Sphera Energy LCI Modelling – 2025

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Agenda

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

Overview Electricity Model

Overview Electricity Model

Life Cycle Assessment of Energy Supply Chains

Extraction & Production → Transport → Conversion → Transmission & Distribution

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

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

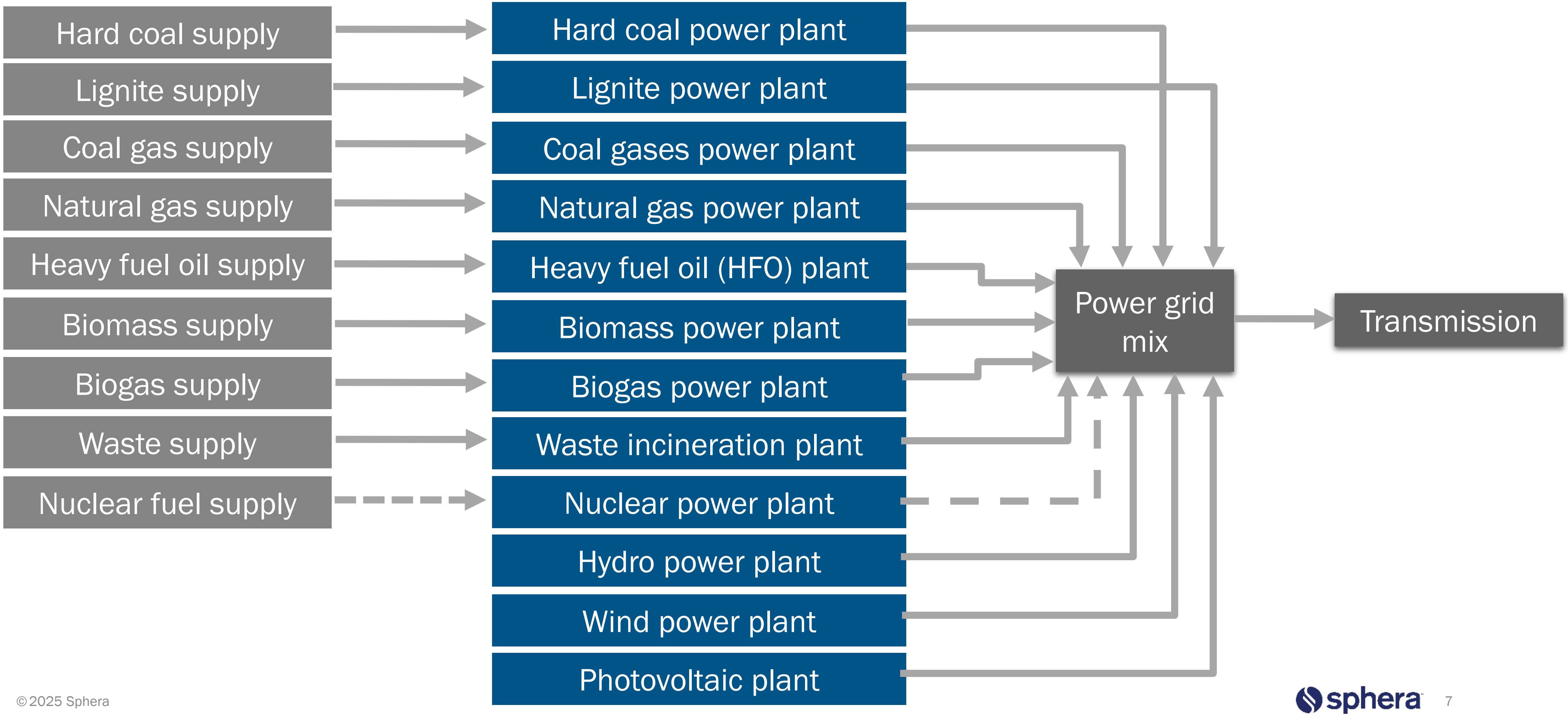
- Calorific value
- Carbon content
- Sulphur content
- etc.

Life Cycle Inventory

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

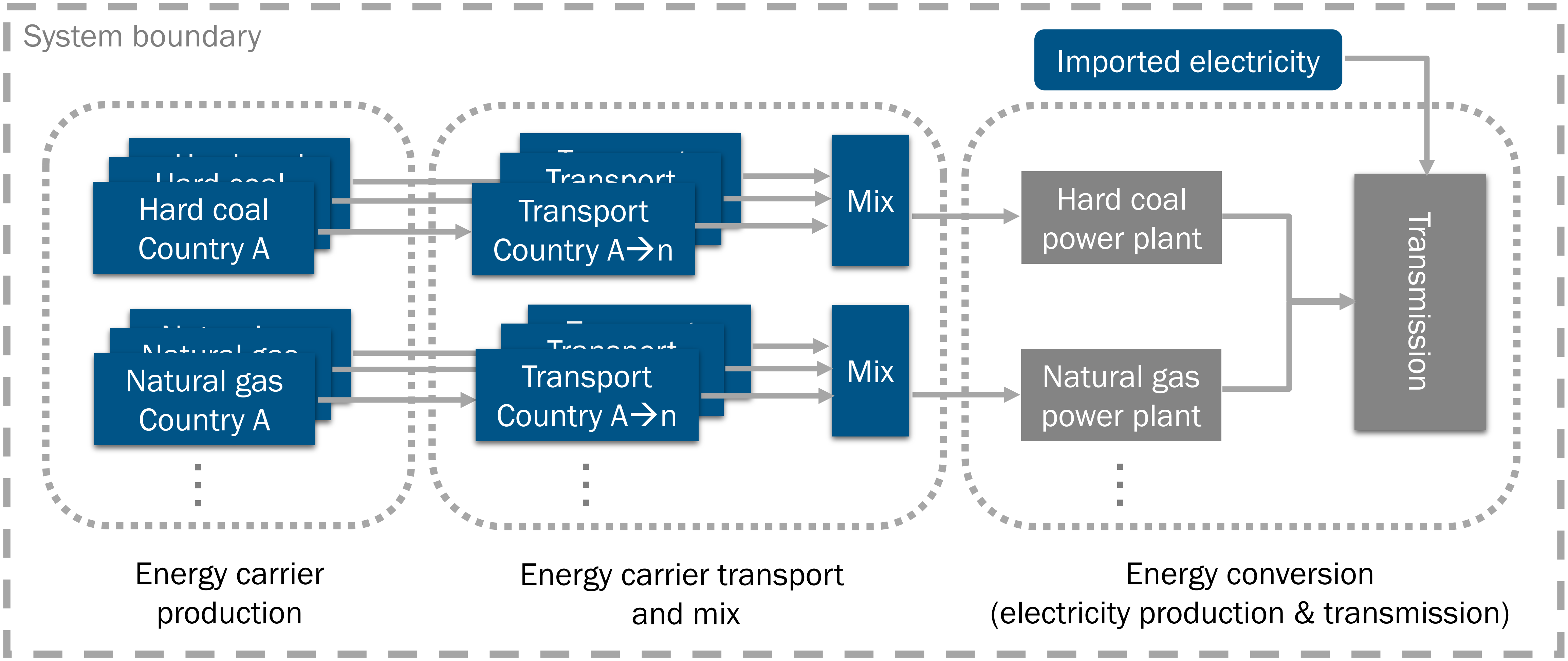
Overview Electricity Model

Parameterized Models – Electricity Grid Mix



Overview Electricity Model

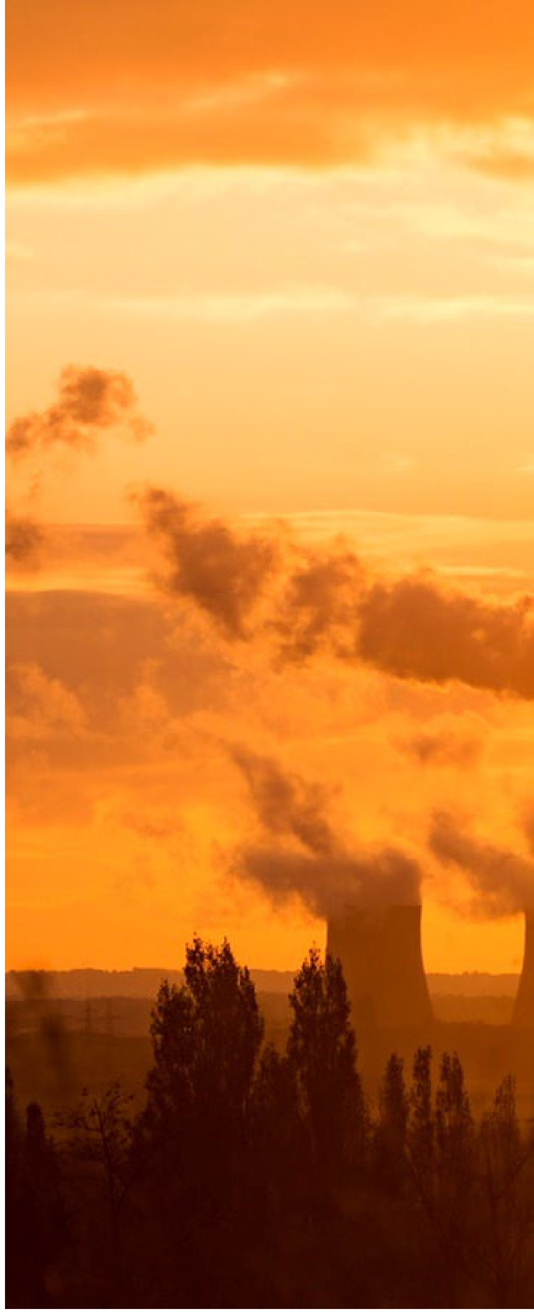
Parameterized Models – Electricity Grid Mix



