CSPBankability Project Report

Draft for an Appendix O – Cost Structures

to the SolarPACES Guideline for Bankable STE Yield Assessment

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Index of contents

Document properties **2**

O. Cost structures **4**

O.1. General structure of costs 4

O.1.1. Capital expenditures (CAPEX) 4

O.1.1.1. EPC costs 4

O.1.1.2. Owner's costs 6

O.1.1.3. Financing costs 7

O.1.2. Operation and maintenance expenditures (OPEX) 8

O.2. Exemplary cost estimate for Reference System PT-Oil 9

O.2.1. Capital expenditures (CAPEX) 9

O.2.2. Operation and maintenance expenditures (OPEX) 12

List of tables **15**

O. Cost structures

O.1. General structure of costs

Depending on the time when project costs are estimated, the project structure and the type of CSP technology, respective cost structures, their level of detail and the accuracy of estimate will differ. The cost structures provided in this guideline refer to a project financed CSP project (see Appendix N) with an EPC turnkey contract. The level of breakdown and accuracy range presented herein corresponds to a project in the planning (feasibility study) phase. General information on cost estimation and typical accuracy ranges which shall be expected for the different estimate classes (project phases) is provided in Section 2.2 of the Guideline.

On a very top level, project expenses are divided into capital expenditures (CAPEX) and operational expenditures (OPEX), as further outlined in the following sections for each of the reference plants. Chapter O.1 provides general aspects on the cost categories valid for all CSP technologies. In chapter O.2 the methodology is applied to the reference system parabolic trough with oil as heat transfer fluid. Corresponding default values for cost items are provided for this technology. In later versions of this document similar chapters will be added for other CSP technologies like molten salt towers.

O.1.1. Capital expenditures (CAPEX)

Capital expenditures consist of the following three main categories:

- EPC costs;
- Owner's costs; and
- Financing costs

The sum of the EPC costs and the Owner's costs is often referred to as "overnight cost", a term used in the power generation industry in order to compare different power plant options on a levelized cost basis. Overnight costs describe the cost of building a power plant "overnight", i.e. the overnight cost does not take into account financing costs or escalation. Financing costs mainly refer to interest during construction and financing fees, as further outlined in Appendix N.

O.1.1.1. EPC costs

In case of an EPC turnkey project, an experienced EPC contractor will carry out the engineering for the project, procure all the equipment and materials necessary, and construct the plant, thus, providing the Owner with a facility which is "ready to use". The EPC contractor has to execute and deliver the project within an agreed time and budget, commonly known as a Lump Sum Turn Key (LSTK) contract and provides the Owner with the respective guarantees.

EPC costs consist of the costs for plant equipment, on-site facilities, and all infrastructure supporting the plant installation (e.g. workshops, offices, or roads), as well as costs for the direct and indirect labor required for the construction of the plant. Further, there are the costs of services provided by the EPC contractor, including the basic and detail engineering, contractor permitting, project and construction management, site related studies, commissioning and start-up services. Last, the EPC costs include the profit margin of the contractor and considered contingencies.

The following general cost breakdown into main categories / subsystem[1] is proposed for the EPC costs:

- Site preparation incl. all site relevant works
- Solar field / heliostat field
- Heat transfer fluid system (incl. central receiver, if applicable)
- Thermal energy storage
- Solar tower (if applicable)
- Power block and Balance of Plant (BoP)
- Auxiliary heaters (if applicable)
- Engineering, project management and other EPC services
- Profit margin and contingencies

The split into these main categories allows a techno-economic optimization, varying the size of the subsystems (e.g. solar field reference aperture area or thermal energy storage capacity) knowing the respective specific cost (e.g. $/m^2 or $/kWh$_t$) and a scaling factor. Scaling factors are considered in particular important for concept studies, in which different plant configurations are compared against another in order to derive the most economic plant configuration.

The economy of scale relationship is based on the following formula:

$$C_2 = C_1 * \left({}^{S_2}/_{S_1} \right)^{sf} \quad \text{(O.1)}$$

With

C_2	Equipment / subsystem cost at target size/capacity S_2
C_1	Equipment / subsystem cost at reference size/capacity S_1
sf	Scaling factor for equipment/subsystem

[1] Further information on the different cost categories are provided in the respective Reference System chapters in this document.

Recommendations for the scaling factors are provided below for each Reference System, see e.g. Table O-6 for parabolic trough oil system. An overview of the corresponding reference and specific reference unit for the EPC cost items is provided in Table O-1. Please note, that for solar field costs, the reference aperture area is used. Since the exact definition of this area is specific for each manufacturer the corresponding costs need to be calculated on a consistent basis. Thus, a cost value for solar field can only be interpreted together with the definition of the reference aperture area and the performance data related to this specific aperture area.

