

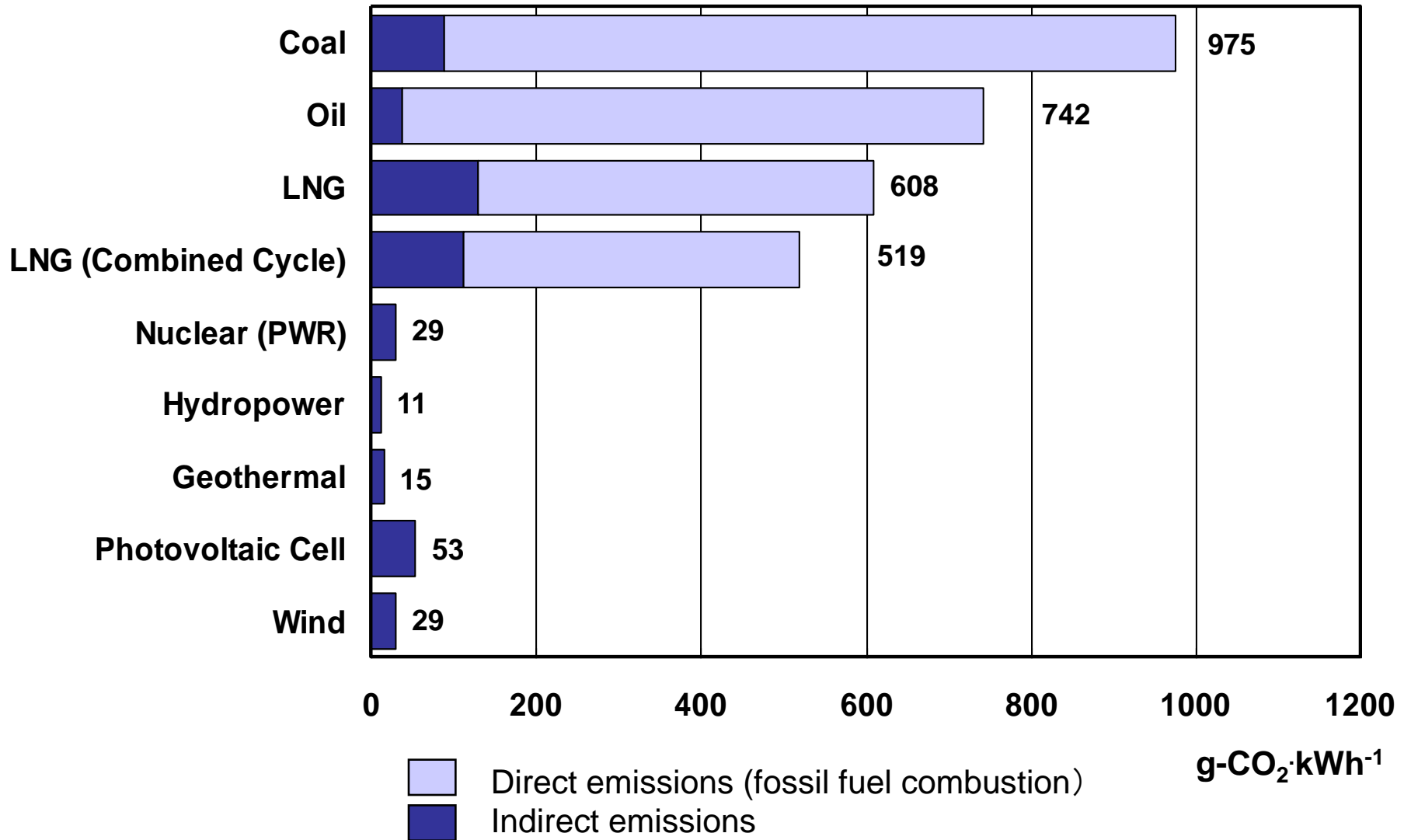
Life Cycle Assessment of Electricity Generation

in terms of CO₂ Emissions

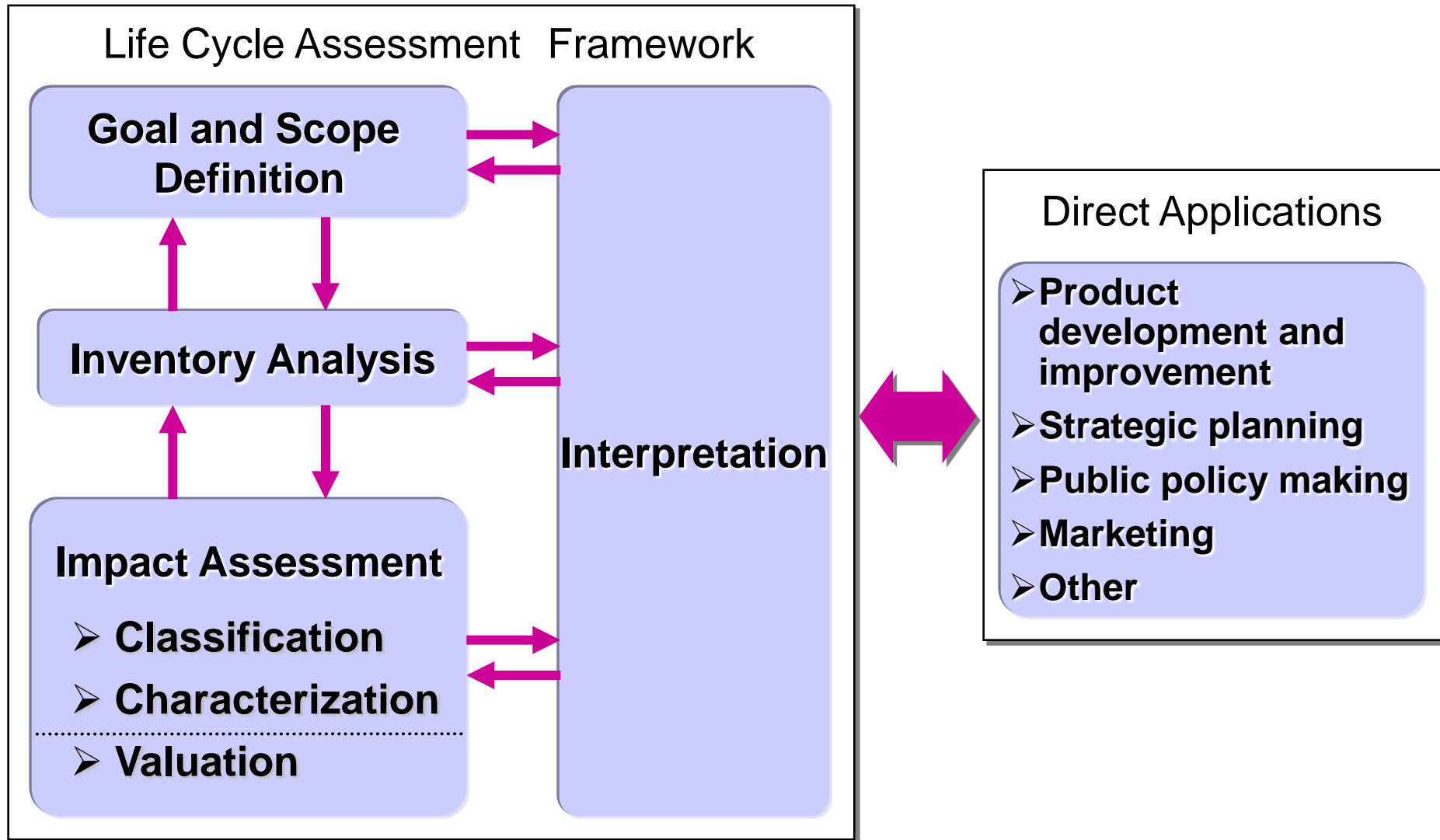
“An LCA of Electric Power in Japan”

