Model

## Parameterized Models – Electricity Grid Mix

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# Overview Electricity Model

## Conclusions

- Generic models offer the adaptability to various country and boundary conditions → micro, macro and global level
- Results are comparable due to consistent approach and system boundaries
- Allows comprehensive LCI, LCIA, carbon footprint and water footprint analysis
- Complex models with a large amount of data, but reduced number of key parameters are easy to manage and adapt
- High quality data with acceptable time effort → reduce costs
- Supports scenario modeling and outlooks
- Creating, maintaining and updating the GaBi databases since 1990

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# Individual Modules – Energy Carriers

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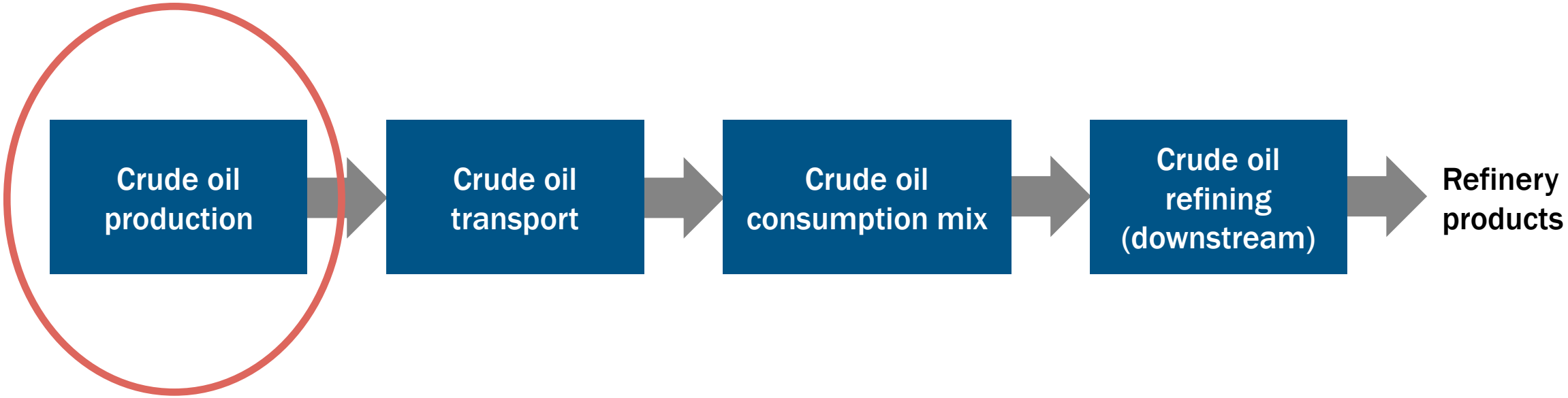
# Individual Modules – Energy Carriers

## Example: Refinery Products – Supply Chain

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# Individual Modules – Energy Carriers

## Example: Refinery Products – Crude Oil Production Technologies

**Crude oil production technologies**

- Conventional crude oil production technologies (onshore, offshore)
  - Primary crude oil production
  - Secondary crude oil production
  - Tertiary crude oil production (enhanced oil recovery):
    steam injection
    solvent injection
    natural gas injection
    nitrogen injection
    carbon dioxide injection
- Unconventional crude oil production technologies (onshore)
  - Oil sands (in-situ, open-pit)
  - Oil shale (in-situ, open-pit, underground)

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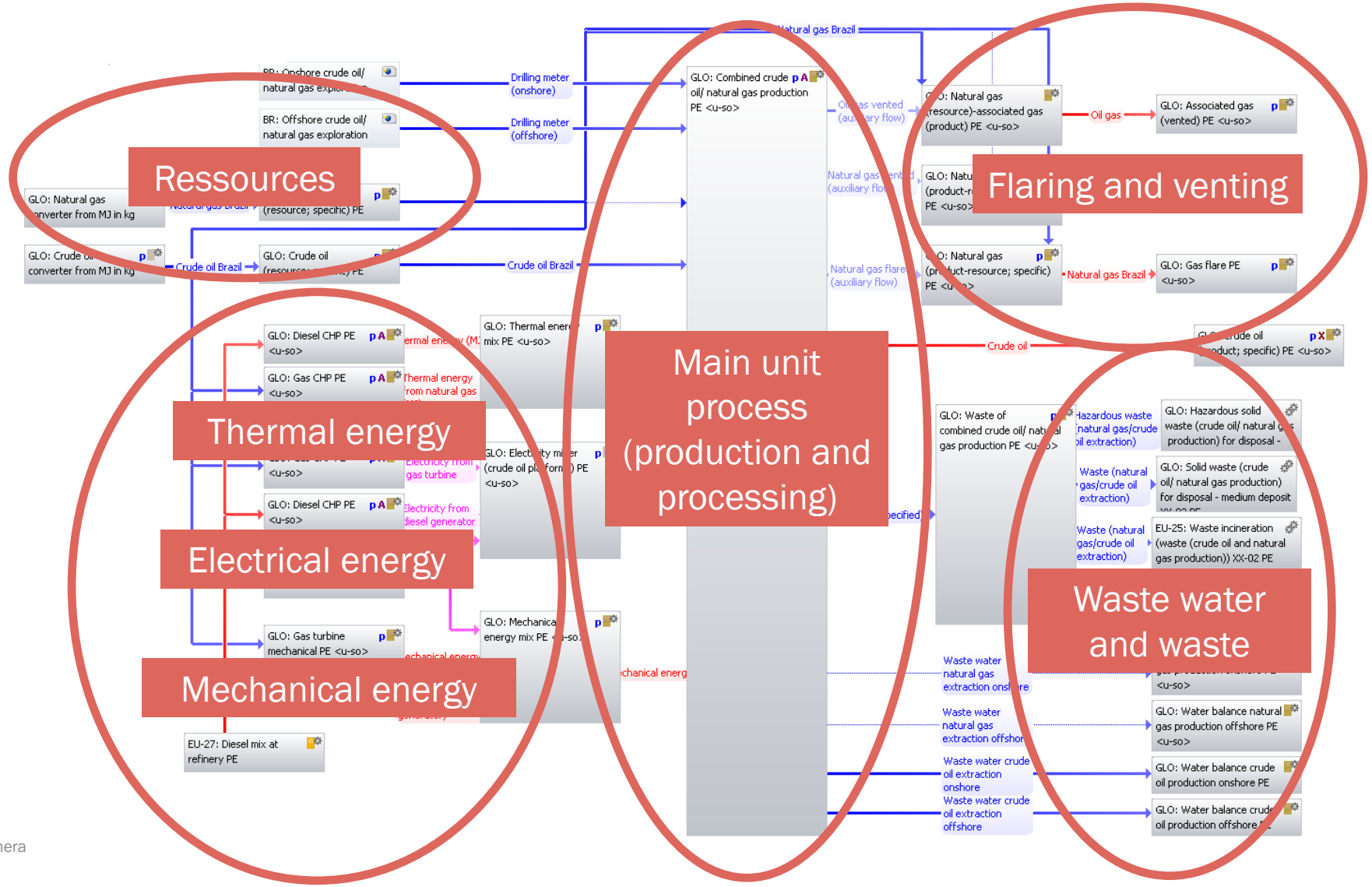
# Individual Modules – Energy Carriers