Table O-1: Reference and specific reference units of EPC cost items

EPC cost item	Reference	Unit
Direct Cost		
Site preparation	total land area	$\$/m^2_{land}$
Solar field / heliostat field	solar field reference aperture area	$\$/m^2$
Heat transfer fluid system (incl. central receiver, if applicable)	solar field reference aperture area or thermal capacity	$\$/m^2$ or $\$/kWh_t$
Thermal energy storage (TES)	thermal capacity of storage system	$\$/kWh_t$
Solar tower (if applicable)	tower height	\$/m
Power block and Balance of Plant (BoP)	nominal capacity of power block	$\$/kW_e$
Auxiliary heater (if applicable)*	thermal capacity of auxiliary heater	$\$/kW_t$
Engineering, management and other EPC services	EPC direct costs	%
Profit margin and contingencies	EPC direct costs	%

* HTF heater or supplementary firing for steam generation

O.1.1.2. Owner's costs

The Owner's costs prior to the Commercial Operation Date (COD) include all expenses for the Owner, which are not included in the EPC turnkey package and which are not related to the financing of the project. The Owner's costs can be grouped into the following:

- Project development (incl. preparatory studies and surveys, permits and licensing, taxes, development fee, incl. premium, etc.)
- Land costs (purchase or land lease during construction)
- Utility connections (incl. grid, water and other necessary connections)

- Additional Owner's costs (Owner's management, Owner's advisors (Owner's engineer, Financial advisor, Tax advisor, Insurance advisor, Legal advisor, etc.) Lender's advisors (Lender's technical advisor, Lender's legal advisor, Lender's insurance advisor; Lender's tax advisor, Financial model auditor, etc.), O&M mobilization, pre-operating costs, contingencies, etc.)

The corresponding references for the Owner's cost items to be used as first approximation are summarized in Table O-2. Both the project development costs and the additional Owner's costs can be determined indicatively as percentage of total EPC cost. Land cost might only be applicable in some cases, i.e. might be included as land lease payments in the fixed OPEX. The cost for utility connections is very project specific (e.g. length of grid connection) and can vary significantly amongst projects. It needs to be further noted, that utility connections are sometimes also within the scope of the EPC contractor or provided by the respective power off-taker (utility).

Table O-2: Reference and specific reference units of Owner's cost items

Owner's cost item	Reference	Unit
Total Project development	EPC cost	%
Land cost (if applicable)*	total land area	$\$/m^2_{land}$
Utility connections**	project specific	$
Additional Owner's costs	EPC cost	%

* if not fully reflected through land lease payments in OPEX

** to be determined on a project specific basis, depending on project constraints

O.1.1.3. Financing costs

The financing costs prior to COD, further described in Appendix N – Financing, shall consider the following items:

- Interest During Construction (IDC);
- Up-front fees;
- Commitment fees;
- Agency fees (if applicable);
- Debt Service Reserve Account (DSRA) (if applicable); and
- Initial Maintenance Reserve Account.

O.1.2. Operation and maintenance expenditures (OPEX)

Annual operation and maintenance expenditures are divided into fixed and variable O&M costs. Fixed O&M costs need to be paid regardless of how much electricity is generated, i.e. regardless of the number of operating hours. In comparison, variable O&M costs are a function of the operation of the plant, i.e. the more operating hours the higher the variable O&M costs.

O&M services are often provided by an experienced O&M contractor, based on a multiyear O&M contract, signed with the project company and including most of the required operation and maintenance activities.

Table O-3 provides an overview of OPEX cost items, together with the respective references and proposed indicative calculation for each of the cost items. In addition, there might be maintenance reserve account payments required, generally at the beginning of the O&M period.

Table O-3: Cost structure - O&M costs

Item	Reference / calculation
Fixed O&M costs	
Solar field & HTF system (material and maintenance)	Fixed percentage of solar field & HTF system direct costs
TES system (material and maintenance)	Fixed percentage of TES system direct costs
Power block, BoP and aux. heater (material and maintenance)	Fixed percentage of PB, BoP and aux. heater direct costs
O&M personnel	Number of staff times average manpower costs
Administration & management	Fixed percentage of direct costs
Land lease (if applicable)	Land area times specific land lease costs
Insurance	Fixed percentage of total direct costs
Variable O&M costs	
Fuel	Fuel price times fuel consumption
Raw water	Raw water price times raw water consumption
Electricity	Electricity price times downtime electricity consumption
Others (e.g. HTF, nitrogen, other consumables etc.)	Fixed specific value times annual power generation ($/MWh$_e$)
Total OPEX	

The required inputs in order to calculate the O&M costs are summarized in Table O-4.

