NATIONAL RENEWABLE ENERGY LABORATORY

SolarDynamics

CSP Best Practices

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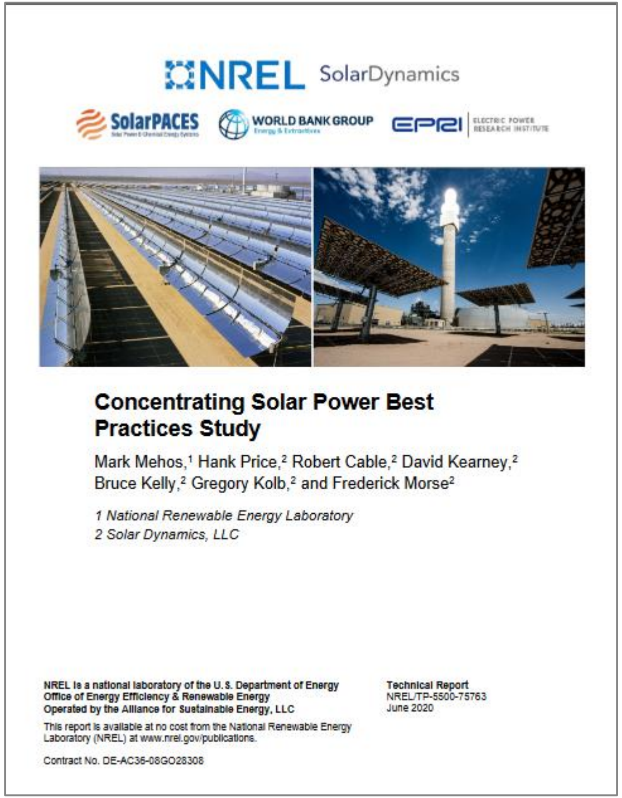
SETO Workshop: CSP Performance and Reliability Improvements

Project Intent, Objective and Audience

- **Objective** - to publish best practices and lessons learned from the engineering, procurement, construction, commissioning, operation and maintenance of existing parabolic trough and central receiver plants.
- **Intent** - to help developers, EPCs and O&M providers avoid the detrimental practices that have hindered some projects in the recent early commercial growth stage of power plants using CSP technology.
- **Audience** - developers, investors, lenders, off-takers, EPC firms, vendors, O&M providers, and policy makers.
- **R&D -** Identify issues that could benefit from further R&D

CSP Best Practices Report

- **Report Released June, 2020**
  - NREL News Release: [Concentrating Solar Power Best Practices Report Is First of Its Kind]
- **Report Structure**
  - Parabolic trough technology
  - Molten-salt tower technology
  - Operation and maintenance
  - Project organization & project execution