Overview Electricity Model

Conclusions

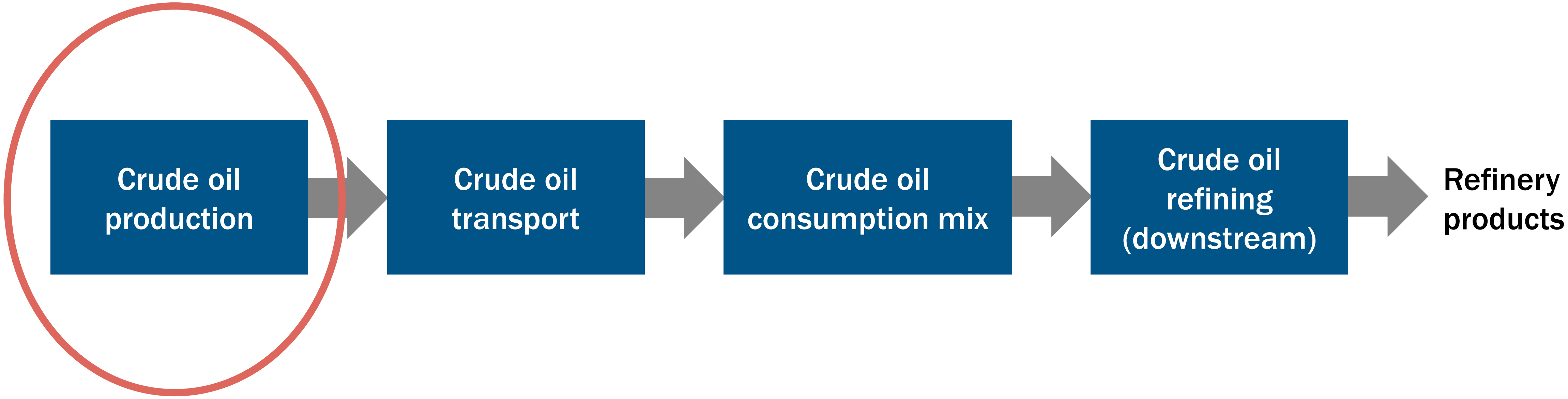
- Generic models offer the adaptability to various country and boundary conditions → micro, macro, and global level
- Results are comparable due to consistent approach and system boundaries
- Allows comprehensive LCI, LCIA, carbon footprint, and water footprint analysis
- Complex models with a large 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 Managed LCA Content (MLC) since 1990



Individual Modules – Energy Carriers

Individual Modules – Energy Carriers

Example: Refinery Products – Supply Chain



Individual Modules – Energy Carriers

Example: Refinery Products – Crude Oil Production Technologies

Crude oil production technologies

Conventional crude oil production technologies (onshore, offshore)

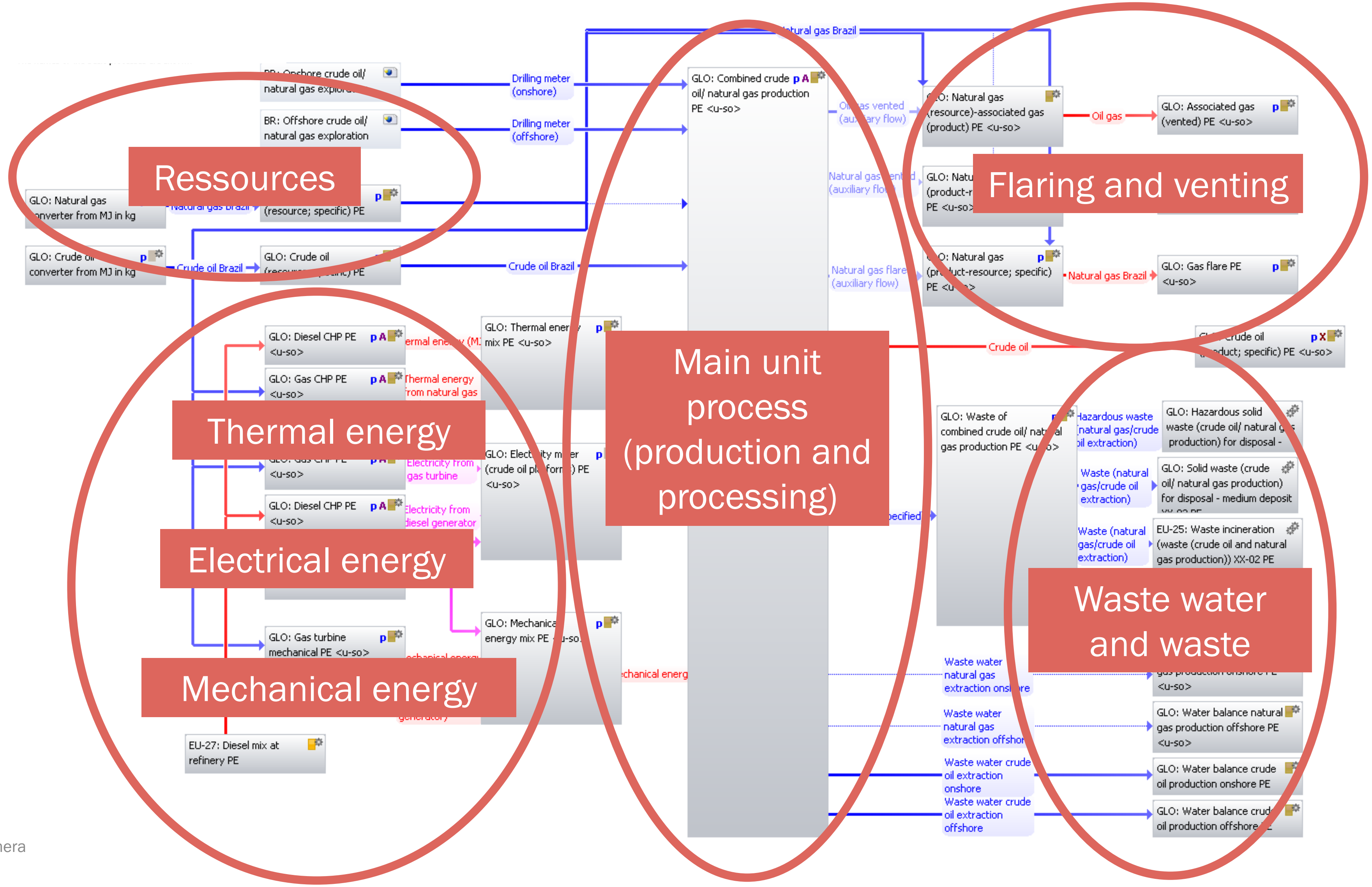
- Primary crude oil production
- Secondary crude oil production
- Tertiary crude oil production (enhanced oil recovery):
  - steam injection
  - solvent injection
  - natural gas injection
  - nitrogen injection
  - carbon dioxide injection

Unconventional crude oil production technologies (onshore)

- Oil sands (in-situ, open-pit)
- Oil shale (in-situ, open-pit, underground)