Kazuhiko YAMADA
Hydropower I.A., IEA

Life-Cycle CO₂-Emission Factors of Electricity Generation



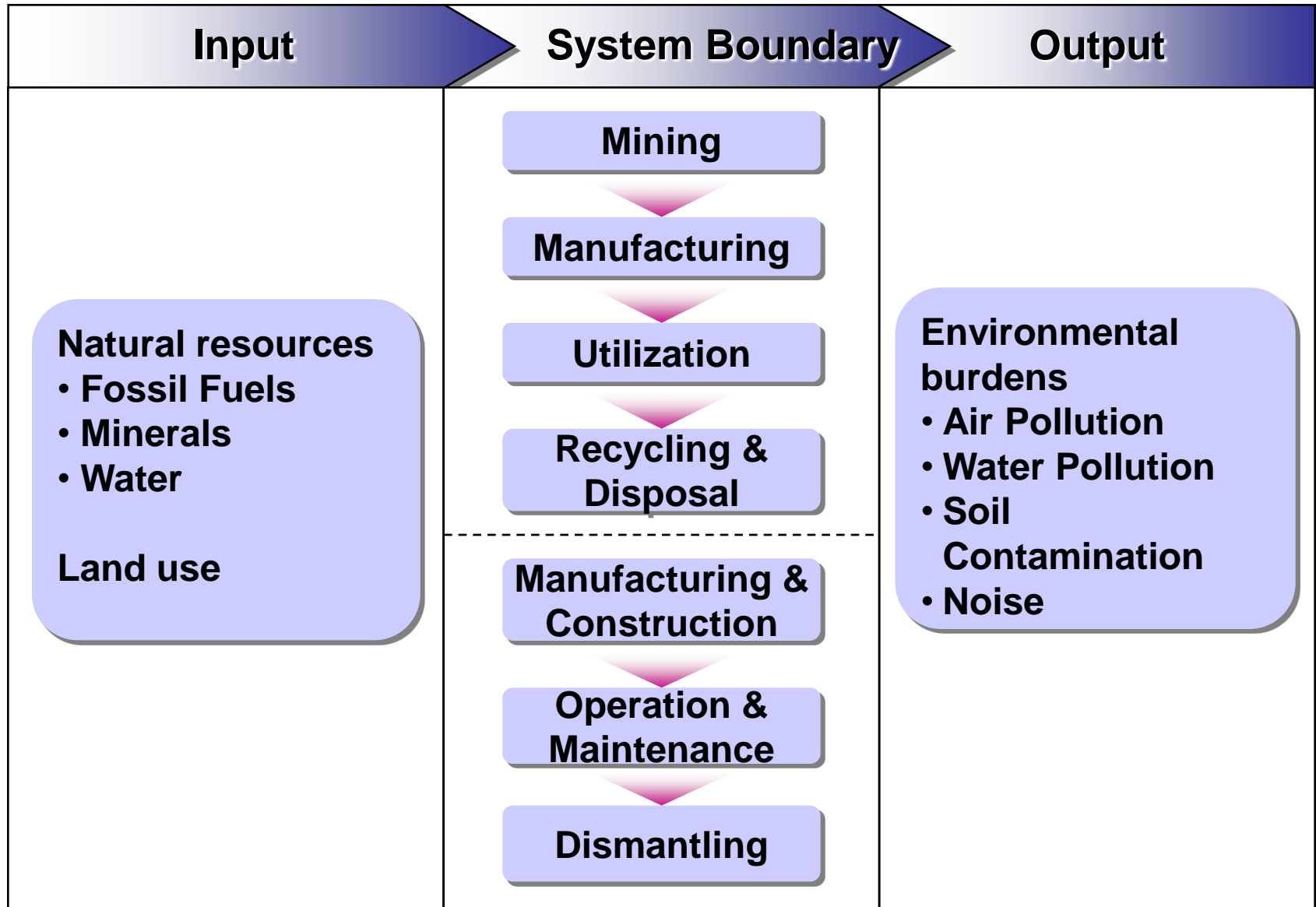
Phases of an Life Cycle Assessment



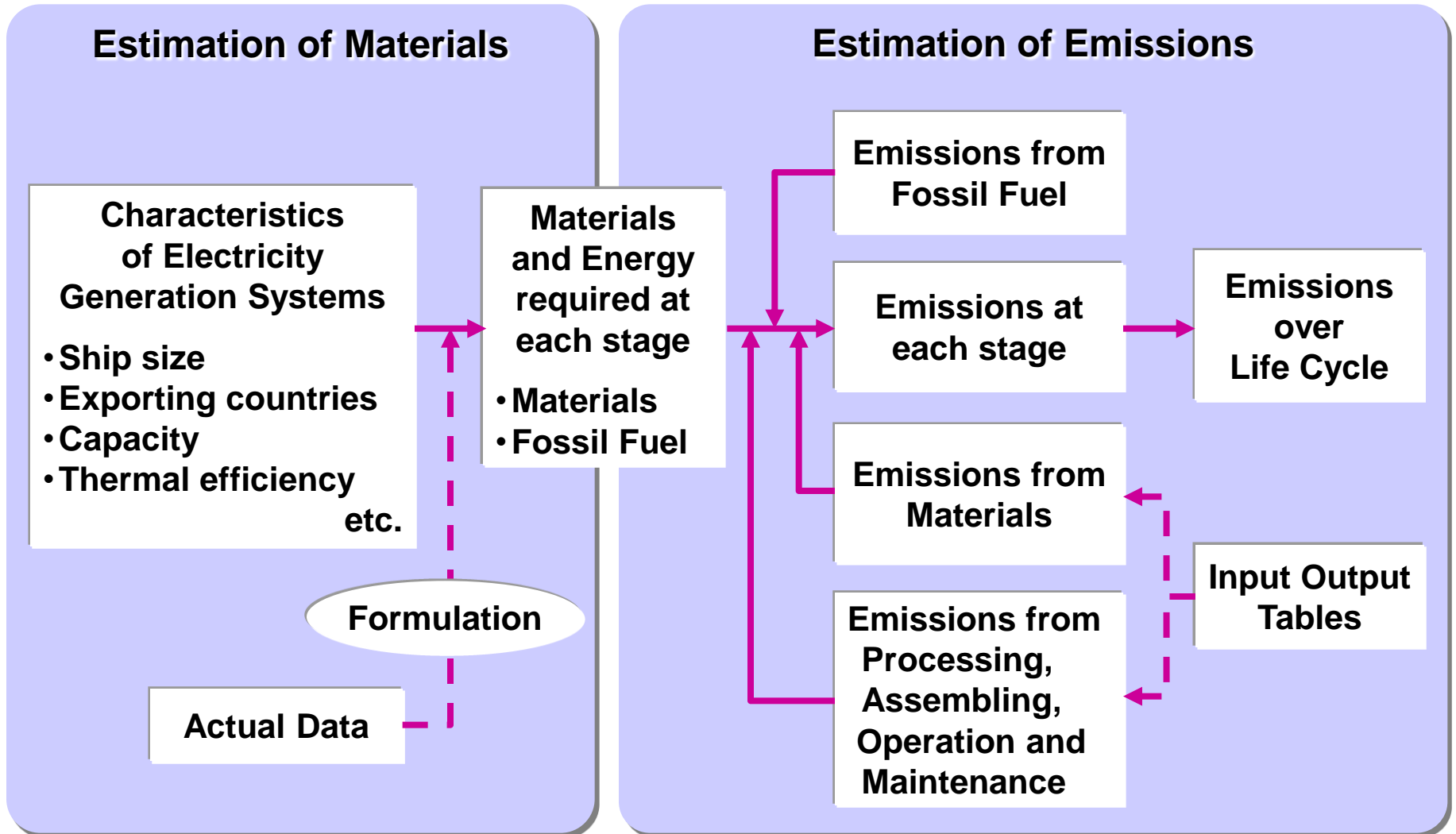
(ISO 14040 LCA Framework)