## Example: Refinery Products – GaBi Screenshot of Crude Oil Production

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# Individual Modules – Energy Carriers

## Refinery Products – Model Parameters of Crude Oil Production

Calculation of energy consumption depending on:

- Reservoir depth
- Water-oil-ratio (at well)
- Steam-oil-ratio and steam quality (if any)
- Amount of injected media (water, steam, solvent, etc.)
- Efficiency (pumps, generators etc.)
- Quality of natural gas (concentration of water, $H_2S$, $CO_2$)

Data from measurements, literature for:

- Flaring and venting rates
- Solid waste
- Waste water
- Share of onshore / offshore production
- Produced amount of crude oil / natural gas / natural gas liquids (NGL) (allocation according to net calorific value)

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# Individual Modules – Energy Carriers

## Refinery Products – Key Parameters of Crude Oil Production

- Technology used (primary, secondary, tertiary production)
- Energy supply (source / efficiency / type of conversion)
- Share of produced crude oil, natural gas and NGL
- Drilling / reservoir depth
- Water-oil-ratio
- Flaring and venting rates
- Share of onshore / offshore production

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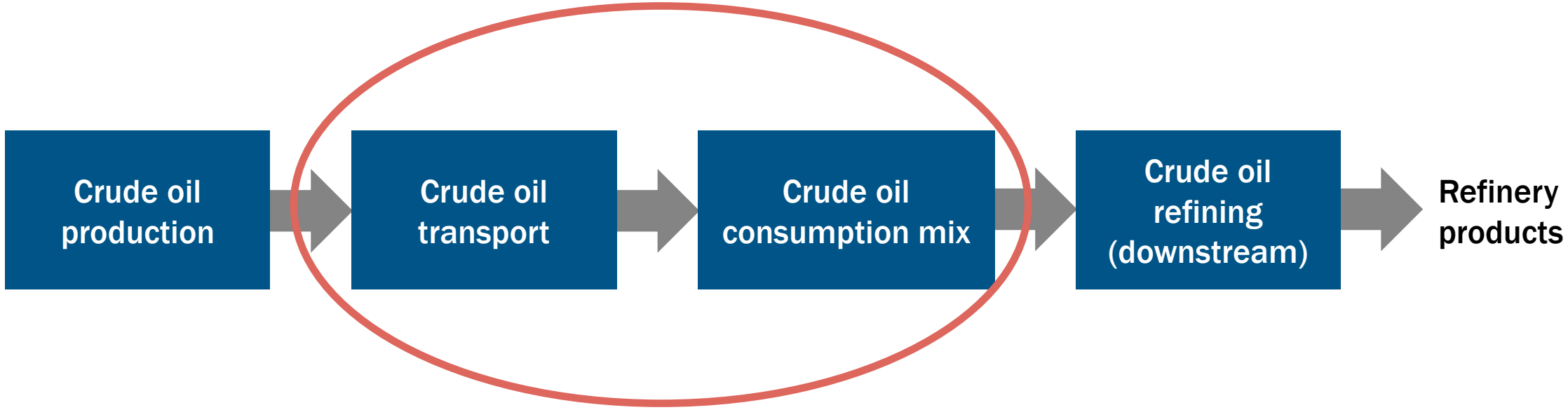
# Individual Modules – Energy Carriers