Individual Modules – Energy Carriers

Example: Refinery Products – Screenshot of Crude Oil Production



Individual Modules – Energy Carriers

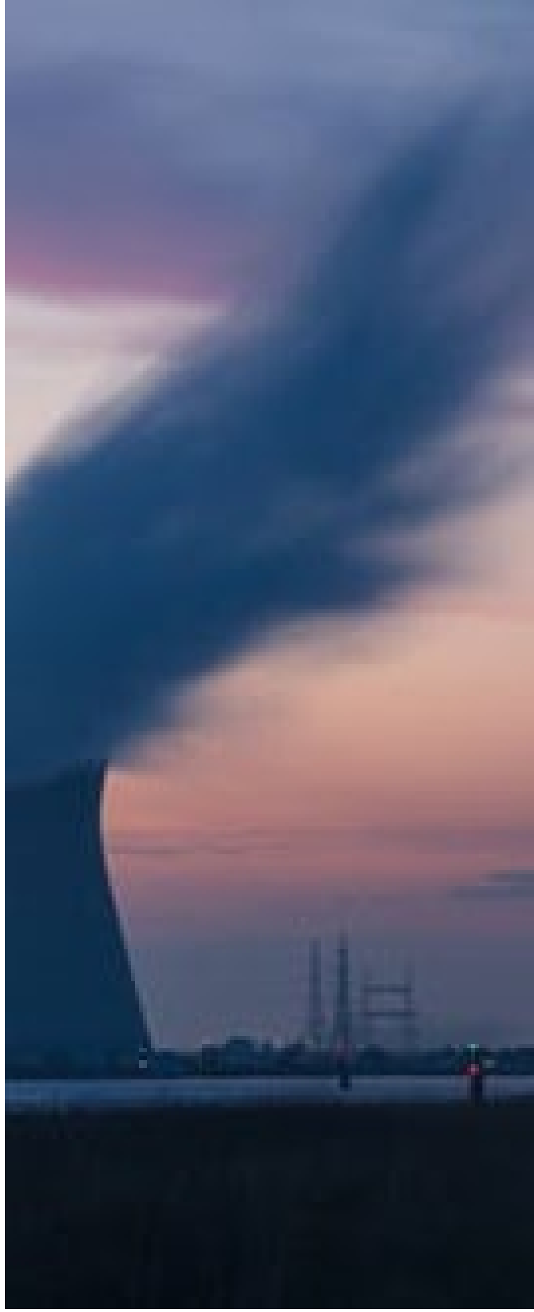
Refinery Products – Model Parameters of Crude Oil Production

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)



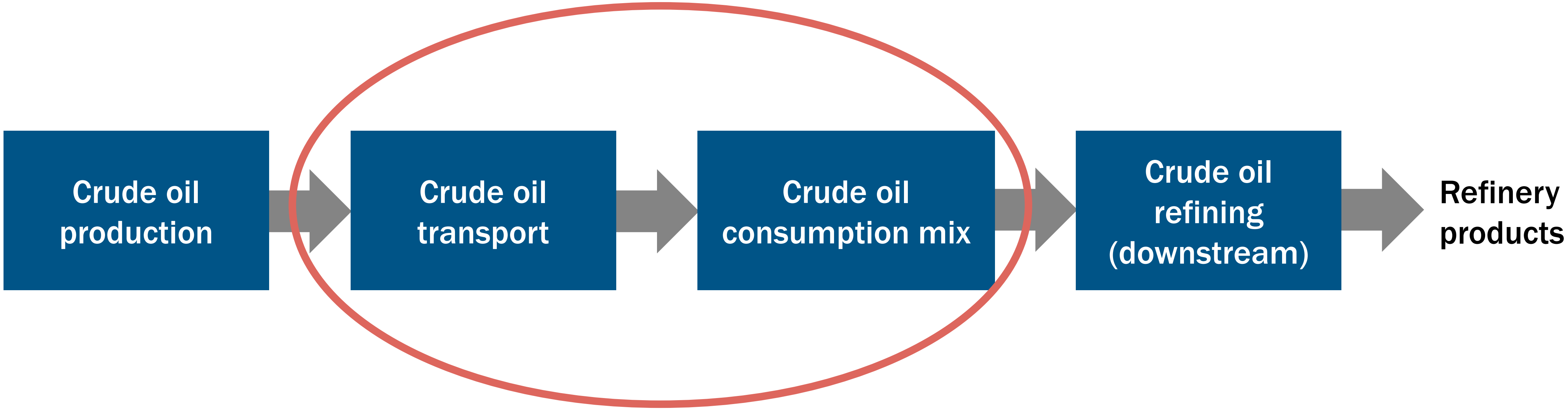
Individual Modules – Energy Carriers

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

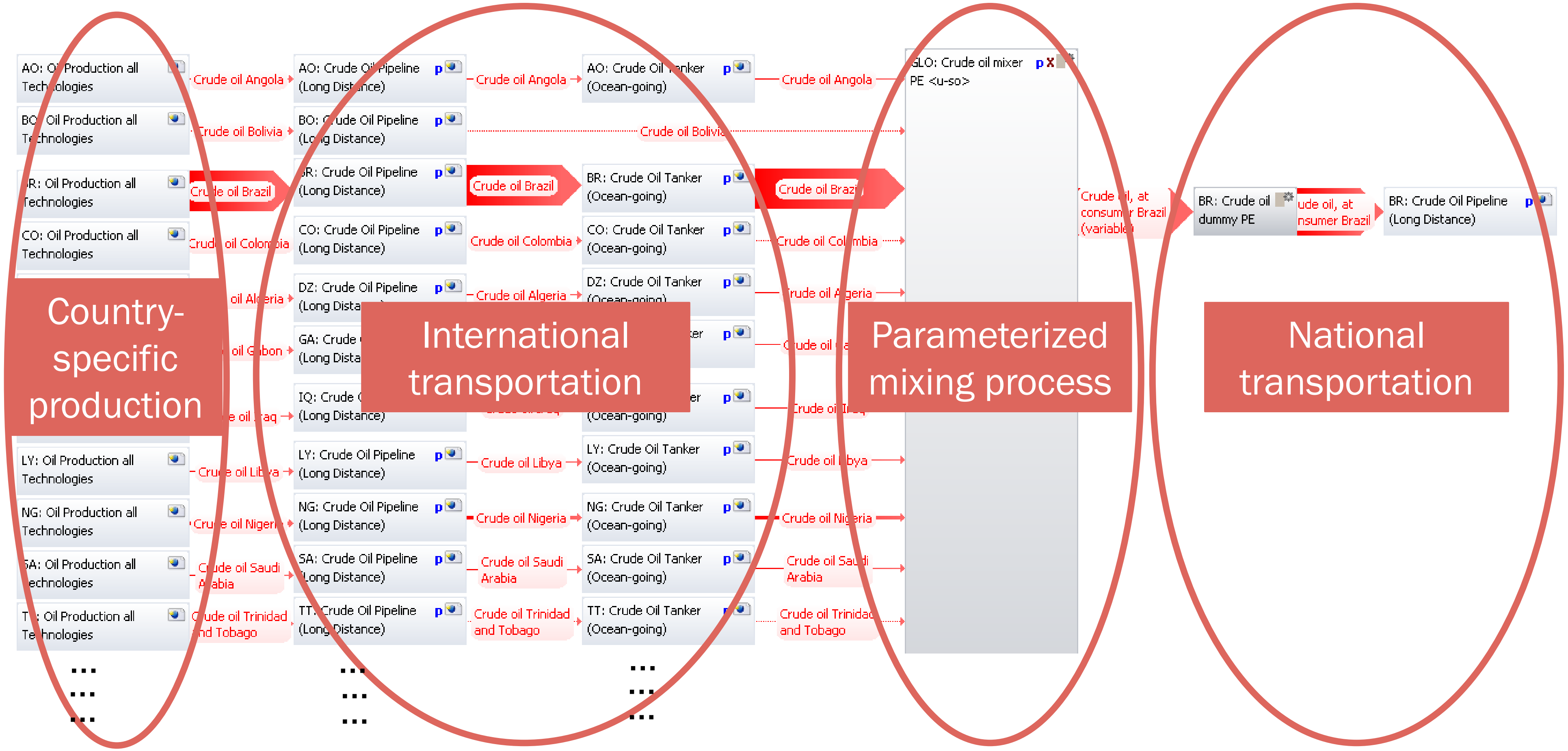
Individual Modules – Energy Carriers

Example: Refinery Products – Supply Chain



Individual Modules – Energy Carriers

Example: Refinery Products – Screenshot of Crude Oil Consumption Mix



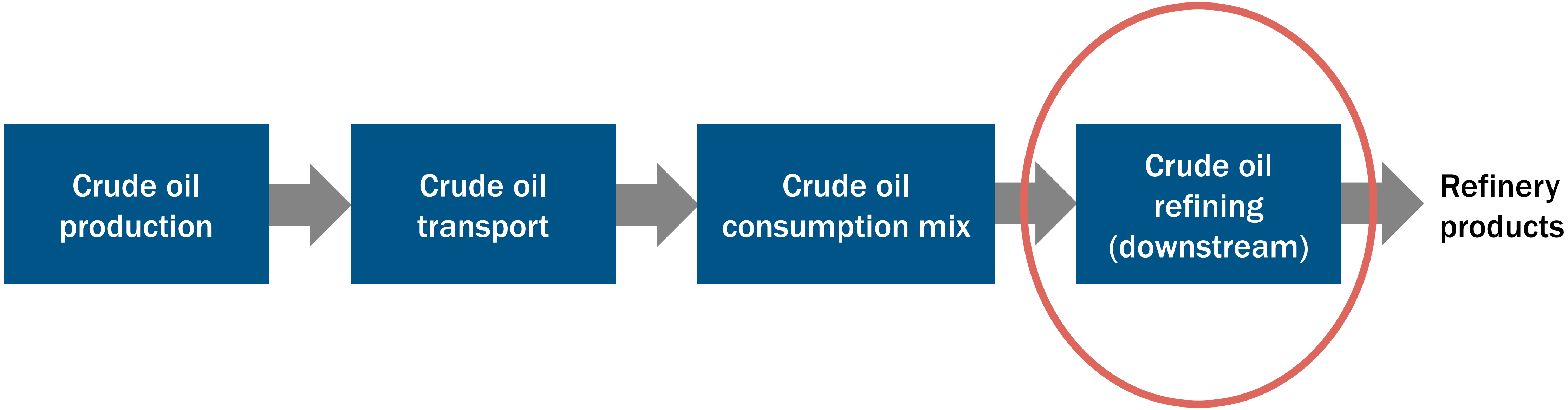
Individual Modules – Energy Carriers

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)