Data: Central Research Institute of Electric Power Industry, Tokyo, Japan, March 2000

Inventory Analysis of Electricity Generation System



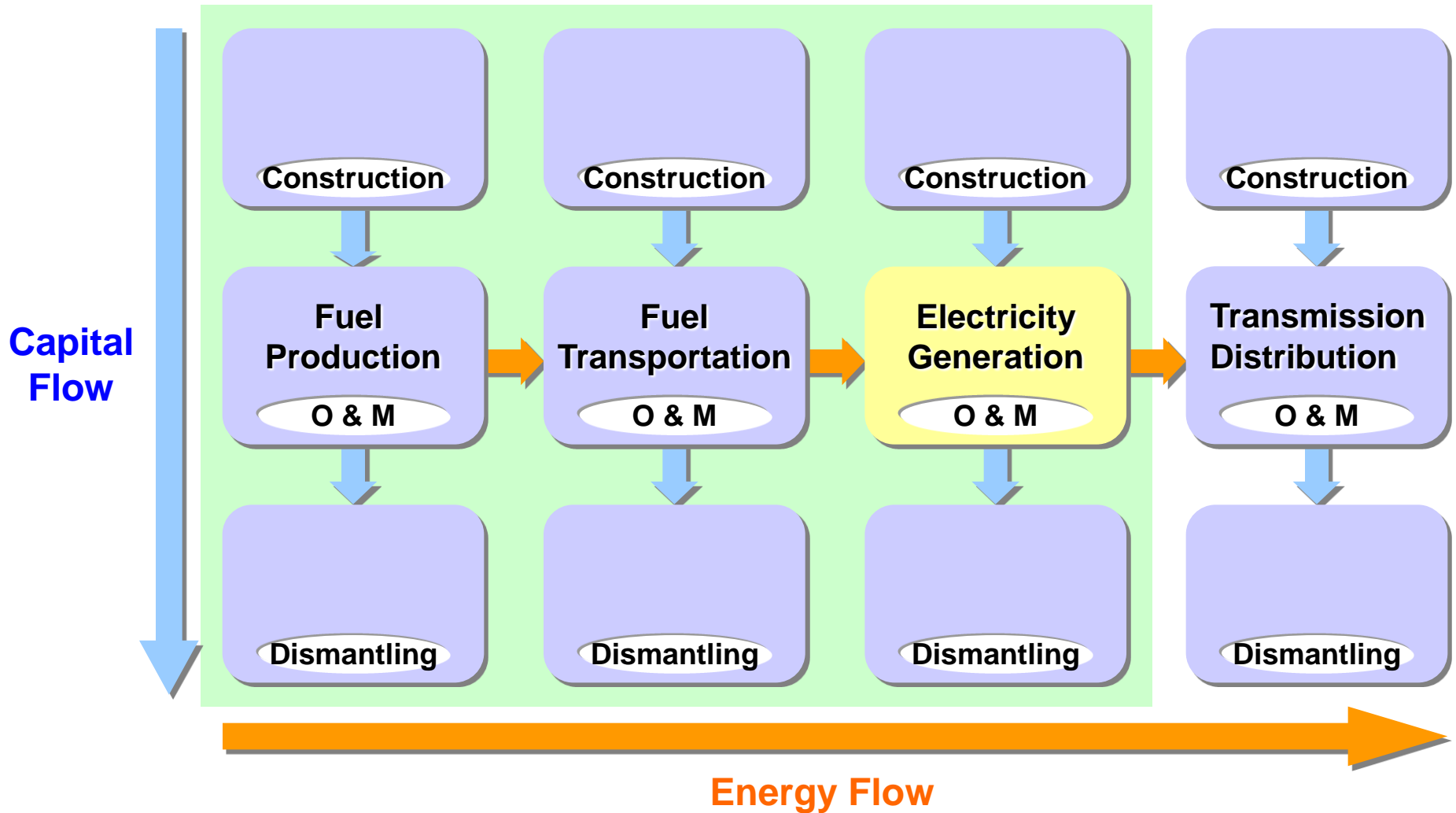
Outline of Inventory Analysis of Electricity Generation