## Example: Refinery Products – Supply Chain

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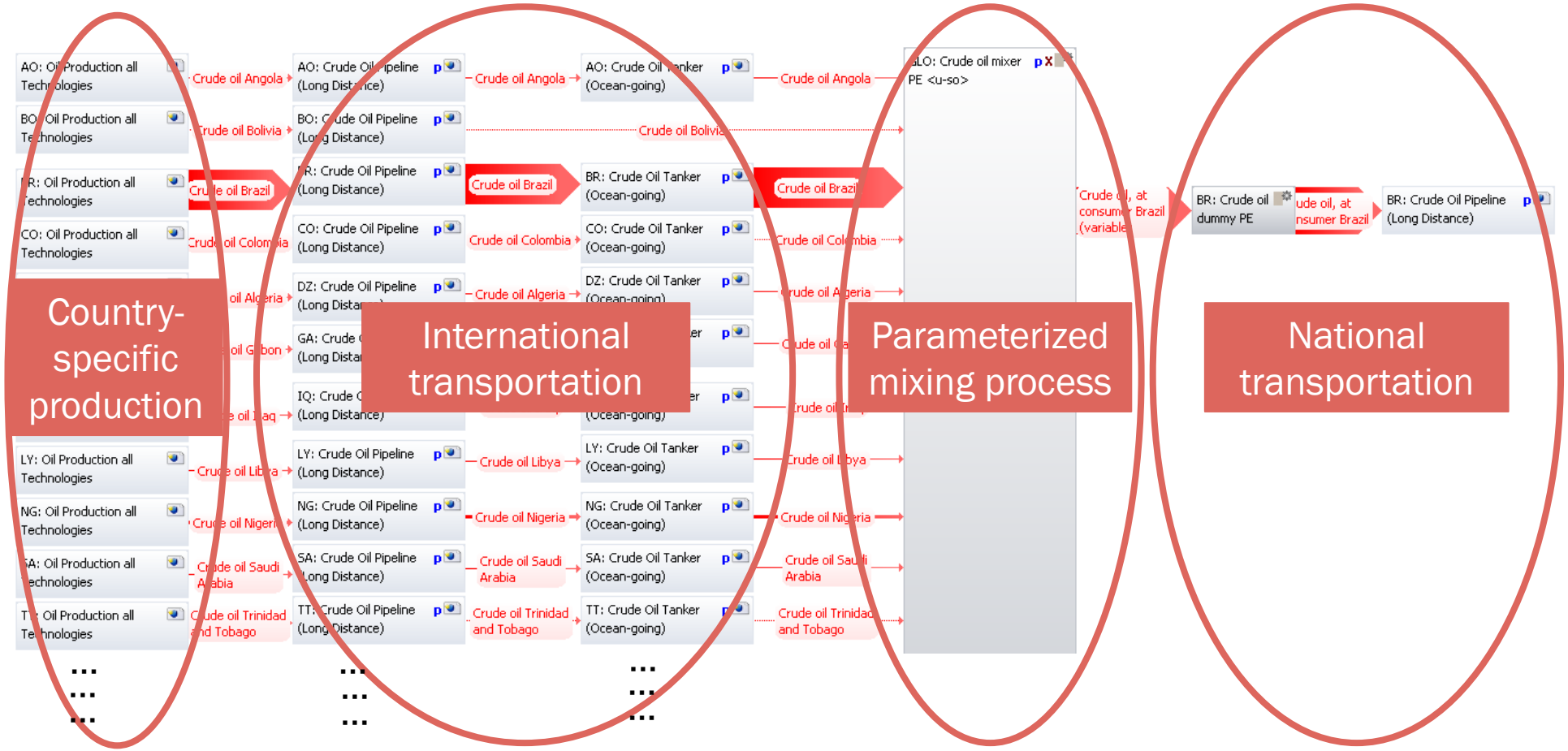
# Individual Modules – Energy Carriers

## Example: Refinery Products – GaBi Screenshot of Crude Oil Consumption Mix



# Individual Modules – Energy Carriers

## Refinery Products – Key Parameters of Crude Oil Production

- Consumption mix by country of origin
- Transport type (pipeline, tanker, LNG tanker)
- Transport distances
- Distribution losses
- Efficiency and distances between compressor stations (pipeline)
- Energy supply of compressors (pipeline)

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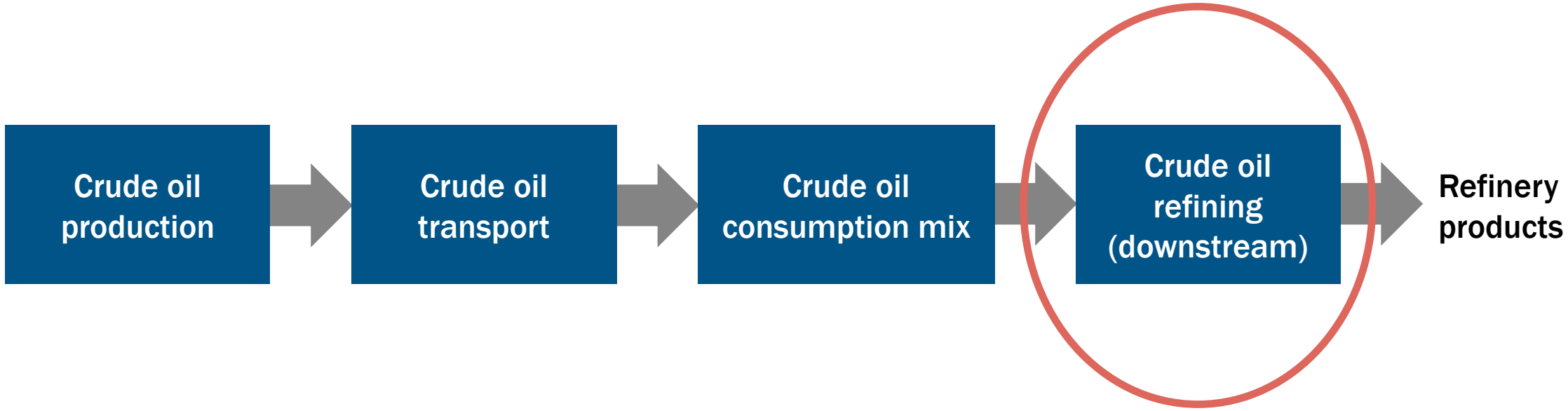
# Individual Modules – Energy Carriers