NREL SolarDynamics

SolarPACES WORLD BANK GROUP EPRI

Concentrating Solar Power Best Practices Study

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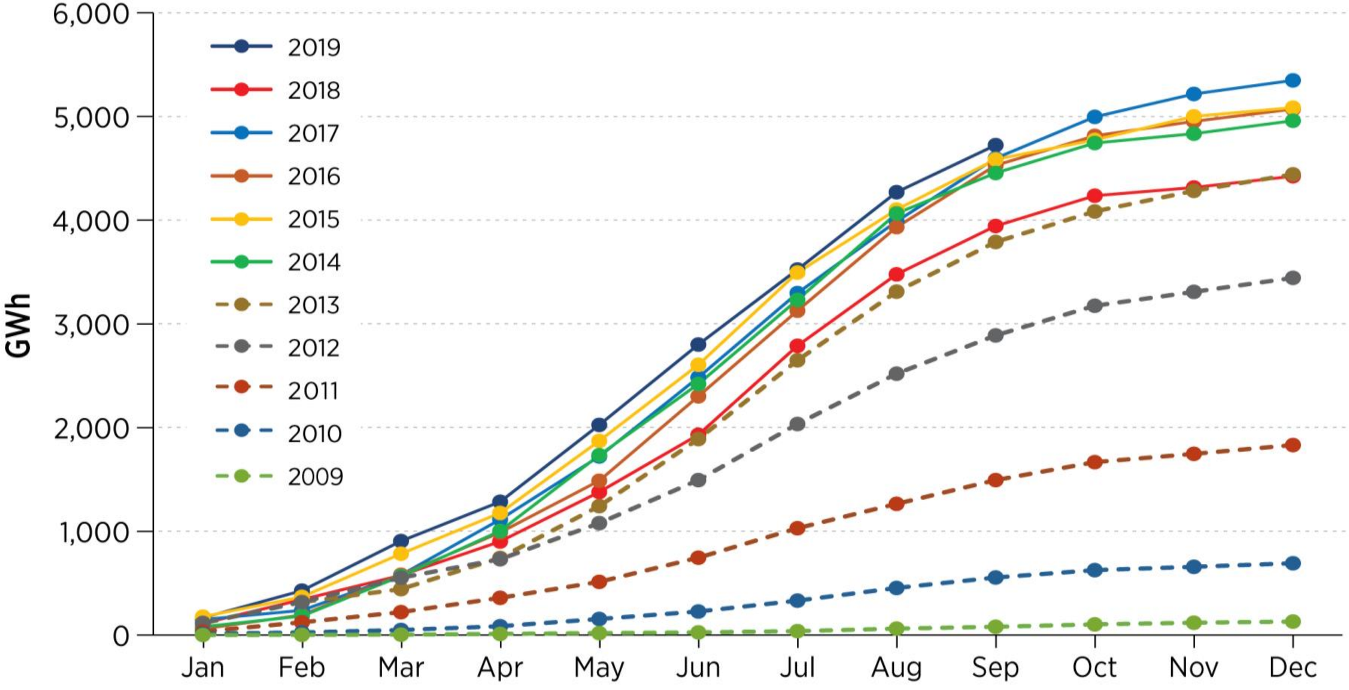
SolarPACES