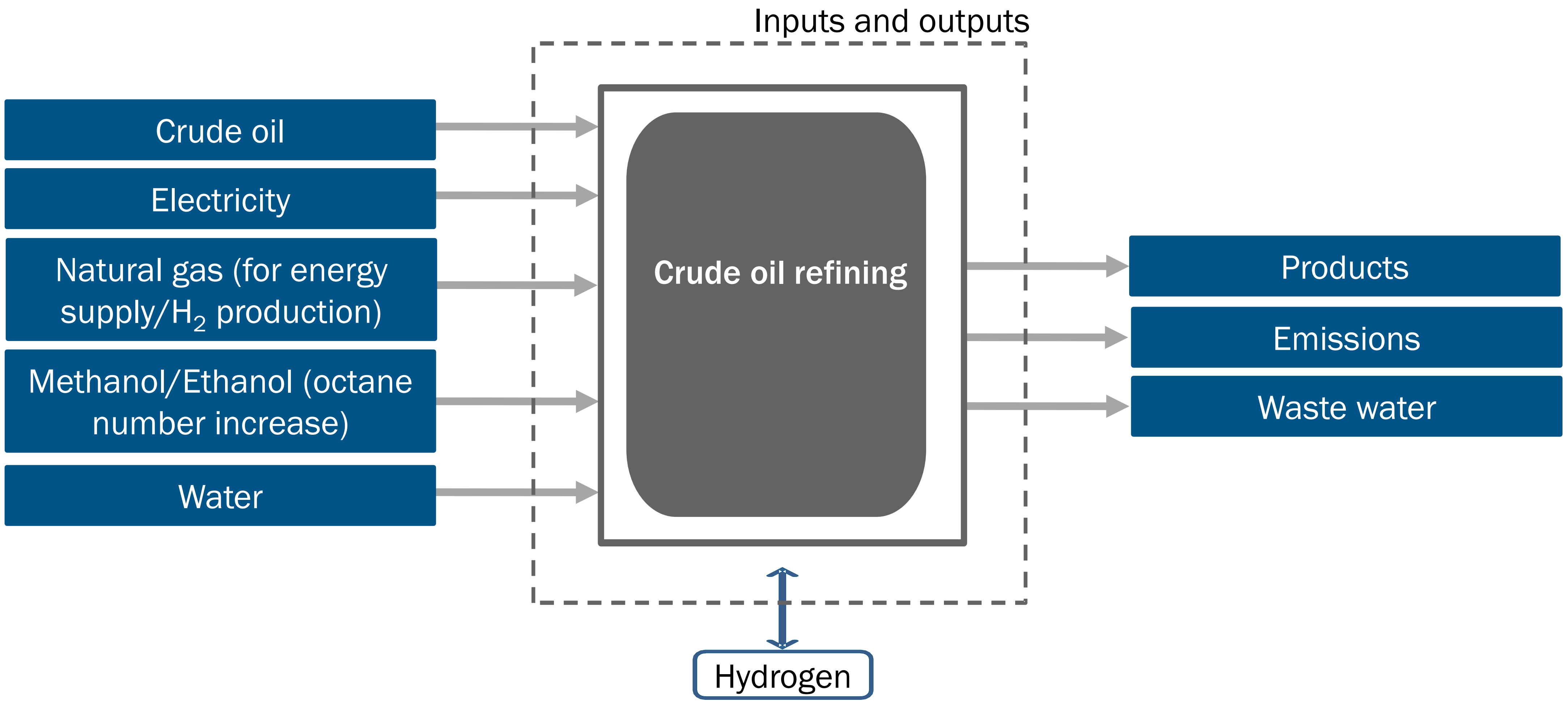
Individual Modules – Energy Carriers

Example: Refinery Products – Supply Chain



Individual Modules – Energy Carriers

Example: Refinery Products – Refinery System Boundary



Individual Modules – Energy Carriers

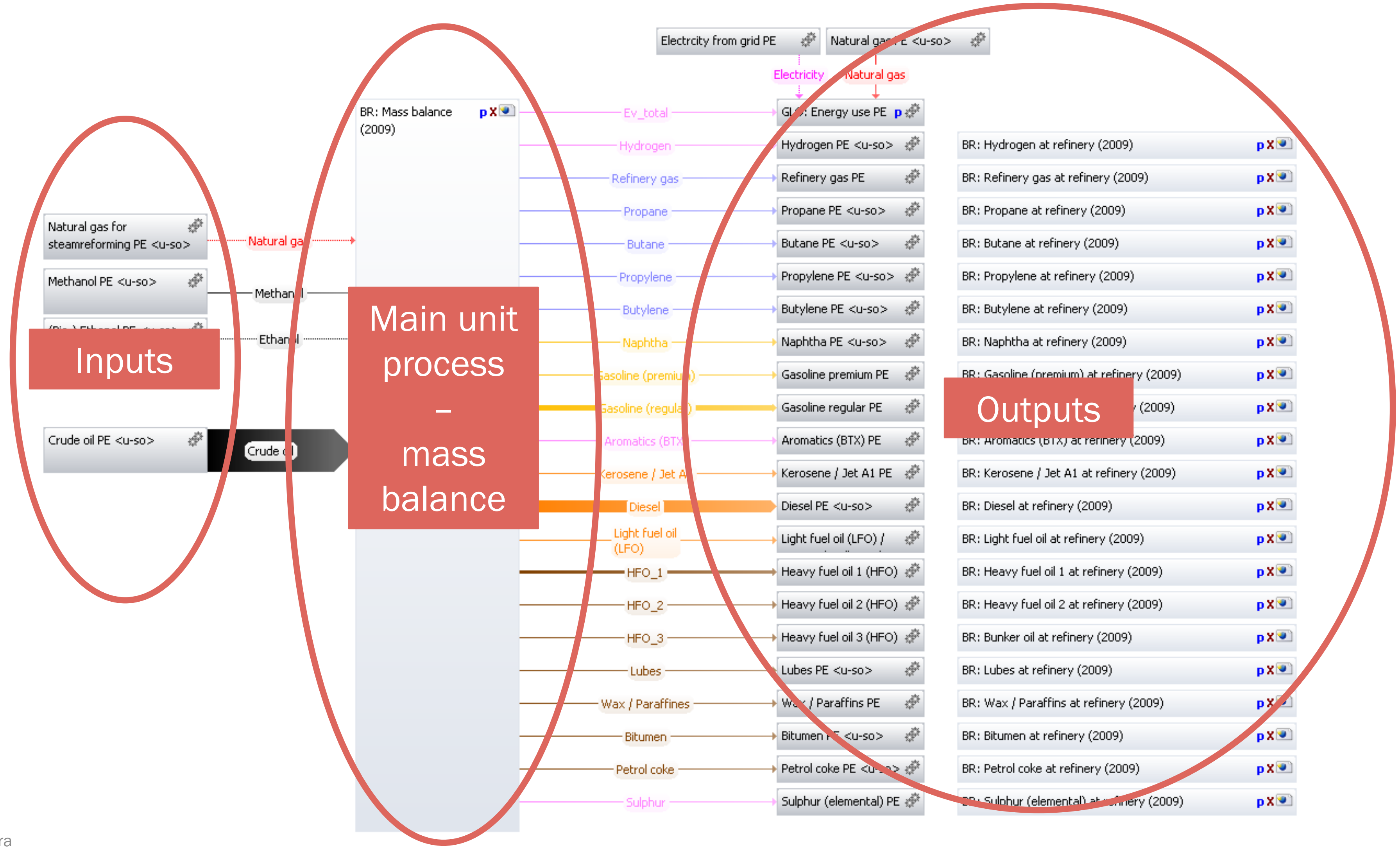
Example: Refinery Products – Refinery System Boundary