## Example: Refinery Products – Supply Chain

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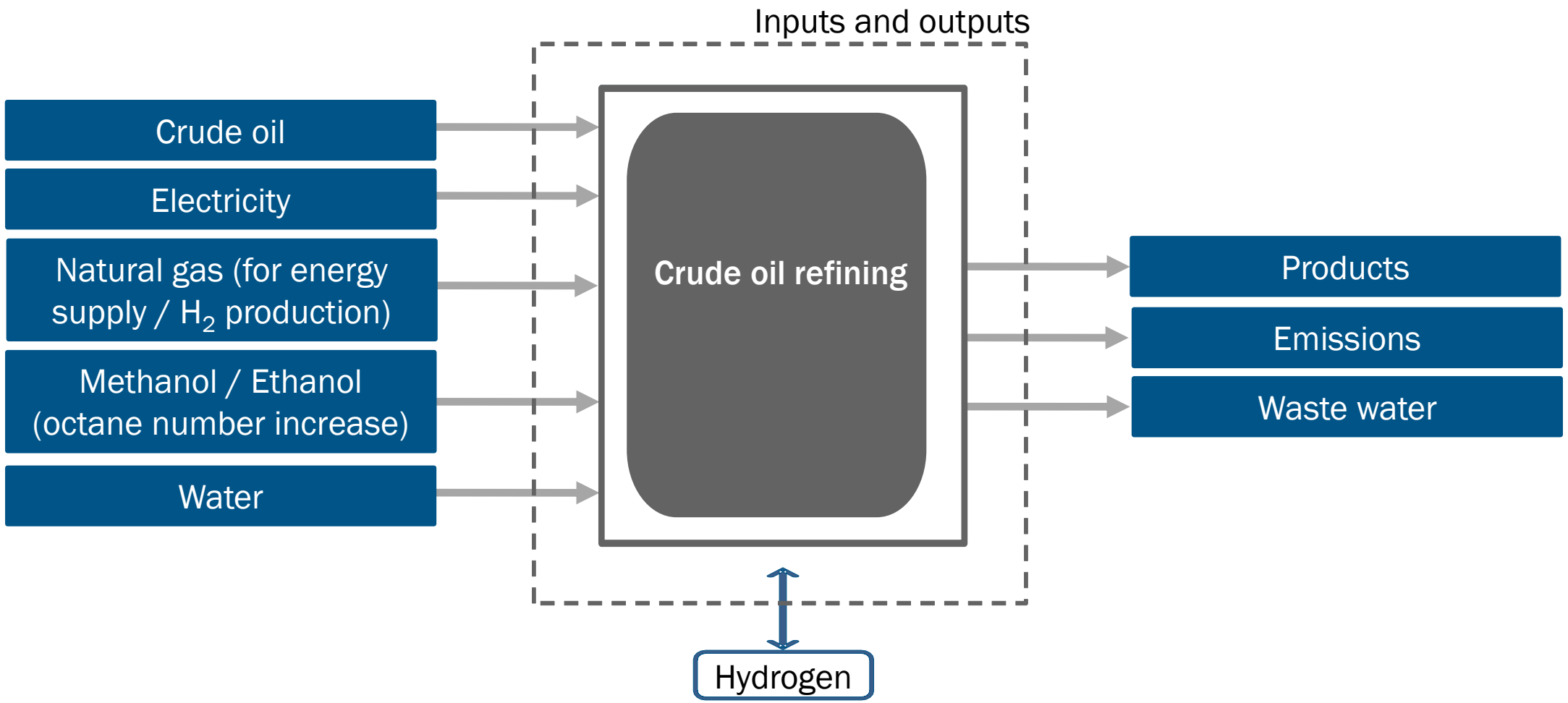
# Individual Modules – Energy Carriers

## Example: Refinery Products – Refinery System Boundary

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# Individual Modules – Energy Carriers

## Example: Refinery Products – Refinery System Boundary

- Petroleum refineries are complex plants.
- The combination and sequence of the processes is usually very specific to the characteristics of the crude oil and the products to be produced.
- Due to the interlinkages within the refinery, all refinery products have to be considered.
- What technologies and processes are used within the refinery?
- Possible approaches regarding level of detail of analysis:
  - Refinery as black box model
  - Detailed refinery analysis (every single process)
  - Hybrid approach
- Level of detail in dependency of scope, level of data availability, etc.