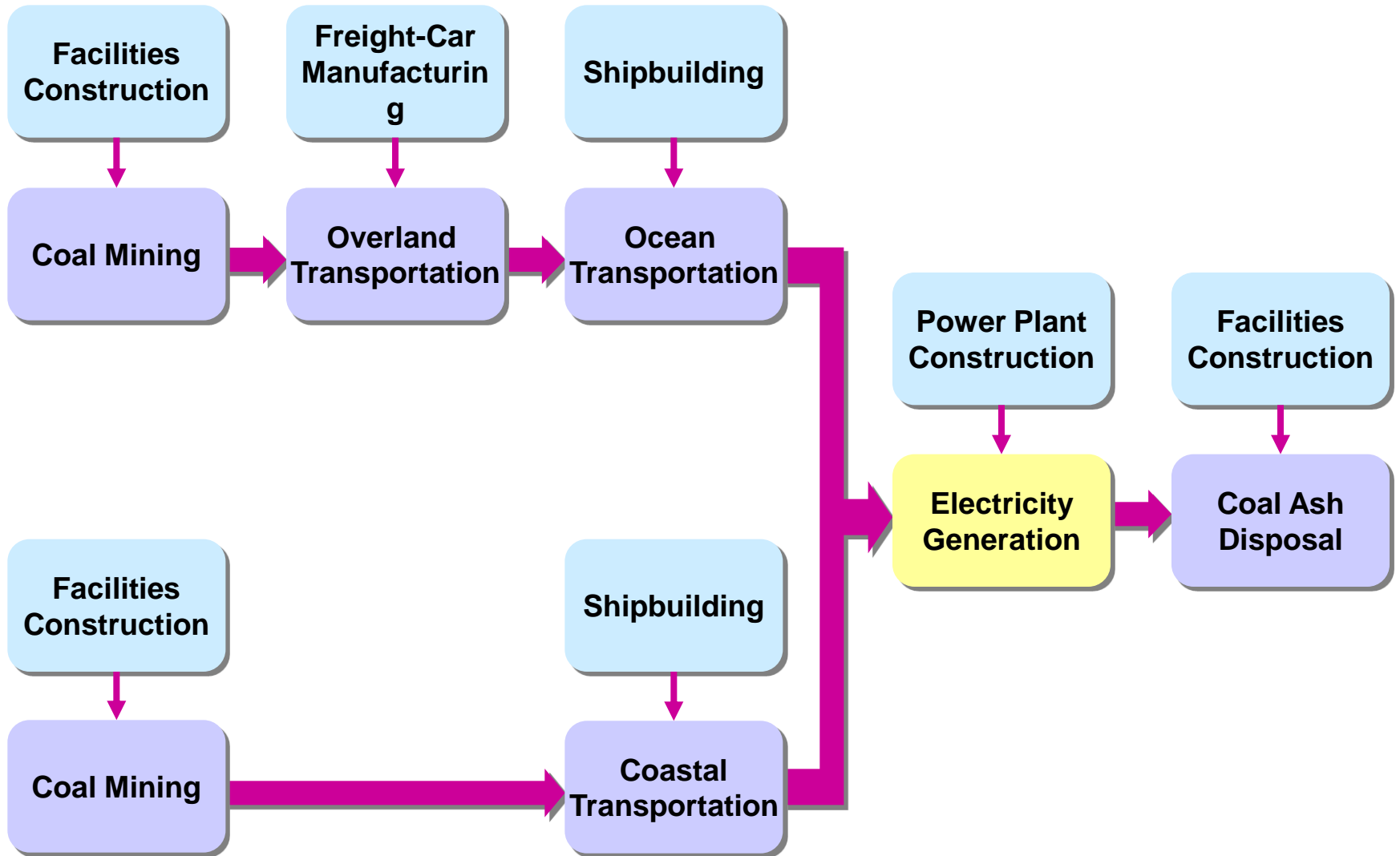
Input Output Tables

- Are compiled every five years by the Ministry of Internal Affairs and Communications, Japan.
- Are commodity-by-commodity tables and valued at producers' price and purchasers' price, which are recorded in the matrix form based on the most detailed classification.
- Do not have any information regarding GHG-emissions, therefore emissions of every single product of each industrial sector were estimated separately.