- 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

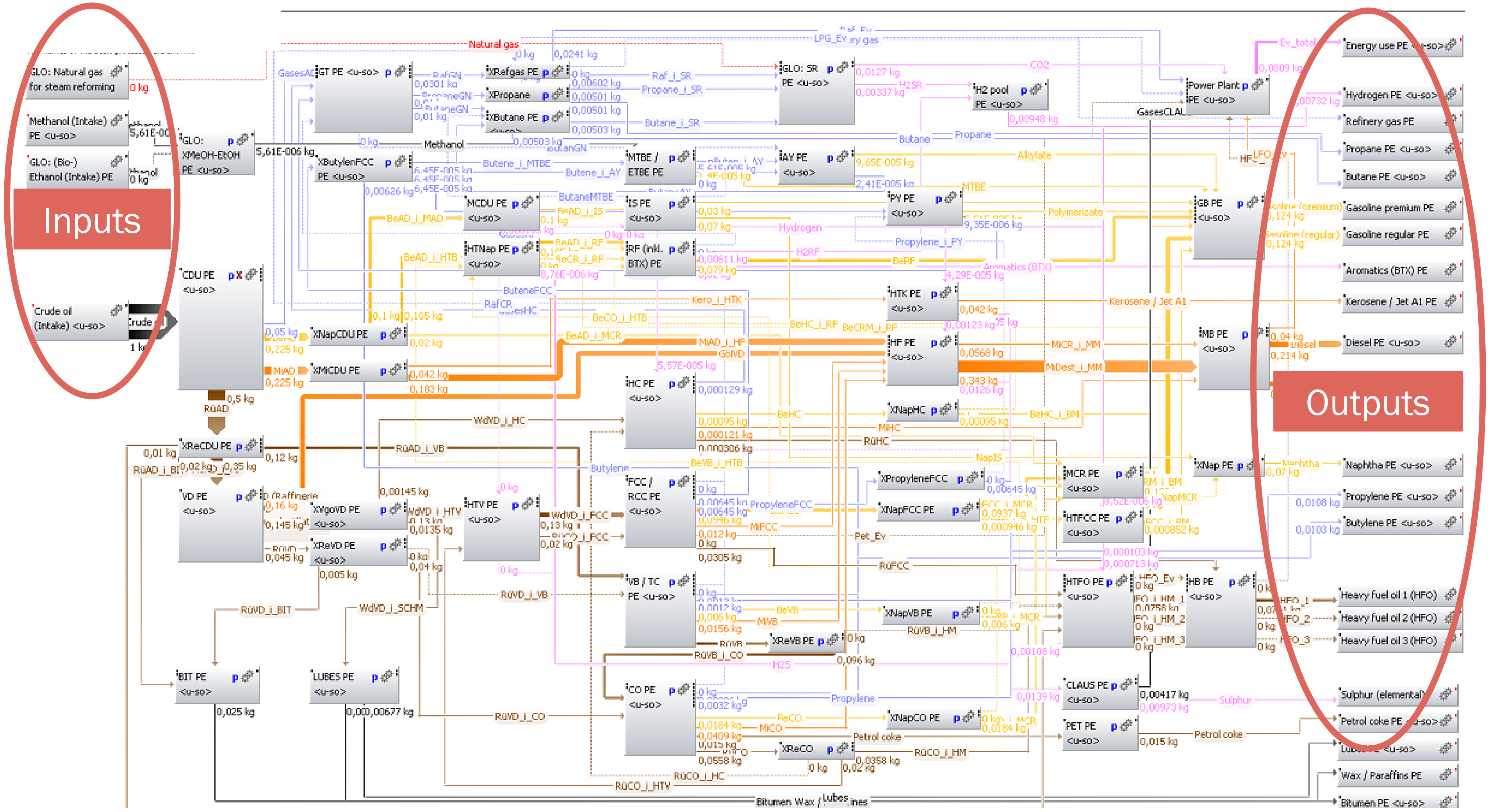
Individual Modules – Energy Carriers

Example: Refinery Products – Screenshot of Refinery



Individual Modules – Energy Carriers

Example: Refinery Products – Screenshot of Refinery



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

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

Individual Modules – Energy Conversion

Individual Modules – Energy Conversion

Example: Hard coal power plant (1 of 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

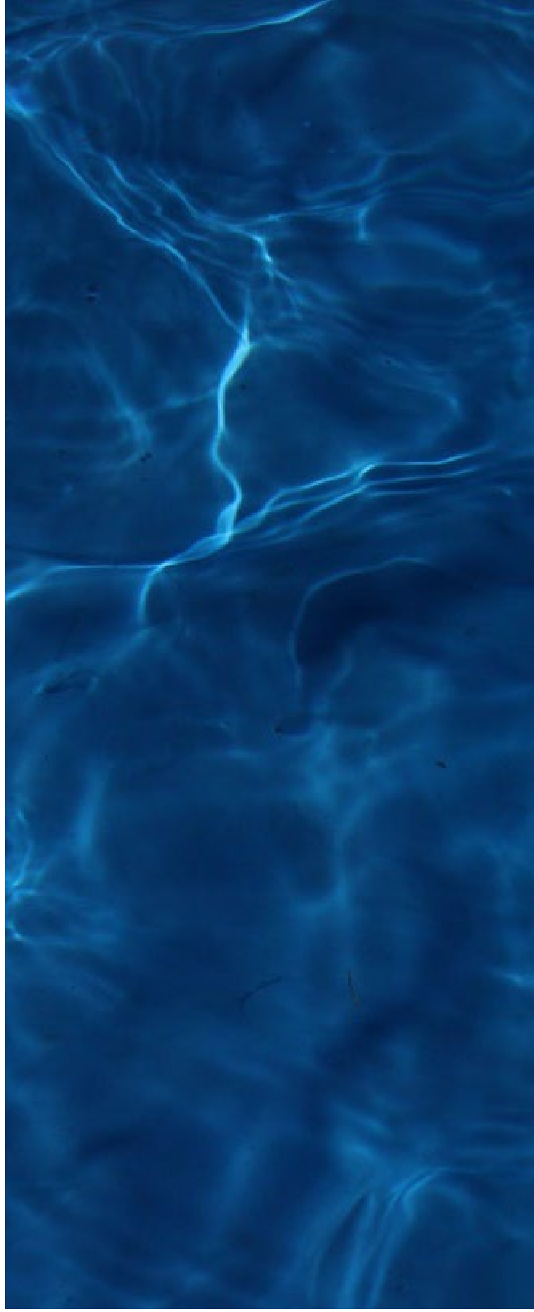
Individual Modules – Energy Conversion

Example: Hard coal power plant (2 of 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)

Individual Modules – Energy Conversion

Example: Hydro Power Plant (1 of 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)