→ Every refinery is individual

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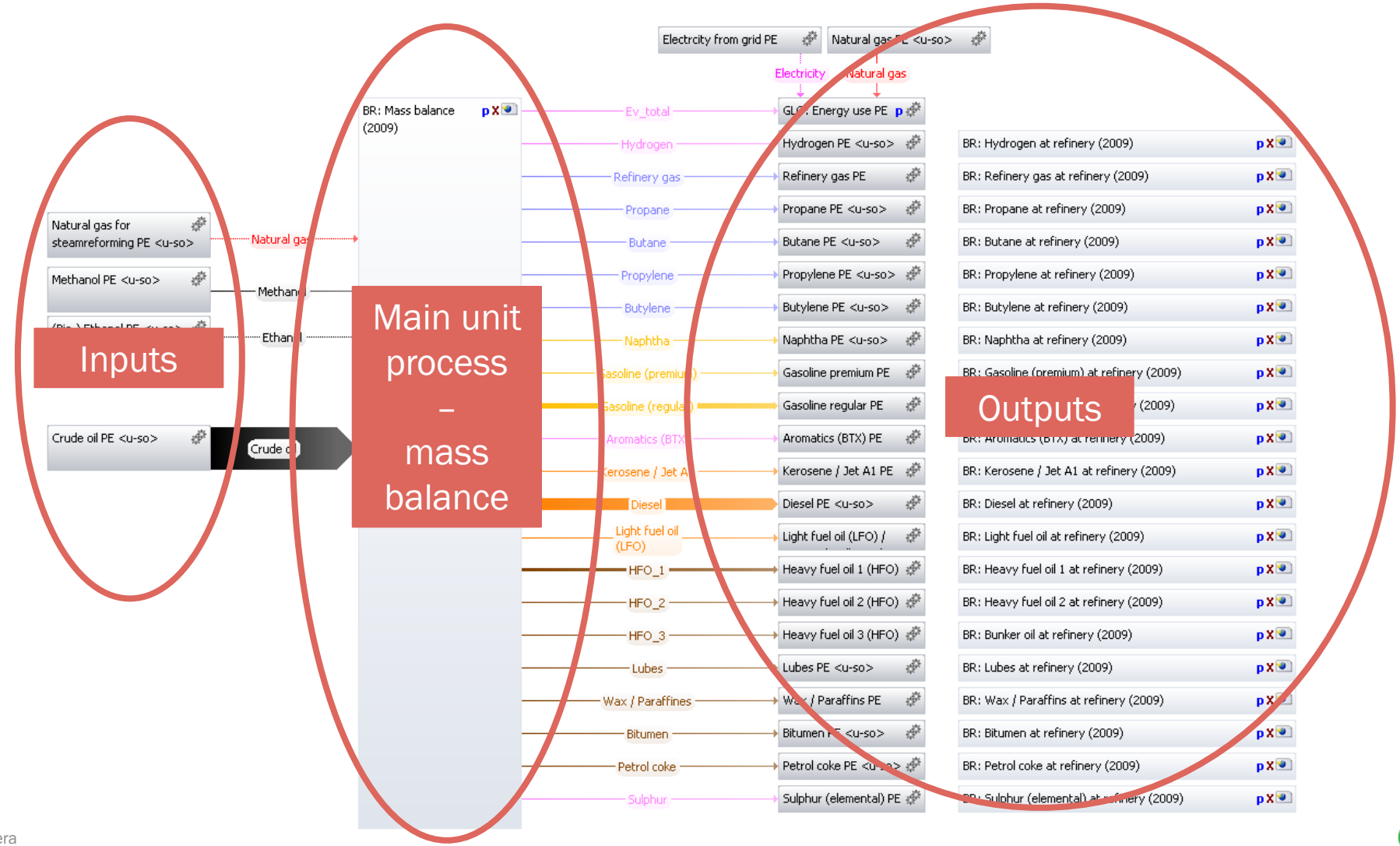
# Individual Modules – Energy Carriers