Table O-4: Input data required for O&M cost estimation

Item	Input / Source	Unit
Power generation	simulation result	GWh/a
Downtime electricity consumption	simulation result	GWh/a
Electricity price	location-specific value	$/MWh
Direct costs for main subsystems (solar field, power block etc.)	EPC cost estimate (as above)	$
Number of operating staff	project-specific value (assumption based on knowledge of amount of staff required for the O&M)	#
Average manpower costs	location-specific value (assumption based on knowledge of required personnel qualification and applicable annual rates)	$/a
Land area	simulation result (solar field size etc.)	m^2
Land lease	location-specific value	$/m^2$
Fuel price	location-specific value	$/MWh
Fuel consumption	simulation result	MWh/a
Raw water price	location-specific value; often water concession - fixed water costs/a	$/m^3$
Annual raw water consumption	simulation result	m^3/a

O.2. Exemplary cost estimate for Reference System PT-Oil

O.2.1. Capital expenditures (CAPEX)

Based on key parameters for the determined Reference System PT Oil, indicative capital expenditures are provided in Table O-5 along with the specific cost figures and calculation.

The considered key parameters are as follows:

- Nominal gross electric power: 100 MW_e
- Solar field reference aperture area: 987,920 m^2 (296 standard collector loops)
- Total land area: 3,870,000 m^2 (approx. land factor of 4, i.e. 4 times SF reference aperture area)
- Thermal storage capacity: 2,052 MWh_t

- Aux. heater nominal thermal power: 40 MW_t

Given the degree of definition for the Reference System, as outlined in the cost estimate chapter of the guideline, the cost estimate has been carried out on a class 3 level. Based on the technical definition of the parabolic trough oil Reference System as given in Appendix B and typical site conditions for a parabolic trough power plant in Spain, an overall accuracy range of -20 to +25% has been determined. . This relates to an accuracy range typically for a cost estimate conducted during the feasibility stage of a project (as outlined in Guideline Section 2.7.3).

Table O-5: CAPEX breakdown for the Reference System PT-Oil

Item	Reference / Calculation	M $
EPC Cost		**511**
Site preparation	4 $/m² total land area	15.5
Solar field	180 $/m² SF ref. aperture area	174.2
HTF system	56 $/m² SF ref. aperture area	54.2
Thermal energy storage (TES)	42 $/$kWh_t$ storage capacity	86.2
Power block and Balance of Plant (BoP)	1050 $/$kW_e$ power block capacity	105
Auxiliary heater	50 $/$kW_t$ auxiliary heater capacity	2
EPC direct costs	Sum of above items	437.1
Engineering, management and other EPC services	5% of EPC direct costs	21.9
Profit margin and contingencies	17% of EPC direct costs	74.3
Owner's cost		**36.7**
Project development	3% of total EPC cost	16
Land cost	N/A (land lease)	-
Utility connections	N/A (fixed estimate for 220 kV)	6
Additional Owner's costs	3% of total EPC cost	16
Total Overnight Cost (-20% / +25% accuracy)		**571.3**

Above cost breakdown items include the following main subsystems, equipment and services:

Site preparation: site clearing and grubbing, site leveling, drainage system, fencing (incl. wind protection), internal roads and parking areas, temporary laydown and storage area, etc.

Solar field: collector foundations, collector support structure, mirrors, receivers, flexible connections (ball joints, flex hoses) and collector piping (cross over piping) incl. insulation,

drives, instrumentation and control, assembly building, collector assembly and installation, initial spare parts, etc.

HTF system: civil works (foundations and structures), ullage and reclamation system, HTF expansion and storage, nitrogen system, HTF pumps and accessories, heat transfer fluid, HTF piping and accessories, insulation, firefighting, instrumentation and control, electrical system, installation, initial spare parts, etc.

Thermal energy storage: civil works (foundations and structures), storage tanks, molten salt pumps, molten salt / HTF heat exchangers, molten salt, immersion heaters, piping and accessories, insulation, firefighting, instrumentation and control, electrical system, installation, initial spare parts, etc.

Power block and Balance of Plant (BoP): civil works (foundations and structures), solar steam generators, steam turbine generator, step-up and auxiliary transformers, main condenser, cooling tower, condensate, feedwater and steam system, general PB piping and accessories, insulation, technical buildings incl. control and electrical building, non-technical building (warehouse etc.), firefighting, water treatment plant, effluent treatment plant, aux. cooling system, aux. steam system, compressed air system, fuel storage and handling, instrumentation and control (incl. DCS and meteorological stations), electrical system (incl. UPS and emergency diesel generators), installation, initial spare parts, etc.

Auxiliary heaters: civil works (foundations and structures), HTF heaters or supplementary firing for steam generation, fans and fuel forwarding pumps, piping and accessories, insulation, firefighting, instrumentation and control, electrical system, installation, initial spare parts, etc.

Engineering, management and other EPC services: overall EPC management, basic and detailed engineering, procurement management, construction management, studies and surveys, EPC permitting, EPC insurance, commissioning and start-up services, training, etc.