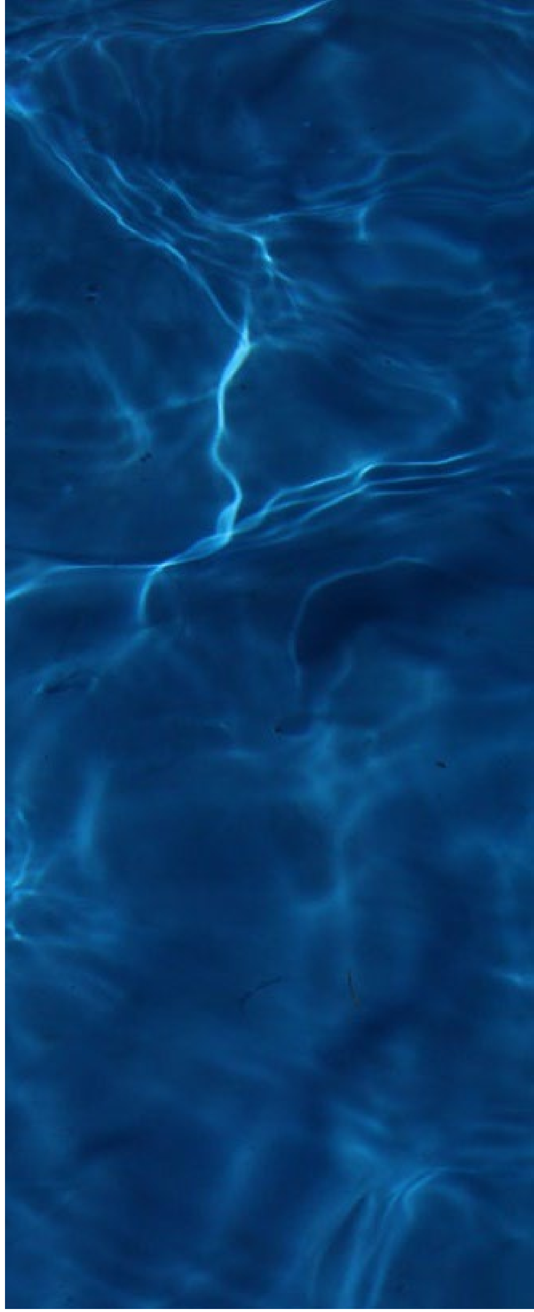
Pumped storage plants

- 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

Individual Modules – Energy Conversion

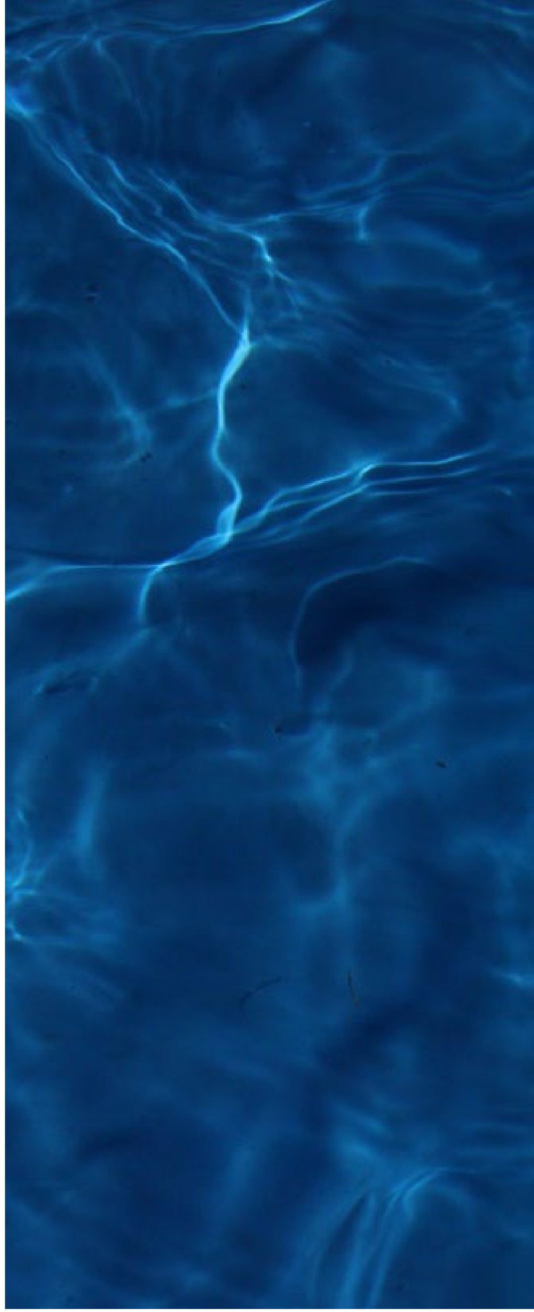
Example: Hydro Power Plant (2 of 3)

- 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



Individual Modules – Energy Conversion

Example: Hydro Power Plant (3 of 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 [%]

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.

Individual Modules – Energy Conversion

Example: New Photovoltaic (PV) model (1 of 3)

Technology Mixes:

- Monocrystalline silicon (mono c-Si), Multicrystalline silicon (multi c-Si), Cadmium Telluride (CdTe), Copper Indium (Gallium) diselenide/sulphide (CI(G)S) modules
- Ground-mounted systems and Roof-top installed systems
- Regionalized electricity grid and thermal energy mixes across the supply chains of PV module manufacturing according to market shares

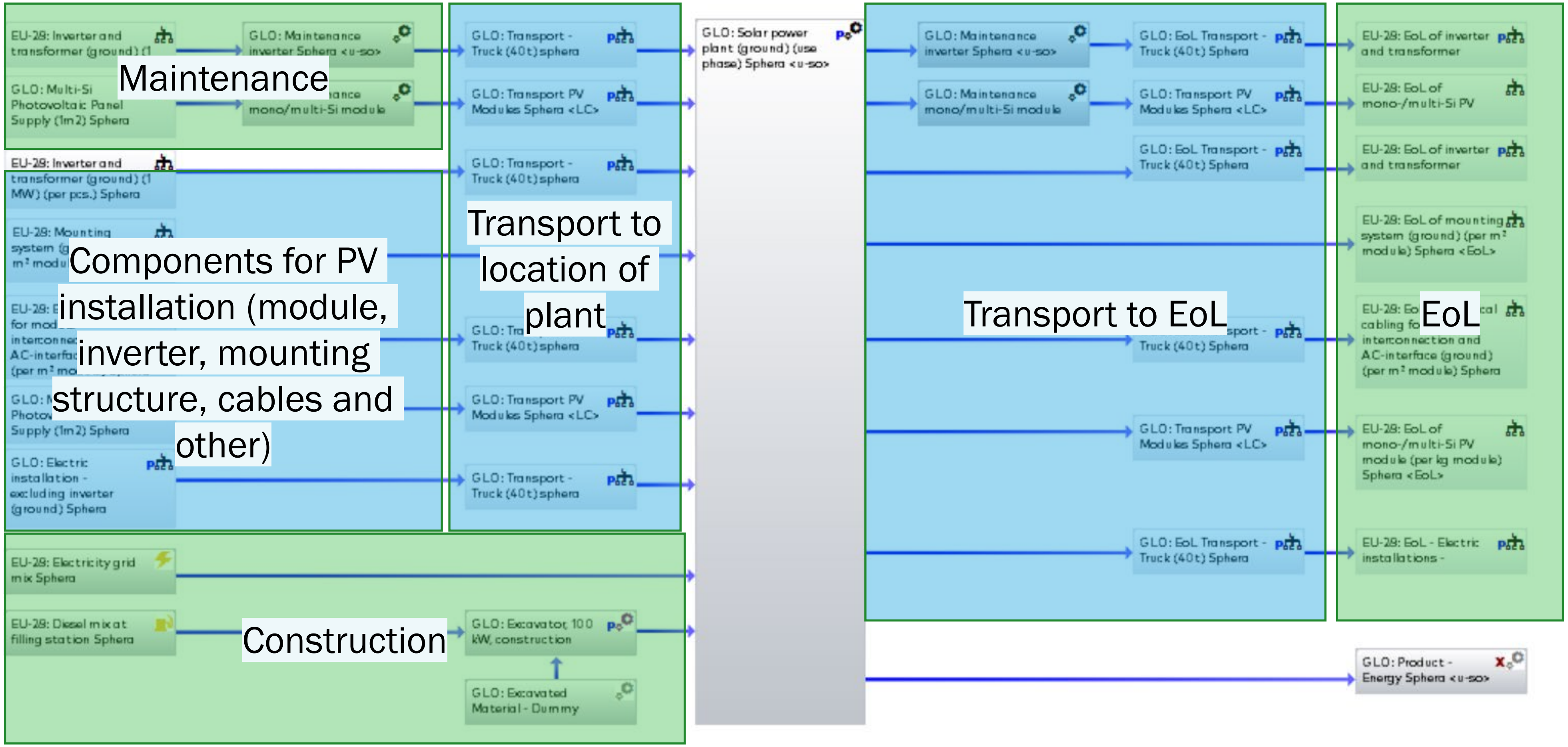
Further parameters:

- Technology specific efficiencies
- Country specific average Solar irradiations, GTI (Global Titled Irradiation)
- Lifetimes and dynamic module degradation rates
- Installation depending performance ratios

Individual Modules – Energy Conversion

Example: New Photovoltaic (PV) model (2 of 3)

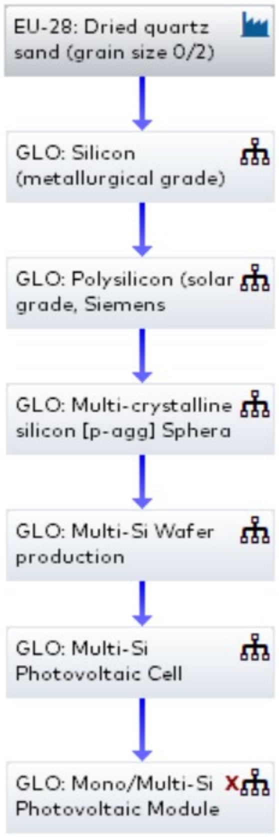
Example: Multi c-Si PV ground mounted system (image 1 of 2):