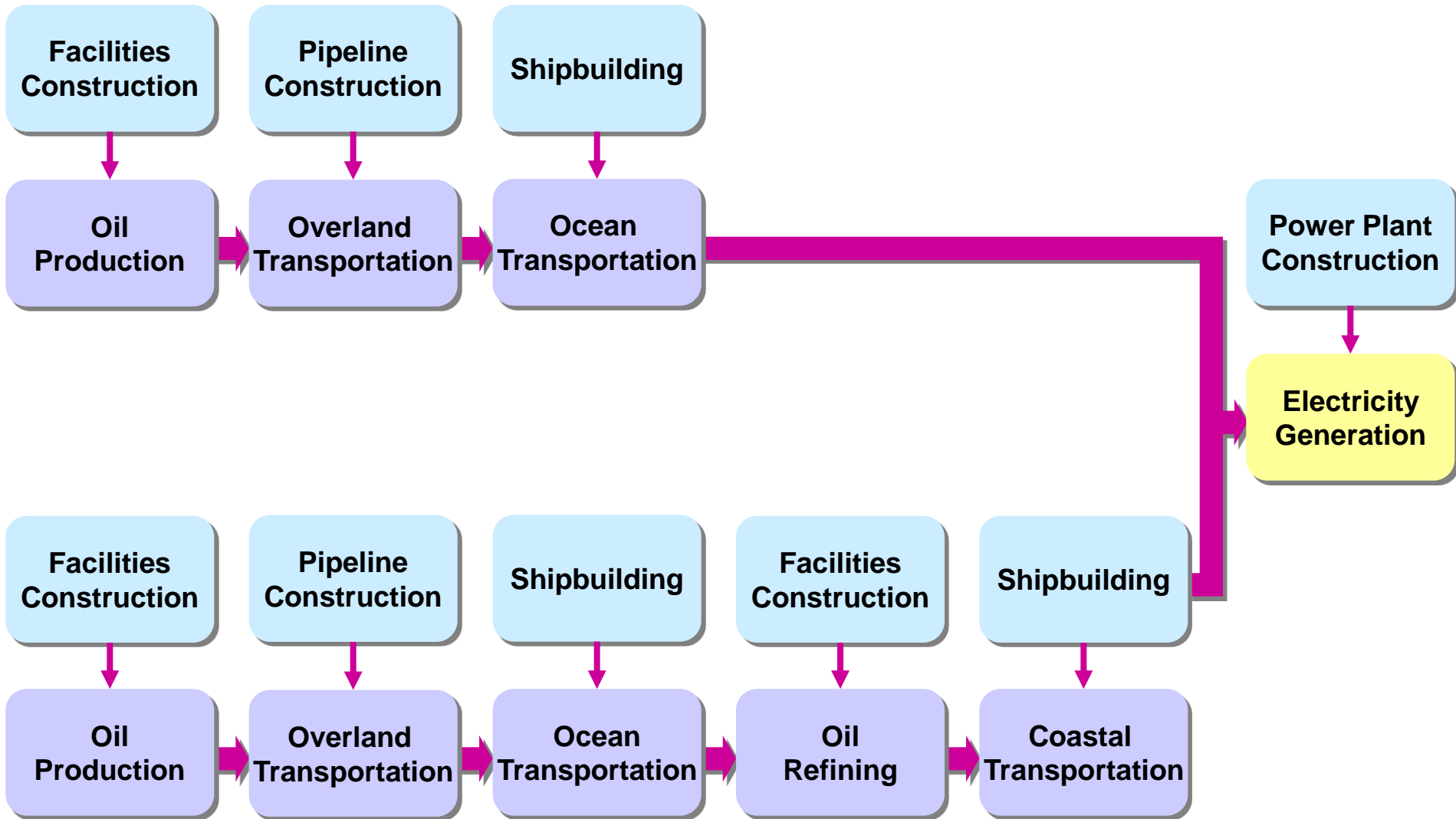
Life Cycle of Electricity Generation



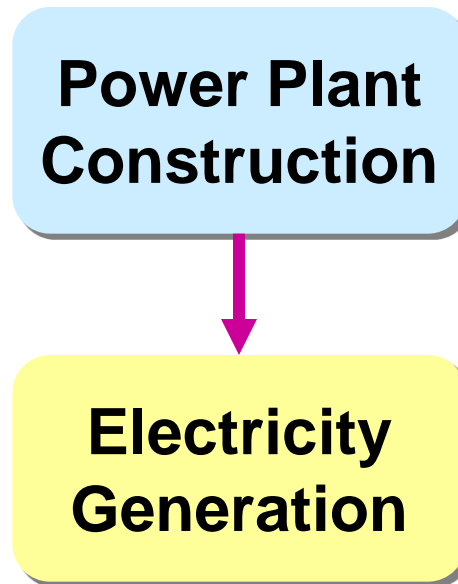
Life Cycle of Coal-fired Electricity Generation



Life Cycle of Oil-fired Electricity Generation



Life Cycle of Hydropower Electricity Generation



Life Cycle CO₂ Emission Factor (1/2)

Life Cycle CO₂ Emission Factor [g-CO₂equiv.kWh⁻¹]

**Fossil Fuel
Combustion**

+

**Power Plant
Construction**

+

**Power Plant
O & M**

+

**Power Plant
Dismantling**

[g-CO₂]

**Net Electric Power Generated
over the Plant Lifetime**

[kWh]

Life Cycle CO₂ Emission Factor (2/2)

Life Cycle CO₂ Emission Factor [g-CO₂equiv.·kWh⁻¹]

$$= \frac{\sum_i GWP_i \times (Ef_i + Ec_i + Eo_i + Ed_i)}{Q}$$

Ef : Direct emission associated with fuel combustion

Ec : Emissions associated with construction of plants and facilities

Eo : Emissions associated with operation and maintenance of plants and facilities

Ed : Emissions associated with dismantling of plants and facilities

GWP : Global warming potential

Q : Electric power generated over lifetime

=Capacity of the Plant [kW] x 8760[h] x Capacity Factor x Lifetime (yr)

i : Kind of GHGs (e.g. CO₂, CH₄)

Conceptual Designs of Electricity Generation Systems (Model Plants)

	Capacity (MW)	Capacity Factor	Thermal Efficiency	In-plant Consumption	Lifetime (yr)
Coal	1000	70%	39.6%	6.93%	30
Oil	1000	70%	38.4%	5.67%	30
LNG	1000	70%	38.9%	4.31%	30
LNG Combined	1000	70%	44.6%	2.18%	30
Nuclear (BWR)	1000	70%	33.7%	4.30%	30
Nuclear (PWR)	1000	70%	33.7%	4.30%	30
Hydropower	10	45%	—	0.68%	30
Geothermal	55	60%	—	7.00%	30
Photovoltaic Cell	0.003	19%	—	0.00%	30
Wind	0.3	20%	—	10.00%	30