ESTELA

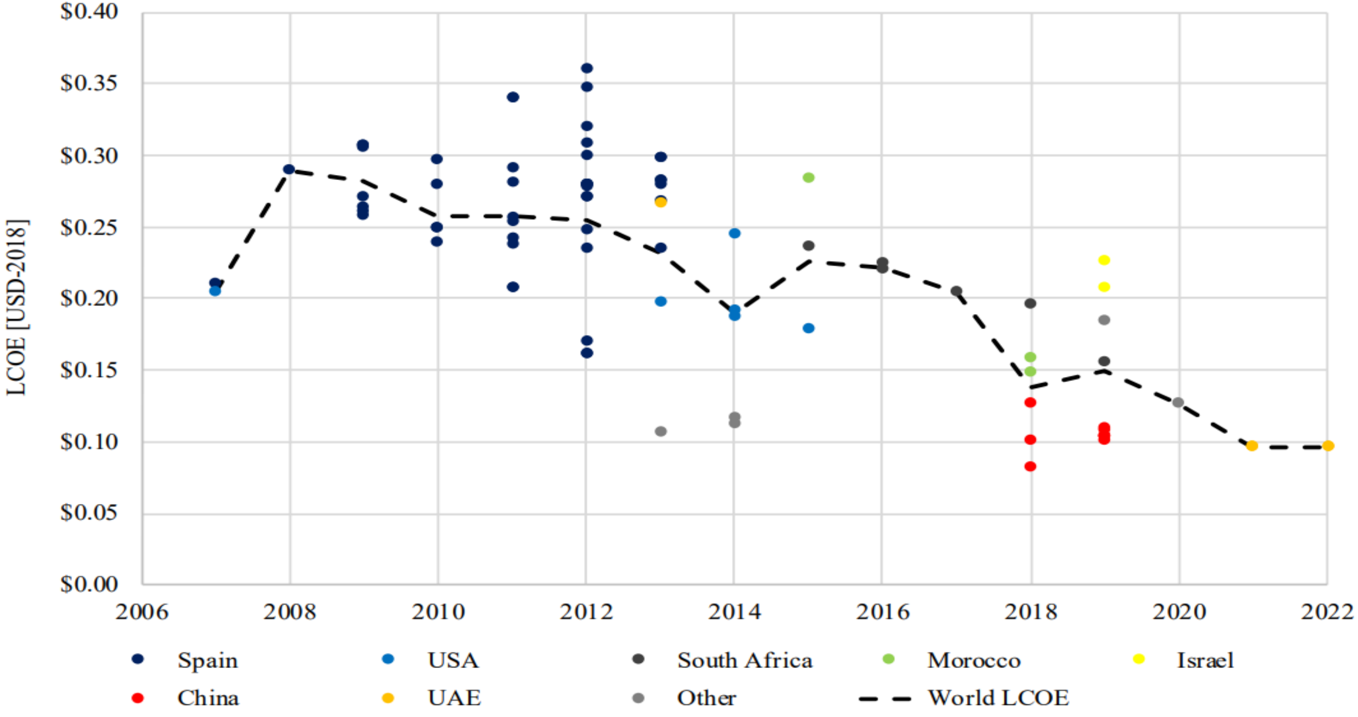
EPRI

Monthly cumulative generation of Spanish CSP plants



Source: Protermosolar

Normalized Levelized Cost of Energy (CSP Guru)



The average LCOE is the generation weighted average of all stations (expected) to start operating in each year. Based on 77 solar-only commercial CSP stations for 2006–2018 (operational) and 2019–2022 (under construction in January 2019, scheduled completion 2019–2022).

CSP Stakeholder Participation

Aalborg
Abengoa
ACWA
Advisian/Worley Parsons
Atlantica Yield
BrightSource
Cerro Dominador
ChemTreat
CMI
Cobra
CSP Services
DEWA

DLR
Gemasolar plant
Fichtner
Flowserve
FTI
Huiyin Group
La Africana plant
Lointek
MASEN
Mott MacDonald
Nevada Solar One
NRG

OCA Global
Parsons Group
Sargent & Lundy
SBP
SENER
SolarReserve
SolEngCo
SUNCAN
Terra-Gen (SEGS VIII/IX)
TSK
Virtual Mechanics
Vast Solar

Plants Visited

Parabolic Trough Plants

La Africana
Noor I and II
Solana
Mojave (Alpha and Beta)
SEGS VIII and IX
Nevada Solar One

Central Receiver Plants

Gemasolar
Ivanpah (1, 2, and 3)
Crescent Dunes
Noor III
Cerro Dominador

90 commercial tower & trough plants in operation

- 14 tower – 6 molten-salt, 8 steam
- 80 trough – 31 with TES

Issue Database

- Technology – Parabolic Trough, Central Receiver, or both
- System – Solar field, heat-transfer fluid (HTF) system, thermal energy storage (TES) system, Power Block, or project level
- Subsystem/Component – Further detailed breakdown within each system
- Issues (design, construction, commissioning, or operational concerns needing resolution)
  - Issue/Description - Brief description of identified issue
  - Impact - Brief description of the impact of the issue
  - Mitigation measures – Description of potential solutions or best practices.
  - Impact Score: 1 – low, 3 – medium, 5 – high
  - Risk Level: 1 – low, 3 – medium, 5 – high
  - Priority = Impact Score * Risk Level
  - Source of Information