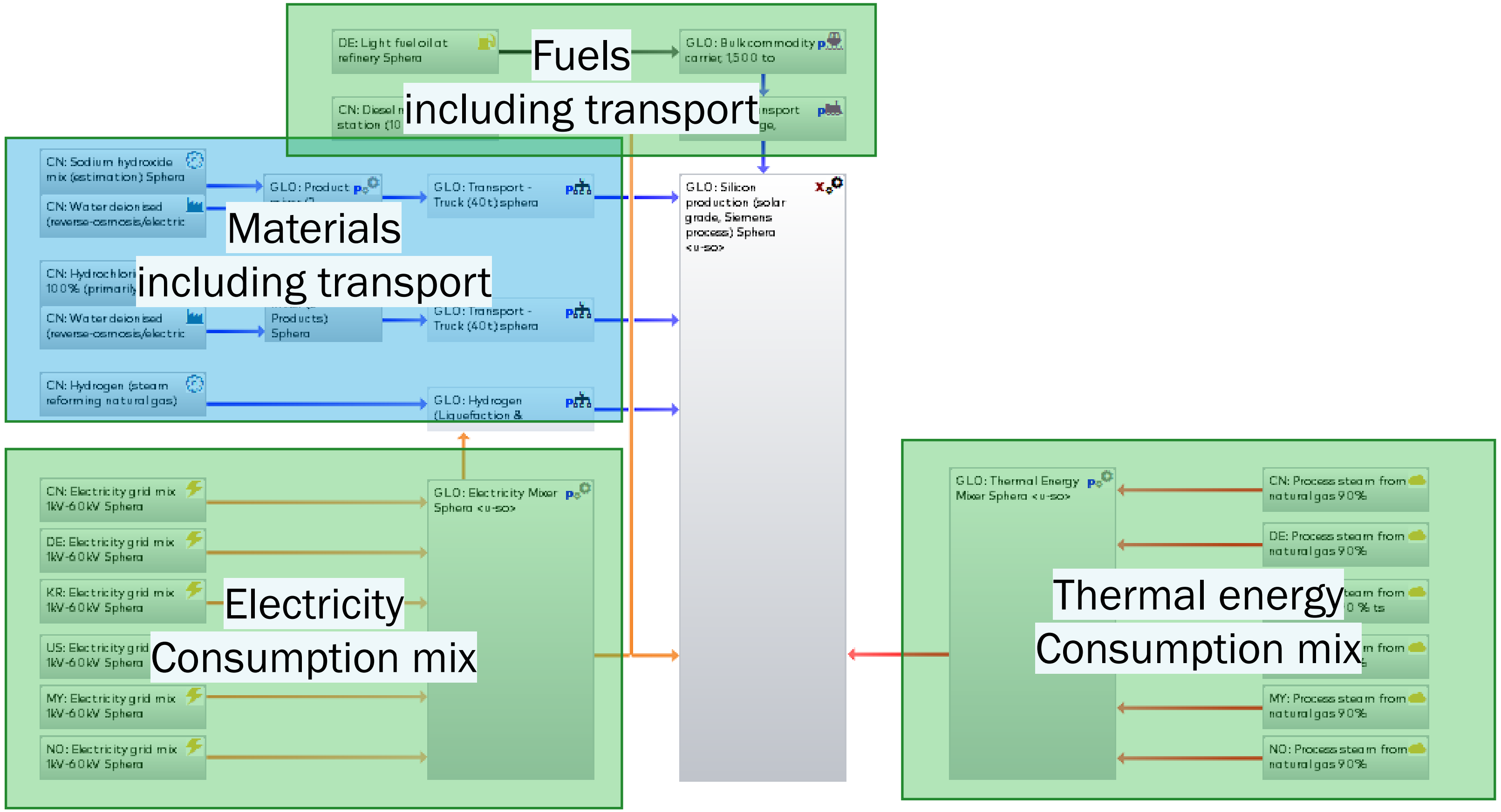


Individual Modules – Energy Conversion

Example: New Photovoltaic (PV) model (3 of 3)

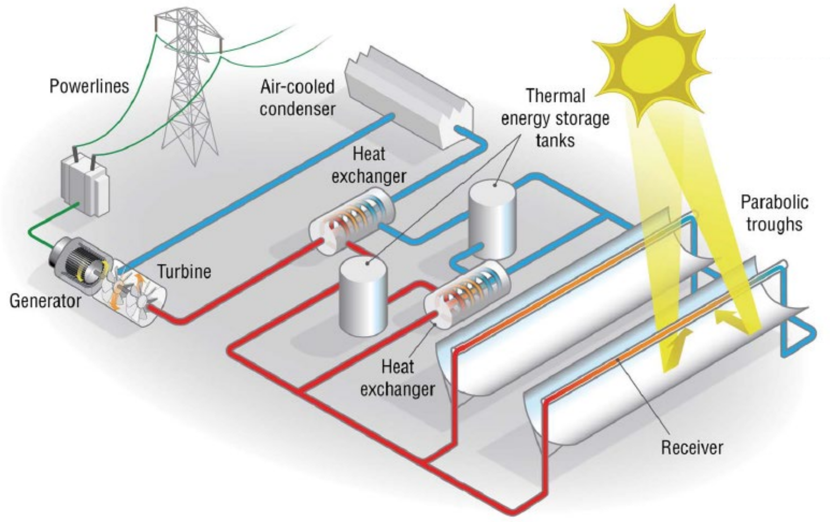
- **Manufacturing of cells and modules (on the left)** (image 2 of 2):
- **Polysilicon production (Siemens process) (on the right)**

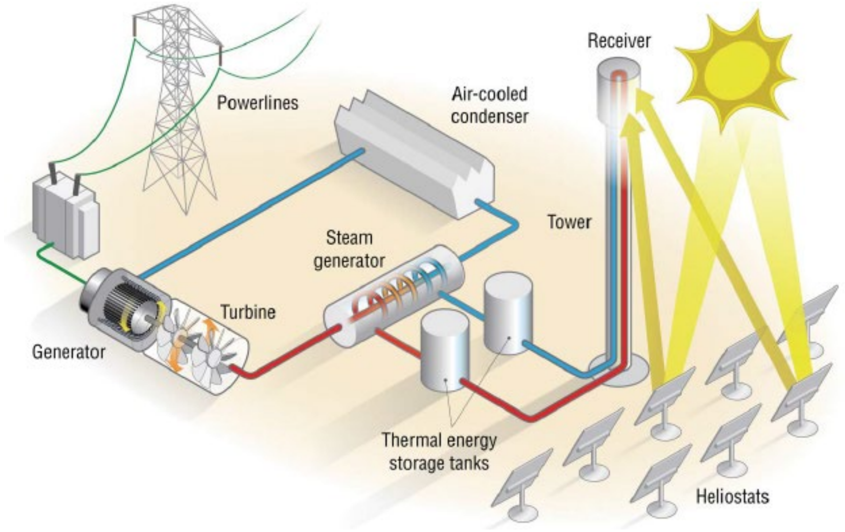




Individual Modules – Energy Conversion

Example: Concentrated Solar Power (CSP) model (1 of 2)