## Example: Refinery Products – GaBi Screenshot of Refinery

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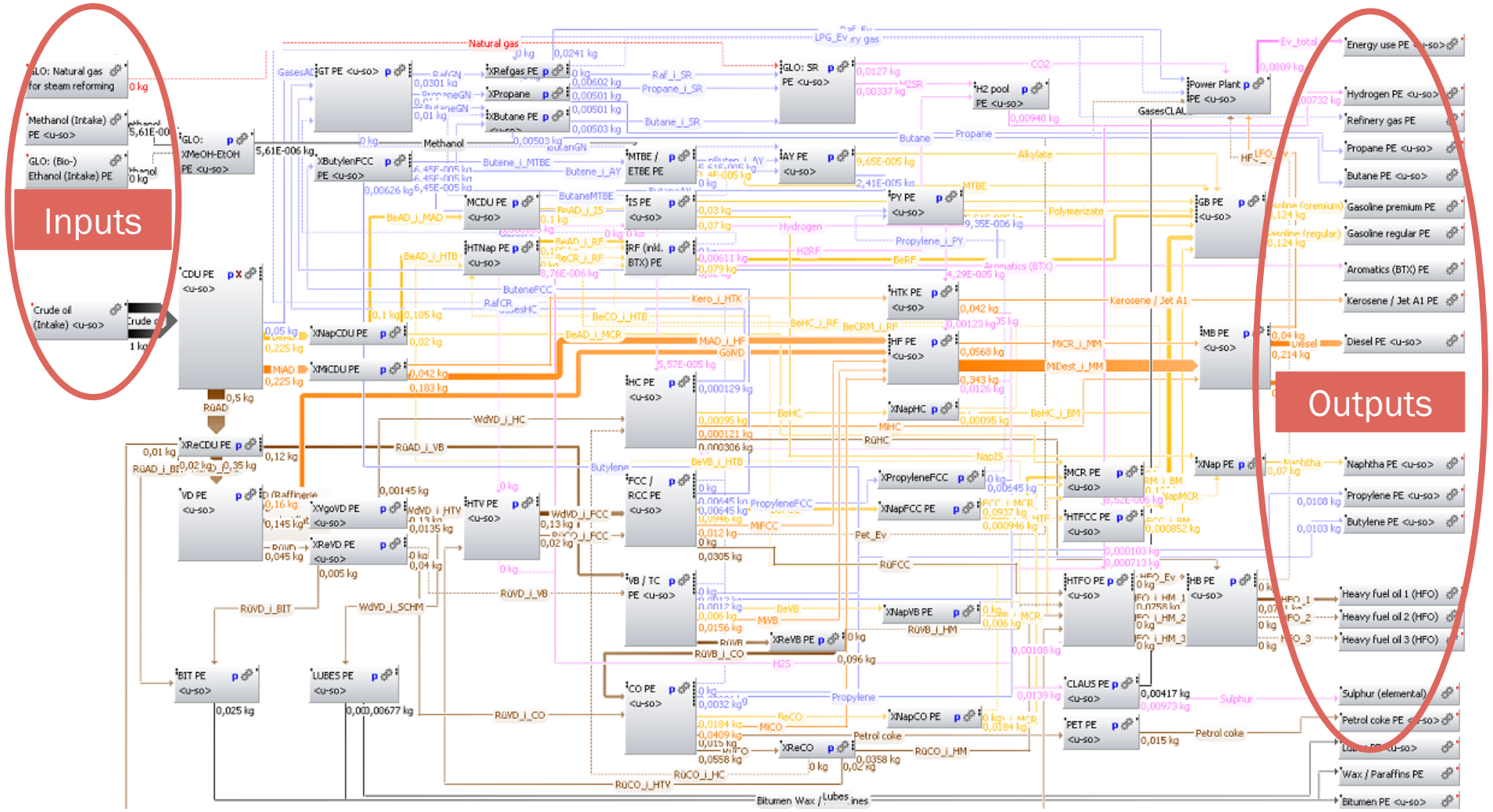
# Individual Modules – Energy Carriers

## Example: Refinery Products – GaBi Screenshot of Refinery




Complex models for the calculation of environmental profiles can be set up and managed

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# Individual Modules – Energy Carriers

## Example: Refinery Products – Refinery Approach

- Method:
  - Detailed modeling of the refinery mass and energy balance
  - Emissions of the total refinery (black box) are allocated to the products
  - But allocation factors are modeled precise (due to detailed mass & energy balance)
- Consequence: Clear, relatively precise, but no environmental analysis of single processes possible
- Which data are required?
  - Input and output flows of refinery
  - Product output spectrum, i.e. 20% diesel, 10% naphtha, 30% gasoline, 2% refinery gas,…
  - Amount of purchased energy from external sources (outside refinery)
  - Process capacities (incl. utilization) of each process → detailed flow chart including figures to model the mass balance
  - Environmental impacts, i.e. emissions of the whole refinery (black box, bubble)
  - Feedstock and product properties (net calorific value, sulphur content,…)
  - Energy demand of each single process

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# Individual Modules – Energy Conversion

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# Individual Modules – Energy Conversion

## Example: Hard coal power plant (1/2)

**Conversion parameter**

**Energy conversion unit:**

- Plant type (direct, CHP, etc.)
- Combustion technology
- Combustion efficiency
- Type of cooling system
- Flue gas cleaning technology
- Allocation method

**Fuel parameter**

- Calorific value
- Carbon content
- Sulphur content
- etc.

**Life Cycle Inventory**

- Auxiliary materials
- Emissions ($CO_2$, $NO_x$)
- Waste heat

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# Individual Modules – Energy Conversion

## Example: Hard coal power plant (2/2)

- Basis for all combustion models
- Efficiency, share of CHP/direct, own consumption: Data are calculated based on statistics and directly used in the power plant models.
- Emissions:
  - Relevant emissions ($CO_2$, CO, $NO_X$, $SO_2$, dust, NMVOC, $N_2O$, $CH_4$, dioxin) are derived country-specific from literature/databases. Data is used directly and partly indirectly (used to determine e.g. efficiency for desulphurization or dedusting in the model.
  - Other emissions like heavy metals, consumption of air, water in flue gas etc. are calculated based on combustion calculation and fuel properties
- Energy input: Input of energy carriers is calculated based on efficiency, allocation and net calorific value (NCV) of energy carrier
- Waste/secondary products (bottom ash, fly ash, gypsum, etc.): Calculation based on fuel properties and combustion calculation (transfer coefficients)

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# Individual Modules – Energy Conversion

## Example: Hydro Power Plant (1/3)

### Run-of-river plants

- Production of base load electricity from hydropower
- Efficiency $\eta \approx 93\ \%$
- Low-pressure plant (low head)
- Kaplan-turbines

### Storage plants

- Production of average and peak load electricity from hydropower
- Efficiency $\eta \approx 85\ \%$
- Medium- or high-pressure plant (medium or high head)
- Two types of dams: concrete dam and earth-/rockfill dam
- Francis-turbines (medium or high head), Pelton-turbines (high head)

### Pumped storage plants

- Efficiency $\eta \approx 75\ \%$ (storage of base load energy)
- Often combined with storage plants (pumped-storage plants with natural inflow)
- Medium- or high-pressure plant (medium or high head)
- Two types of dams: concrete dam and earth-/rockfill dam
- Francis-turbines (medium or high head), Pelton-turbines (high head), combined with pumps