Project development (Owner's cost up to financial close): permits and licensing (building license, environmental permit, etc.), preparatory studies and surveys, local taxes and concessions, tendering, third party services (technical, legal due diligence, etc.), return for project developer (development fee or multiple), etc.

Utility connections: HV grid connection, back-up power supply (MV) grid connection, water connection, fuel connection, access road, etc.

Additional Owner's costs: Owner's management and administration, Owner's advisors (Owner's engineer, Financial advisor, Tax advisor, Insurance advisor, Legal advisor, etc.) Lender's advisors (Lender's technical advisor, Lender's legal advisor, Lender's insurance advisor; Lender's tax advisor, Financial model auditor, etc.), permitting during construction, supply of consumables during construction (water, power, etc.)

As indicted above, scaling factors might be used in case of techno-economic optimizations, varying the size of the subsystems (e.g. solar field reference aperture area or thermal energy storage capacity) knowing the respective specific cost (e.g. $/m^2 or $/kWh$_t$) and scaling factor. Table O-6 provides indicative scaling factors for the respective cost items, in case of a parabolic trough power plant. Additionally, incremental design changes (e.g. chance of single storage tank pair to multiple storage tank pairs) need to be considered.

Table O-6: Recommended scaling factors – reference system PT-Oil

Item	Scaling Factor / Range
Site preparation	0.8 - 0.9
Solar field	0.9 - 0.95
HTF system	0.8-0.9
Thermal energy storage (TES)	0.85-0.9
Power block and Balance of Plant (BoP)	0.7- 0.8
Auxiliary firing	0.7- 0.8
Engineering, management and other EPC services	0.3 - 0.5
Profit margin and contingencies	1
Project development	0.3 - 0.5
Land costs	0.9 - 1
Utility connections	N.A.
Additional Owner's costs	0.3 - 0.5

O.2.2. Operation and maintenance expenditures (OPEX)

Based on the key parameters and simulation results for the Reference System PT Oil, the indicative direct cost figures presented above as well as Spanish specific operational and price assumptions, the indicative O&M costs for the Reference System PT Oil have been calculated and are presented in Table O-7. Given the degree of project definition, presented in this guideline, also for the OPEX estimate an overall accuracy range of -20 to +25% can be considered.

The input data used to calculate the indicative O&M cost is summarized below, whereas the cost figures are presented in the subsequent table.

Table O-7: Input data O&M cost estimate - Reference System PT-Oil

Item	Unit	Value
Net power generation	GWh/a	363
Downtime electricity consumption	GWh/a	8
Electricity price	$/MWh	80
Direct cost	M $	422
Direct cost - solar field + HTF system	M $	228
Direct cost - thermal energy storage	M $	86
Direct cost - power block + BoP + aux. heater	M $	107
Number of operating staff	#	48
Average manpower costs	$/a	40,000
Land area	m²	387
Land lease	$/m²/a	0.17
Fuel price (e.g. NG)	$/MWh	28
Fuel consumption (e.g. NG)	MWh/a	180
Raw water price	$/m³	0.5
Annual raw water consumption	m³/a	1,270,500

Table O-8: OPEX breakdown for the Reference System PT-Oil

Item	Reference / calculation	Value [M$/a]
Fixed O&M costs		**7.14**
Solar field & HTF system (material and maintenance)	0.5%of solar field & HTF system direct costs	1.14
TES system (material and maintenance)	0.3% of TES system direct costs	0.26
Power block, BoP and aux. heater (material and maintenance)	1% of PB, BoP and aux. heater direct costs	1.1
O&M personnel	Number of staff times average manpower costs	2.1
Administration & management	0.15% of direct costs	0.63
Land lease (if applicable)	Land area times land lease costs	0.66
Insurance	0.3% of direct costs	1.26
Variable O&M costs		**1.64**
Fuel	Fuel price times fuel consumption	0.01
Raw water	Raw water price times raw water consumption (3.5 m^3/MWh_e)	0.64
Electricity	Electricity price times downtime electricity consumption	0.64
Others (e.g. HTF, nitrogen, other consumables etc.)	1 $/$MWh_e$ times annual power generation	0.36
Total OPEX (-20% / +25% accuracy)		**8.78**

List of tables

Table O-1: Reference and specific reference units of EPC cost items 6
Table O-2: Reference and specific reference units of Owner's cost items 7
Table O-3: Cost structure - O&M costs 8
Table O-4: Input data required for O&M cost estimation 9
Table O-5: CAPEX breakdown for the Reference System PT-Oil 10
Table O-6: Recommended scaling factors – reference system PT-Oil 12
Table O-7: Input data O&M cost estimate - Reference System PT-Oil 13
Table O-8: OPEX breakdown for the Reference System PT-Oil 14