Life-cycle CO₂ Emissions

Coal-fired

Capacity	1,000 MW	
Capacity factor	70 %	
In-plant consumption	6.93 %	
Thermal efficiency	39.55 %	
Electricity generated (net)	5,707 GWh	
Domestic-coal : Imported-coal (weight)	10.6 : 89.4 %	
	g-CO₂/kWh	Percentage
Fuel combustion	886.81	90.9%
Facilities construction		
Domestic-coal mining	0.04	0.0%
Imported-coal mining	0.41	0.0%
Domestic-coal coastal transportation	0.02	0.0%
Imported-coal overland transportation	0.03	0.0%
Imported-coal ocean transportation	0.37	0.0%
Power plant	2.39	0.2%
Ash disposal	0.34	0.0%
	Sub-total	3.60 0.4%
Facilities operation and maintenance		
Domestic-coal mining	Fuel	0.23 0.0%
	Electricity	1.22 0.1%
	Expendables	0.19 0.0%
Imported-coal mining	Fuel	3.26 0.3%
	Electricity	3.65 0.4%
	Expendables	1.15 0.1%
Domestic-coal coastal transportation	0.51	0.1%
Imported-coal overland transportation	4.41	0.5%
Imported-coal ocean transportation	10.66	1.1%
Electricity generated Expendables		2.93 0.3%
	Maintenance	3.74 0.4%
Ash disposal	0.03	0.0%
	Sub-total	31.97 3.3%
Methane leakage		
Domestic-coal mining	13.30	1.4%
Imported-coal mining	39.56	4.1%
	Sub-total	52.86 5.4%
Life-cycle total	975.24	100.0%

Oil-fired

Capacity	1,000 MW	
Capacity factor	70 %	
In-plant consumption	5.67 %	
Thermal efficiency	38.42 %	
Electricity generated (net)	5,784 GWh	
Crude oil : C heavy-oil (heat Value)	54.1 : 45.9 %	
	g-CO₂/kWh	Percentage
Fuel combustion	704.34	94.9%
Facilities construction		
Oil production (crude)	0.19	0.0%
Oil production (refined)	0.15	0.0%
Ocean transportation (crude)	0.07	0.0%
Ocean transportation (refined)	0.13	0.0%
Oil refining	0.07	0.0%
Heavy-oil inland transportation	0.02	0.0%
Power plant	1.69	0.2%
	Sub-total	2.32 0.3%
Facilities operation and maintenance		
Oil production (crude)	Fuel	3.75 0.5%
	Flare	2.26 0.3%
Oil production (refined)	Fuel	2.97 0.4%
	Flare	2.10 0.3%
Ocean transportation (crude)	3.15	0.4%
Ocean transportation (refined)	3.30	0.4%
Oil refining	12.63	1.7%
Heavy-oil inland transportation	0.26	0.0%
Power plant	Expendables	1.12 0.2%
	Maintenance	3.69 0.5%
	Sub-total	35.22 4.7%
Methane leakage		
Oil production (crude)	0.14	0.0%
Oil production (refined)	0.11	0.0%
	Sub-total	0.25 0.0%
Life-cycle Total	742.14	100.0%

Life-cycle CO₂ Emissions

LNG-fired

Capacity	1,000 MW	
Capacity factor	70 %	
In-plant consumption	4.31 %	
Thermal efficiency	38.88 %	
Electricity generated (net)	5,867 GWh	
	g-CO₂/kWh	Percentage
Fuel combustion	477.947	78.7%
Facilities construction		
LNG production	0.80	0.1%
Ocean transportation	0.41	0.1%
Power plant	1.69	0.3%
Sub-total	2.90	0.5%
Facilities operation and maintenance		
LNG production	Fuel	
	67.63	11.1%
	CO ₂ contained	
	26.16	4.3%
Ocean transportation	19.38	3.2%
Power plant	Expendables	
	0.90	0.1%
	Maintenance	
	3.64	0.6%
Sub-total	117.71	19.4%
Methane leakage		
LNG production	9.07	1.5%
Sub-total	9.07	1.5%
Life-cycle Total	607.63	100.0%

LNG Combined-cycle

Capacity	1,000 MW	
Capacity factor	70 %	
In-plant consumption	2.18 %	
Thermal efficiency	44.61 %	
Electricity generated (net)	5,999 GWh	
	g-CO₂/kWh	Percentage
Fuel combustion	407.469	78.5%
Facilities construction		
LNG production	0.68	0.1%
Ocean transportation	0.35	0.1%
Power plant	1.65	0.3%
Sub-total	2.68	0.5%
Facilities operation and maintenance		
LNG production	Fuel	
	57.66	11.1%
	CO ₂ contained	
	22.30	4.3%
Ocean transportation	16.52	3.2%
Power plant	Expendables	
	0.90	0.2%
	Maintenance	
	3.56	0.7%
Sub-total	100.94	19.5%
Methane leak		
LNG production	7.73	1.5%
Sub-total	7.73	1.5%
Life-cycle Total	518.83	100.0%

Life-cycle CO₂ Emissions

Nuclear (BWR)

Capacity	1000 MW	
Capacity factor	70 %	
In-plant consumption	4.3 %	
Thermal efficiency	33.67 %	
Electricity generated (net)	5,868 GWh	
	g-CO₂/kWh	Percentage
Facilities construction		
Mining and milling	0.17	0.7%
Vaporizing	0.02	0.1%
Enrichment	0.08	0.3%
Fuel fabrication	0.00	0.0%
Fuel transportation	0.00	0.0%
Power plant	1.61	6.8%
Intermediate storage	0.14	0.6%
LLW transportation	0.00	0.0%
LLW disposal (Final storage)	0.29	1.2%
Sub-total	2.31	9.8%
Facilities operation and maintenance		
Mining and milling	1.09	4.6%
Vaporizing	0.22	0.9%
Enrichment	14.95	63.3%
Fuel fabrication	0.67	2.9%
Fuel transportation	0.05	0.2%
Power plant	3.16	13.4%
Intermediate storage	0.69	2.9%
LLW transportation	0.04	0.2%
LLW disposal (Final storage)	0.04	0.2%
Sub-total	20.91	88.5%
Facilities dismantling		
Enrichment	0.01	0.0%
Fuel fabrication	0.00	0.0%
Power plant (Reactor)	0.41	1.7%
Sub-total	0.42	1.8%
Life-cycle Total	23.64	100.0%

Nuclear (PWR)