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# Individual Modules – Energy Conversion

## Example: Hydro Power Plant (2/3)

- Greenhouse gas emissions during the operation of run-of-river, storage and pumped-storage plants are a result of biomass degradation in the dammed water depending on
  - climatic boundary conditions:
    - climatic cold and moderate regions: Increasing $CO_2$ emissions from aerobic degradation of biomass in the first years of operation, then temporary decreasing within the first 10 years of operation
    - climatic tropical regions: Increasing $CH_4$ emissions from anaerobic degradation of biomass in the first years then slower temporary decreasing, which can be longer than the first 10 years of operation
  - vegetal boundary conditions (amount of inundated biomass): Sub polar lea, cultivated land, steppe, boreal forest, rain forest
- Used values of emissions are arithmetic mean values over 100 years of operation and are based on gross greenhouse gas emissions (problem of absorbed $CO_2$ from atmosphere), net emissions are estimated to be 30 – 50 % lower
- Greenhouse gas emissions of run-of-river plants are minimal since the water is not stored for a long time

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# Individual Modules – Energy Conversion

## Example: Hydro Power Plant (3/3)

**Model parameters of the hydro power LCA-models:**

- Country-specific distribution of electricity production by hydropower [%]
- Country-specific relation between consumed electricity and generated electricity by pumped-storage [kWh/kWh]
- Country-specific greenhouse gas emissions from operation [kg CO2 eq. / kWh]
- Plant-specific efficiency [%]
- Country-specific plant life span and life spans of components [a]
- Country-specific share of concrete dams as a part of storage and pumped storage plants [%]

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# Individual Modules – Energy Conversion

## Example: Wind Power Plant

### Construction

- considers main components (foundation, tower, nacelle rotor), and
- transports are included.

### Operation and maintenance

- full load hours determined by electricity produced from wind divided by installed capacity, and
- maintenance considered.

### End of life

- recycling potential for metals,
- incineration of polymers,
- inert materials to landfill, and
- foundation not recycled.

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# Electricity Mixes

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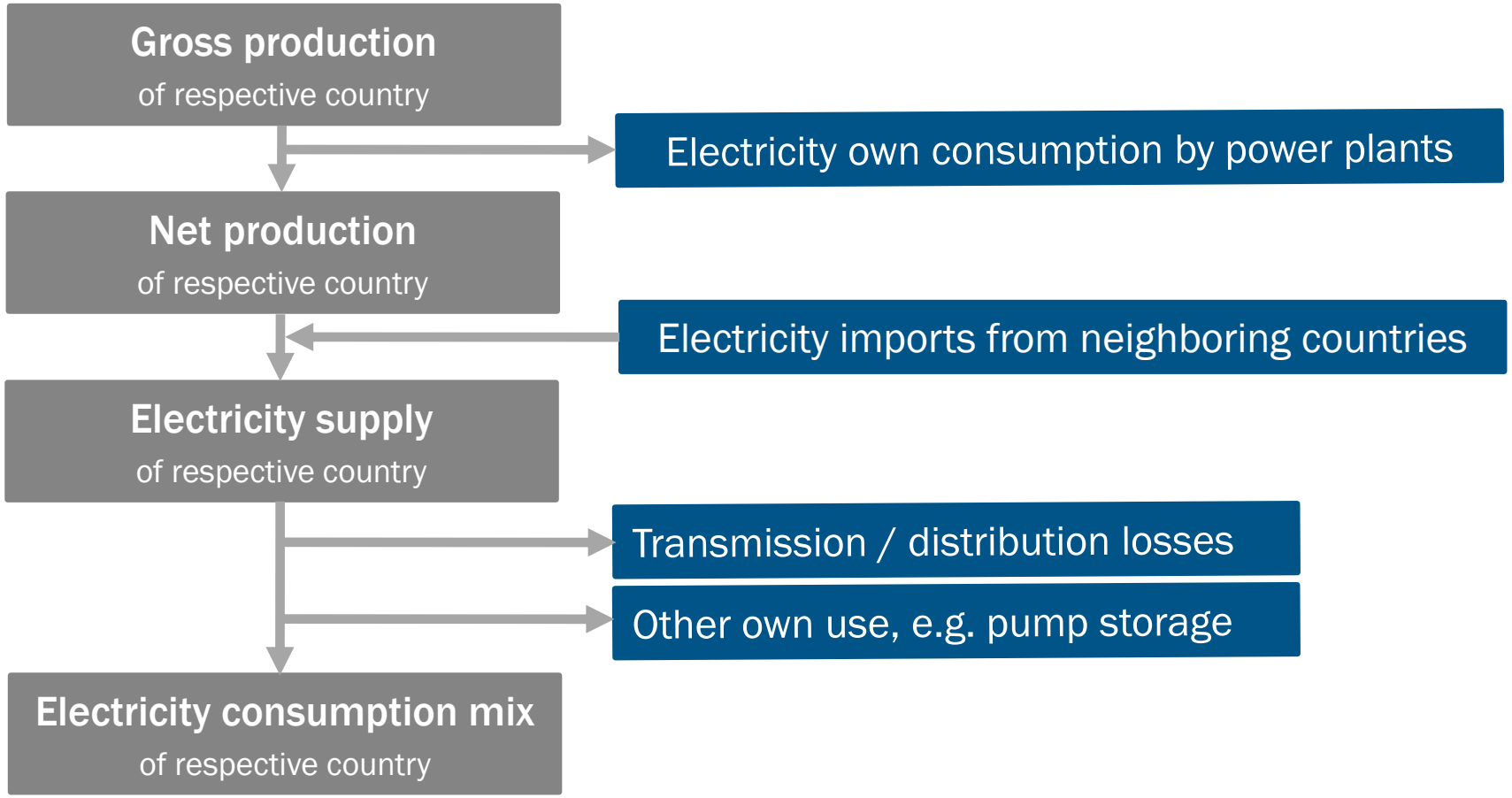
# Electricity Mixes