Parabolic trough, no storage

- No storage capacity

Parabolic trough, indirect storage

- 18 h molten salt storage

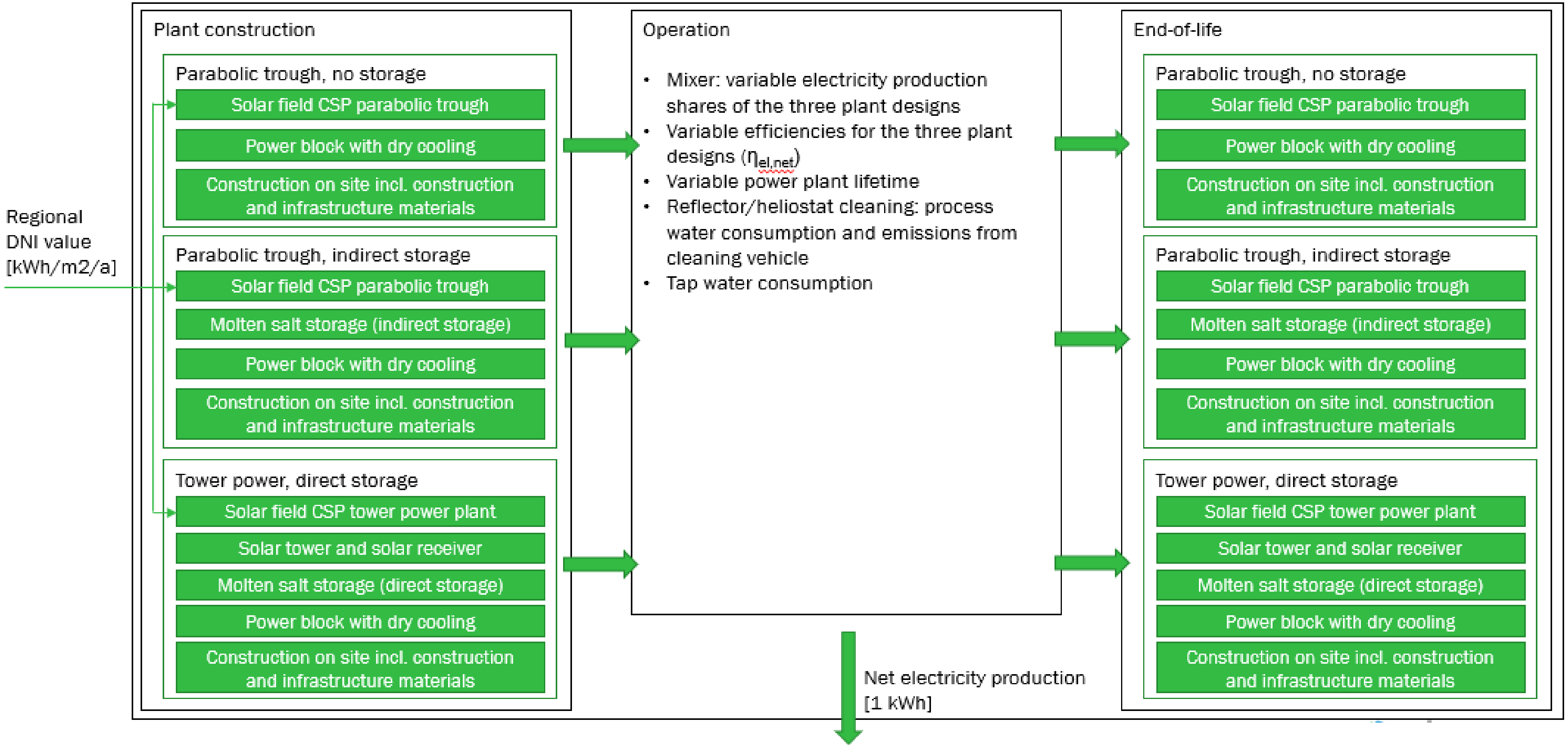
Tower power, direct storage

- 18 h molten salt storage

Source: Kutscher C., Concentrating Solar Power (CSP), NREL

Individual Modules – Energy Conversion

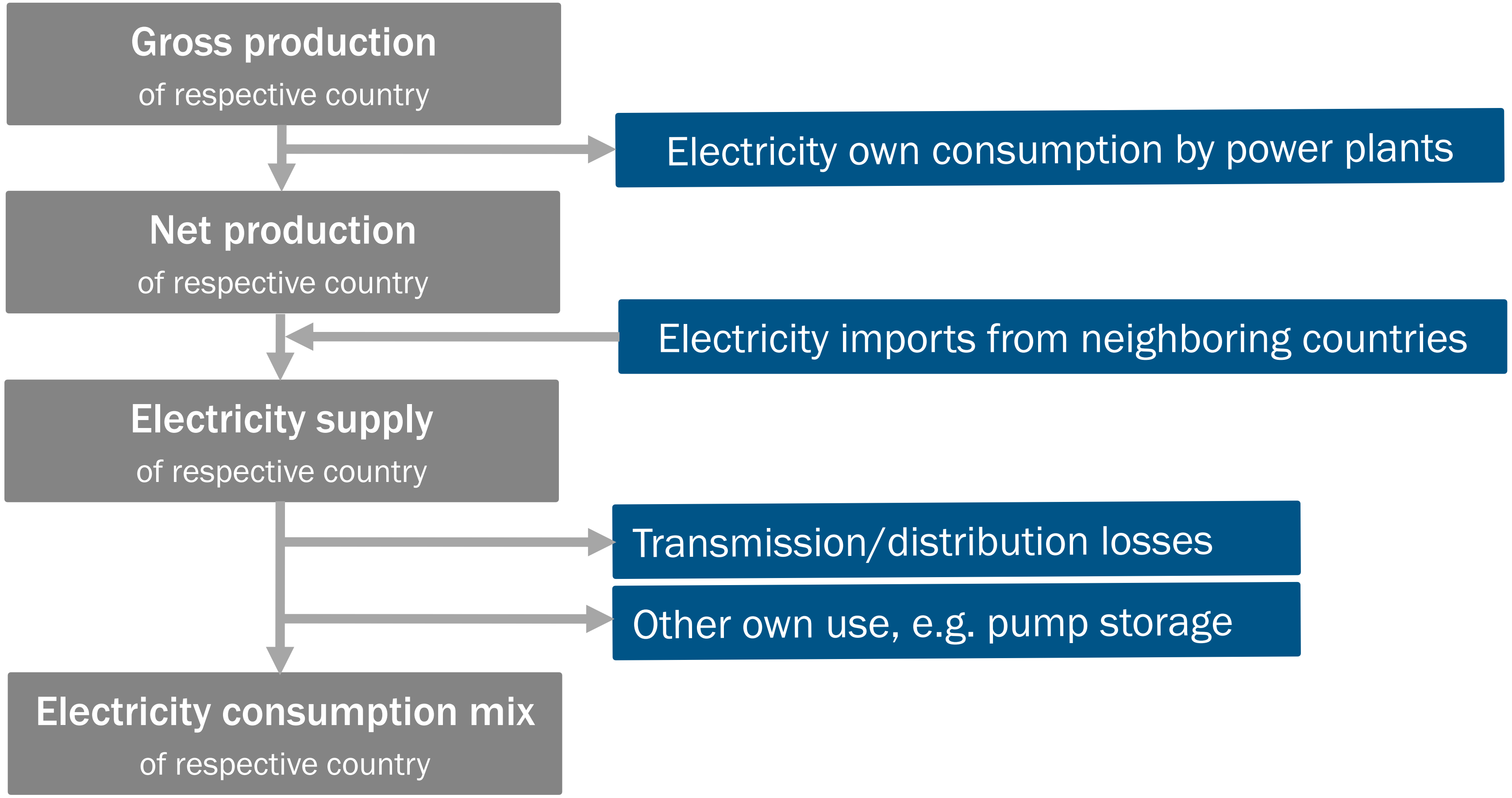
Example: Concentrated Solar Power (CSP) model (2 of 2)



Electricity Mixes

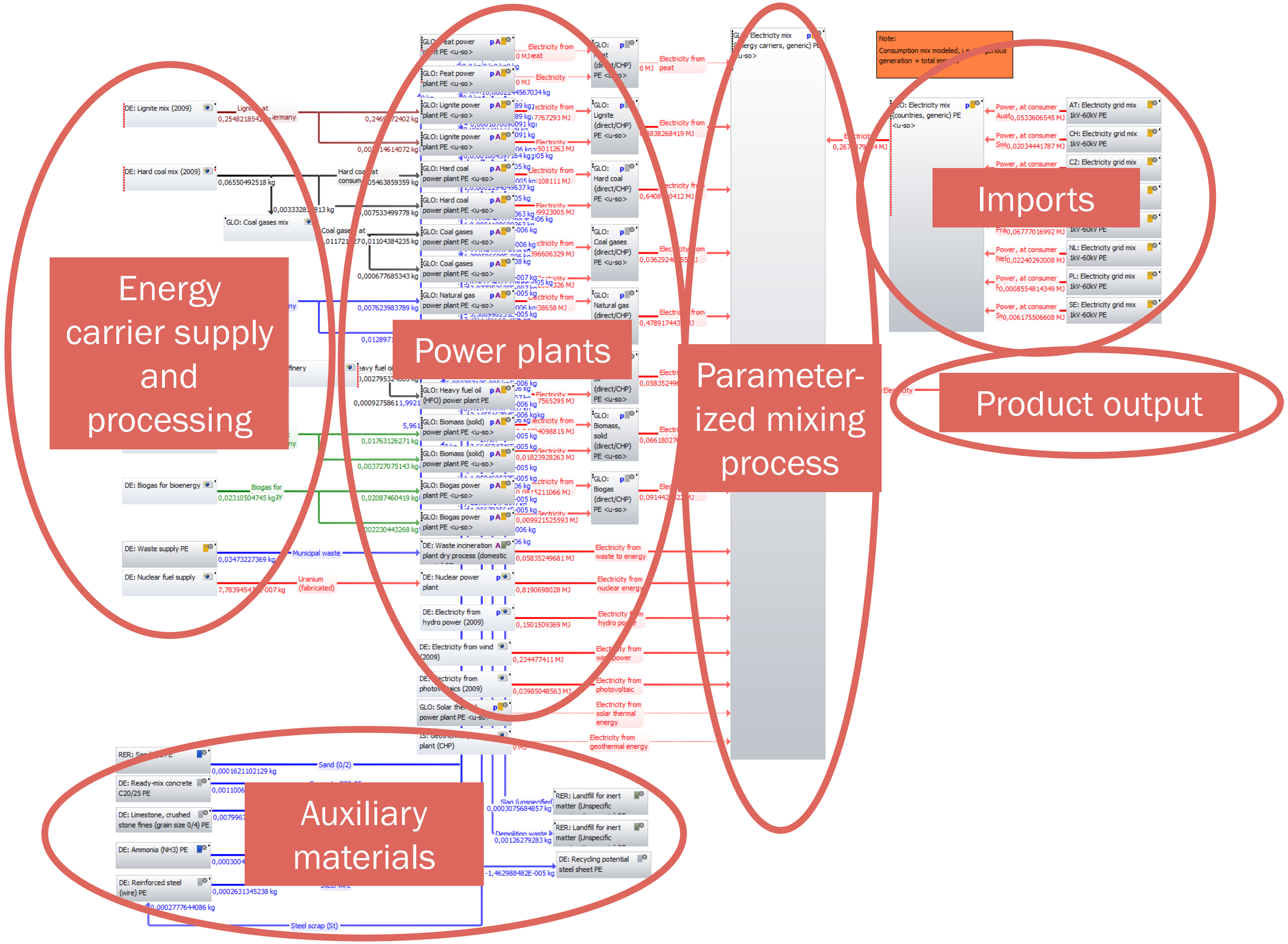
Electricity Mixes

Modeling of Electricity Consumption Mixes



Electricity Mixes

Screenshot of Electricity Consumption Mix



Managed LCA Content - Available Documents

MLC documents:

- Sphera LCA Databases Modelling Principles
- Sphera Water LCI Modelling & Assessment
- Sphera Duty Vehicles LCI Modelling
- Sphera Passenger Vehicles LCI Modelling
- Sphera Land Use Change LCI Modelling & Assessment
- Sphera Land Use LCI Modelling & Assessment
- Sphera Agricultural LCI Model
- Sphera Energy LCI Modelling
- Sphera Refinery LCI Model
- Upgrades and Improvements (compared to preceding version)

Contact customercare@sphera.com for more information.