Capacity	1,000 MW	
Capacity factor	70 %	
In-plant consumption	4.3 %	
Thermal efficiency	33.67 %	
Electricity generated (net)	5,868 GWh	
	g-CO₂/kWh	Percentage
Facilities construction		
Mining and milling	0.21	0.7%
Vaporizing	0.03	0.1%
Enrichment	0.10	0.4%
Fuel fabrication	0.00	0.0%
Fuel transportation	0.01	0.0%
Power plant	1.61	5.6%
Intermediate storage	0.14	0.5%
LLW transportation	0.00	0.0%
LLW disposal (Final storage)	0.29	1.0%
Sub-total	2.38	8.3%
Facilities operation and maintenance		
Mining and milling	1.33	4.6%
Vaporizing	0.27	1.0%
Enrichment	19.60	68.4%
Fuel fabrication	0.67	2.4%
Fuel transportation	0.05	0.2%
Power plant	3.16	11.0%
Intermediate storage	0.69	2.4%
LLW transportation	0.04	0.1%
LLW disposal (Final storage)	0.04	0.1%
Sub-total	25.86	90.2%
Facilities dismantling		
Enrichment	0.01	0.0%
Fuel fabrication	0.00	0.0%
Power plant (Reactor)	0.41	1.4%
Sub-total	0.42	1.5%
Life-cycle Total	28.66	100.0%

Life-cycle CO₂ Emissions

Hydropower

Capacity	10 MW	
Capacity factor	45 %	
In-plant consumption	0.68 %	
Electricity generated (net)	39 GWh	
Type	Dam and conduit	
Maximum discharge	4.8 m ³ /s	
Penstock	490 m	
Dam	2,000 m ³	
Headrace	9,000 m	
g-CO₂/kWh Percentage		
Facilities construction		
Machinery	0.90	8.0%
Dam	0.51	4.5%
Conduit	4.48	39.8%
Other civil structures	2.36	21.0%
On-site civil works	1.08	9.6%
Sub-total	9.33	82.8%
Facilities operation and maintenance		
Power plant Maintenance	1.93	17.2%
Sub-total	1.93	17.2%
Life-cycle Total 11.26 100.0%		

Geothermal

Capacity	55 MW	
Capacity factor	60 %	
In-plant consumption	7 %	
Electricity generated (net)	268.844 GWh	
g-CO₂/kWh Percentage		
Facilities construction		
Civil structure	1.98	13.2%
Main facilities	3.18	21.2%
Development facilities	0.14	0.9%
Sub-total	5.31	35.3%
Facilities operation and maintenance		
Power plant Auxiliary well	2.95	19.6%
Maintenance	2.27	15.1%
Replacement	4.51	30.0%
Sub-total	9.72	64.7%
Life-cycle Total 15.03 100.0%		

Note: Possible GHG-emissions from reservoirs are not taken into account.

Data: Central Research Institute of Electric Power Industry, Tokyo, Japan, March 2000

Life-cycle CO₂ Emissions

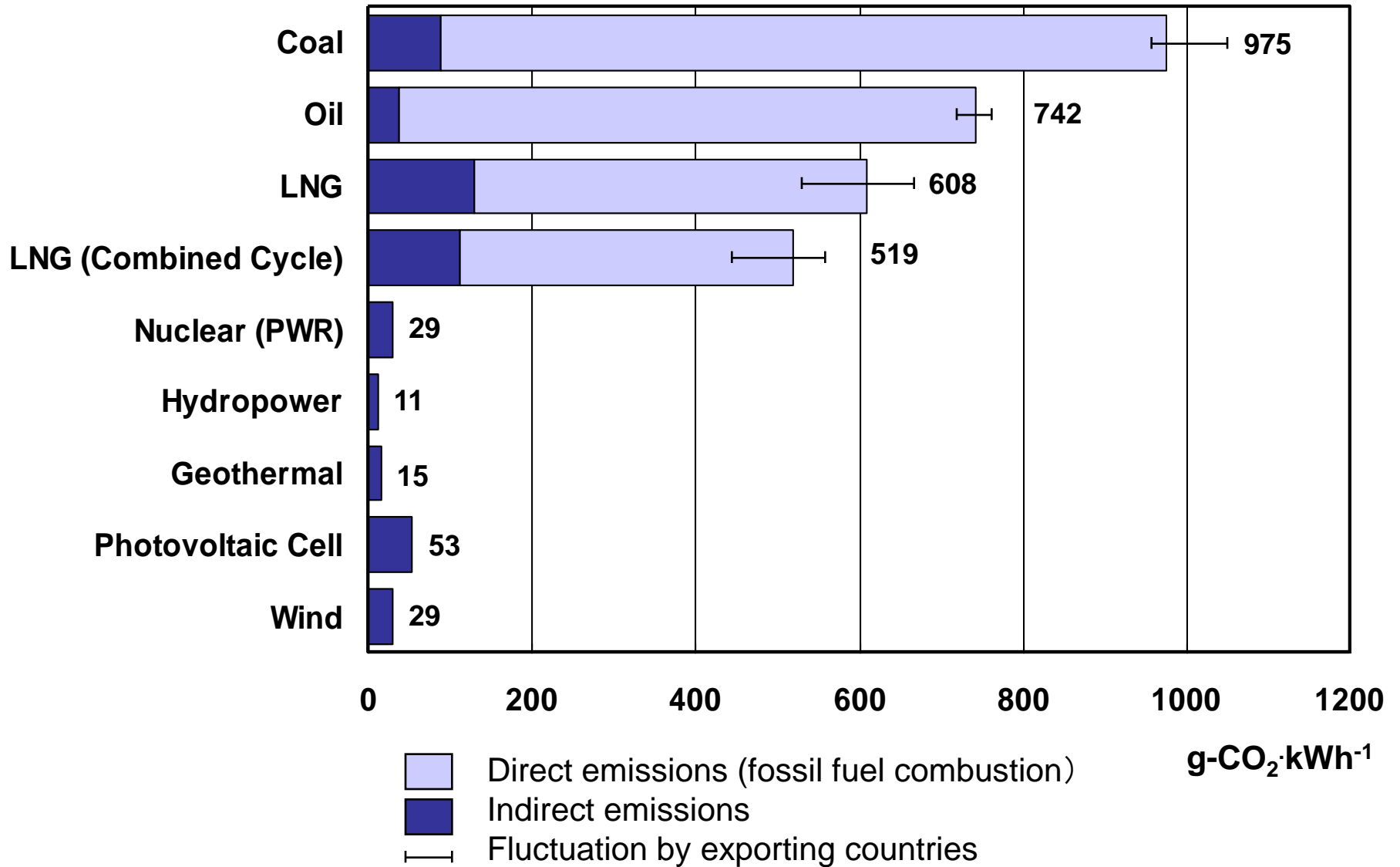
Solar (photovoltaic)