## Modeling of Electricity Consumption Mixes

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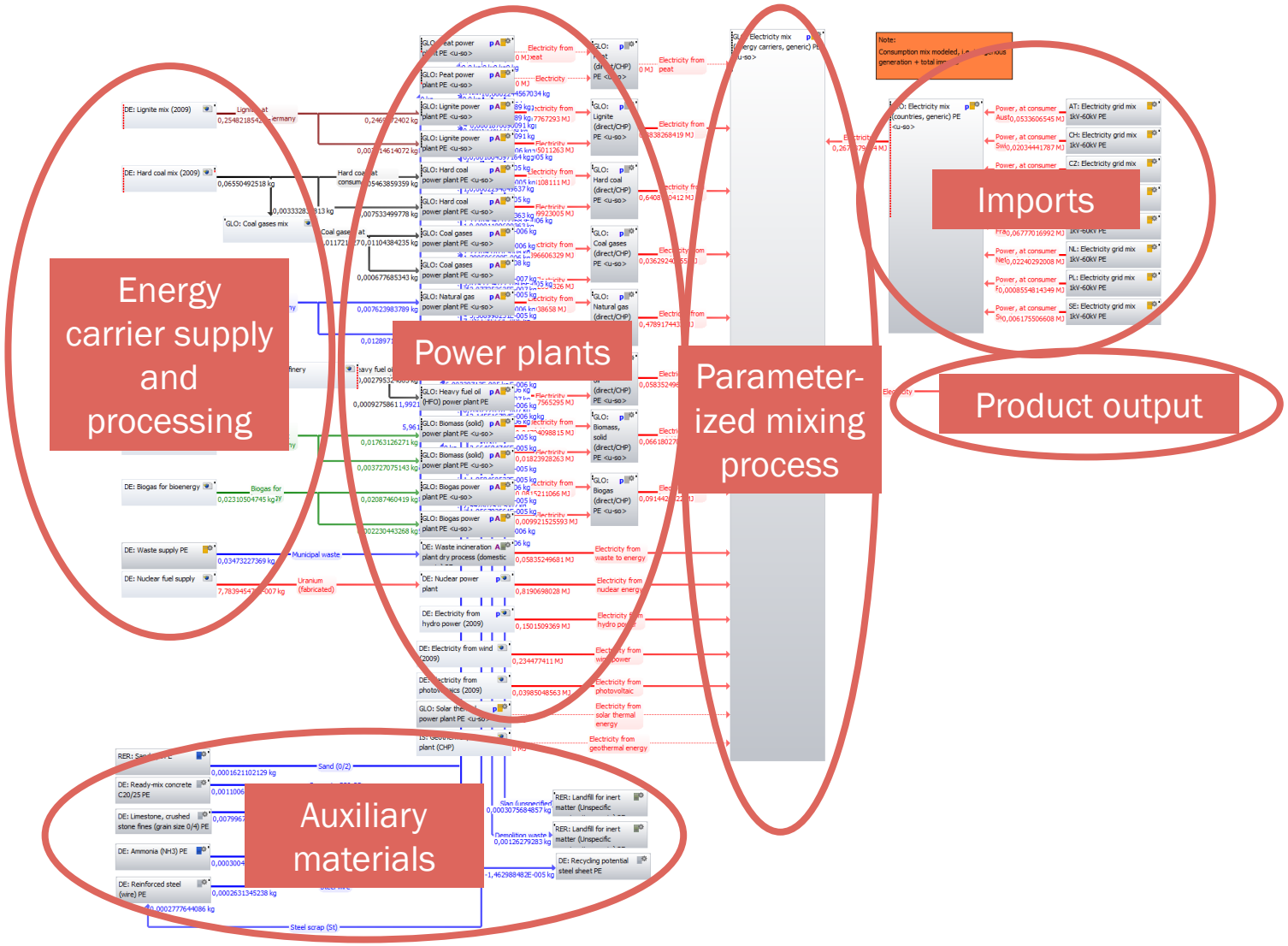
# Electricity Mixes

## GaBi Screenshot of Electricity Consumption Mix

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# GaBi Software - Available Documents

**GaBi documents:** https://www.gabi-software.com/international/support/gabi/gabi-modelling-principles

- GaBi Databases & Modeling Principles
- Introduction to Water Use Assessment in GaBi
- Documentation for Duty Vehicle Processes in GaBi
- Documentation for Passenger Vehicle Processes in GaBi
- Documentation for Evaluation of Land Use Change Emissions in GaBi
- Documentation for Land Use Inventory (LANCA) in GaBi
- Documentation for the Agriculture LCI Model
- Energy Modeling in GaBi
- The GaBi LCA Refinery Model
- Details and Reasons for Changes (compared to preceding upgrade)

https://www.gabi-software.com/international/support/latestupdate

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