Capacity	3 kW	
Capacity factor	15 %	
In-plant consumption	0 %	
Electricity generated (net)	3.94 GWh	
	g-CO₂/kWh	Percentage
Facilities construction		
Alley panel	28.33	53.0%
Trestle	9.79	18.3%
Incidental equipment	2.97	5.6%
Sub-total	41.08	76.9%
Facilities operation and maintenance		
Generator Maintenance	12.33	23.1%
Sub-total	12.33	23.1%
Life-cycle Total	53.41	100.0%

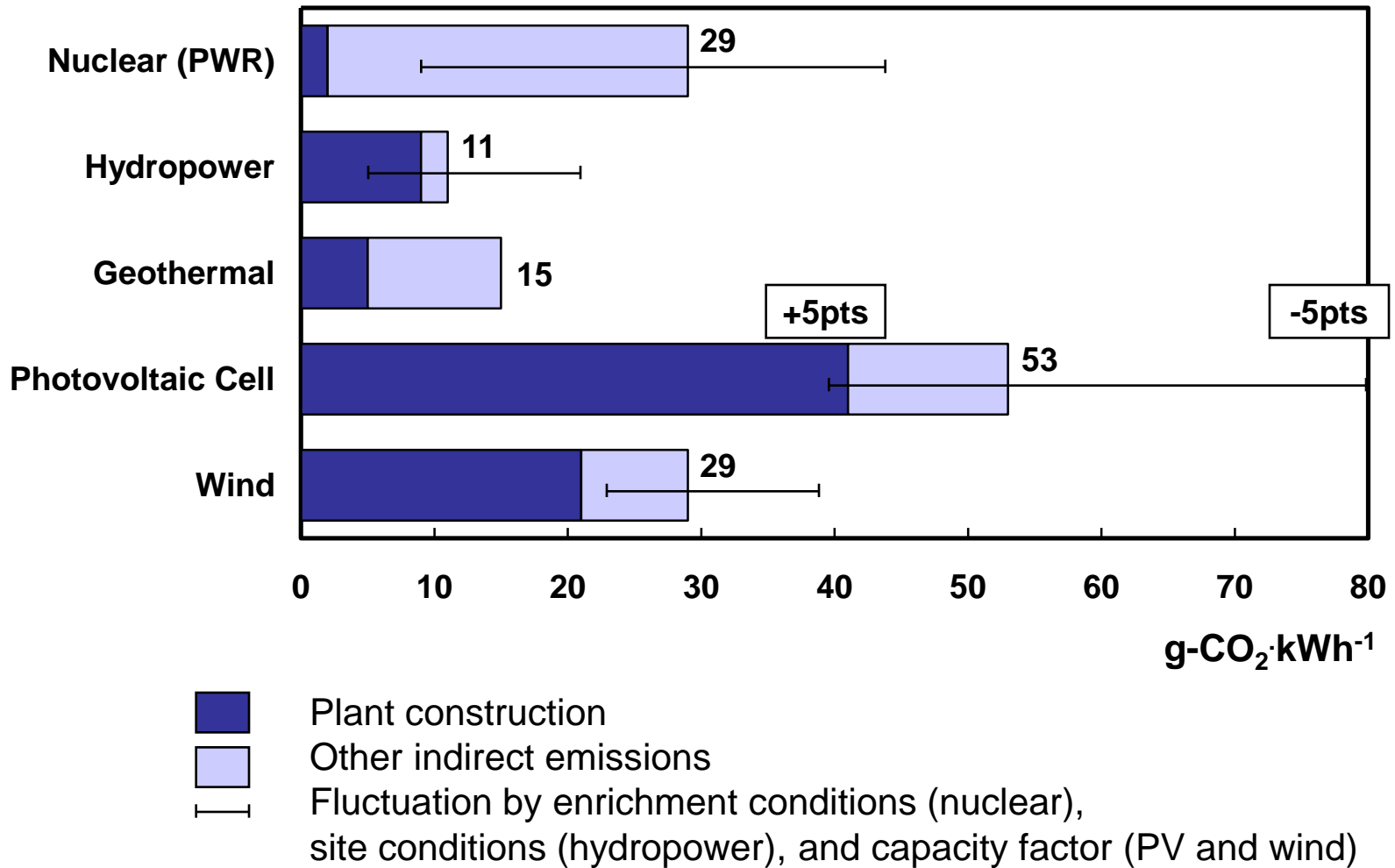
Wind

Capacity	300 kW	
Capacity factor	20 %	
In-plant consumption	10 %	
Electricity generated (net)	473.04 GWh	
	g-CO₂/kWh	Percentage
Facilities construction		
Civil structure	7.40	25.1%
Blade	1.43	4.8%
Nacelle	5.91	20.0%
Steel tower	3.44	11.7%
Generator & incidental equipme	3.03	10.3%
Sub-total	21.21	71.9%
Facilities operation and maintenance		
Generator Maintenance	8.29	28.1%
Sub-total	8.29	28.1%
Life-cycle Total	29.49	100.0%

Life-Cycle CO₂-Emission Factors of Electricity Generation (1/2)



Life-Cycle CO₂-Emission Factors of Electricity Generation (2/2)



Issues requiring consecutive analysis

- LCA of Electricity Generation in Japan will be re-estimated, based on the latest information and data, by the Central Research Institute of Electric Power Industry, Tokyo JAPAN.
- Impacts of climate change on hydropower generation should be taken into account, but it is not an immediate issue and might be anticipated in the long run.

References

- Evaluation of Power Generation Technologies based on Life Cycle CO₂ Emissions – Re-estimation using the Latest Data and Effects of the Difference of Conditions. Tokyo, Japan: Central Research Institute of Electric Power Industry; 2000 Mar.
- Evaluation of Nuclear Power Generation Technology based on Life Cycle CO₂ Emissions. Tokyo, Japan: Central Research Institute of Electric Power Industry; 2001 Aug.
- Environmental and Health Impacts of Electricity Generation - A Comparison of Environmental Impacts of Hydropower with those of Other Generation Technologies. Paris, France: IEA - Implementing Agreement for Hydropower Technologies and Programs; 2002 Jun.
Available at: <http://www.ieahydro.org/annex3.htm>.

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