CSP Best Practices Report

- **Report Structure**
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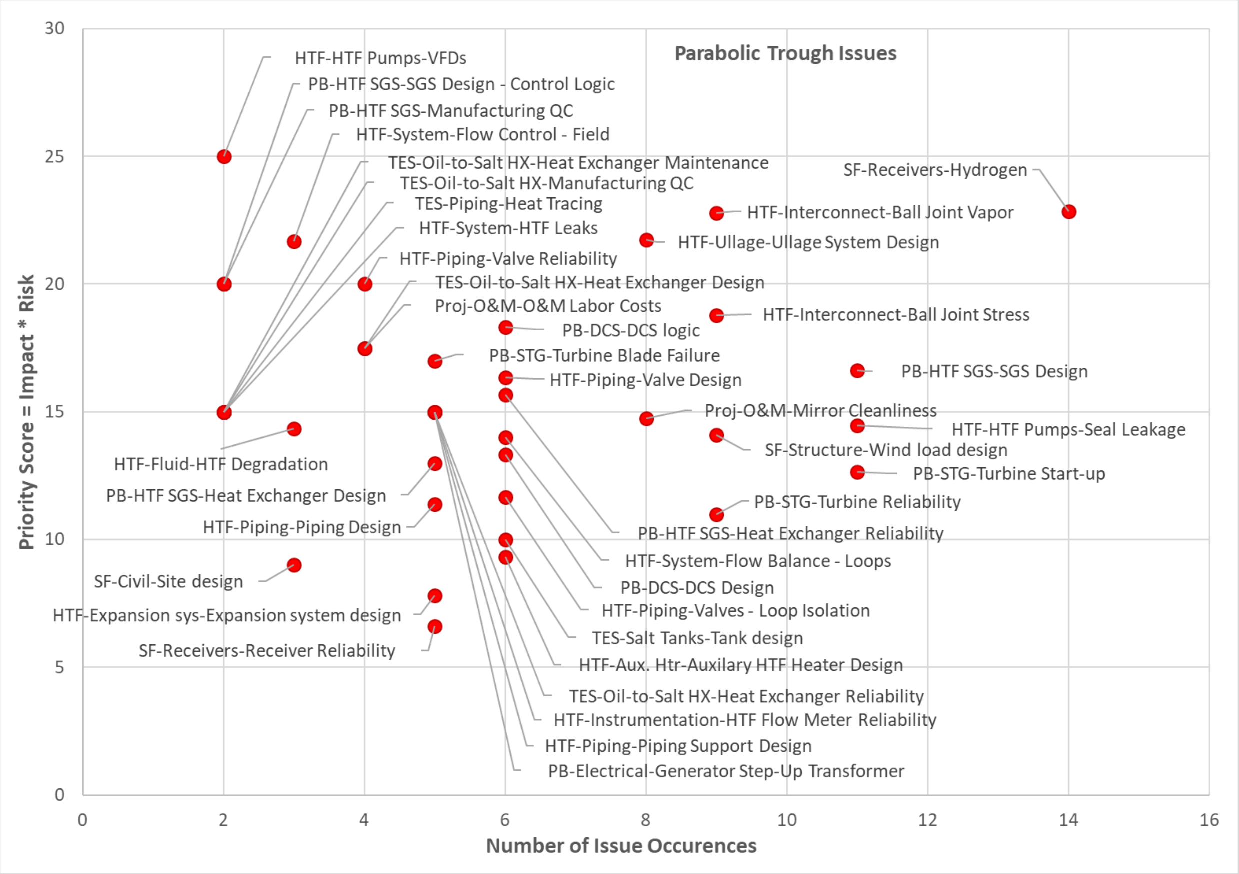
} Today

General Findings

- **CSP plants are relatively complex power projects**
  - More of the issues identified are related to implementation in contrast to technology
  - It is best to work with experienced teams with proven solar plant track records
  - Projects need to have detailed Owner Technical Specifications (OTS)
  - Projects with more involved owners often fare better
  - Well-executed QA/QC in all phases of the development, design, procurement, construction, commissioning, and operation of a CSP power plant cannot be overstated
- **Some of the more significant problems are with conventional equipment**
  - Such as heat exchangers, valves, pumps, instrumentation, heat tracing
  - Plants need to be designed for good reliability and performance in off-design cases
- **Efforts to cut costs can end up costing projects more in the long run**
  - E.g. Low cost valves are not cheaper in the long run
- **Performance modeling has not been adequate for many projects**
  - The PM needs to handle transient plant behavior during startup and intermittent clouds to be accurate

Parabolic Trough Issue Ranking



Trough plant technology experience

- **Successes**
  - Most trough plants are reported as operating well
  - Solar technology generally mature
  - Globalized supply chain
- **Areas where issues remain**
  - Hydrogen: decomposition of HTF causing elevated hydrogen levels in HTF
    - Hydrogen can build up in receivers over time and cause significant drop in SF performance.
    - Approaches for removal of hydrogen – venting, membranes,
    - Ullage system: important to remove and control degradation products in HTF
    - Reduce HTF operating temperatures.
  - Collector interconnection issues with ball joints, rotary joints, and flex hoses
    - Ball joints have issues with leaks and binding, resulting in significant O&M expense
    - Better solutions than current designs needed.

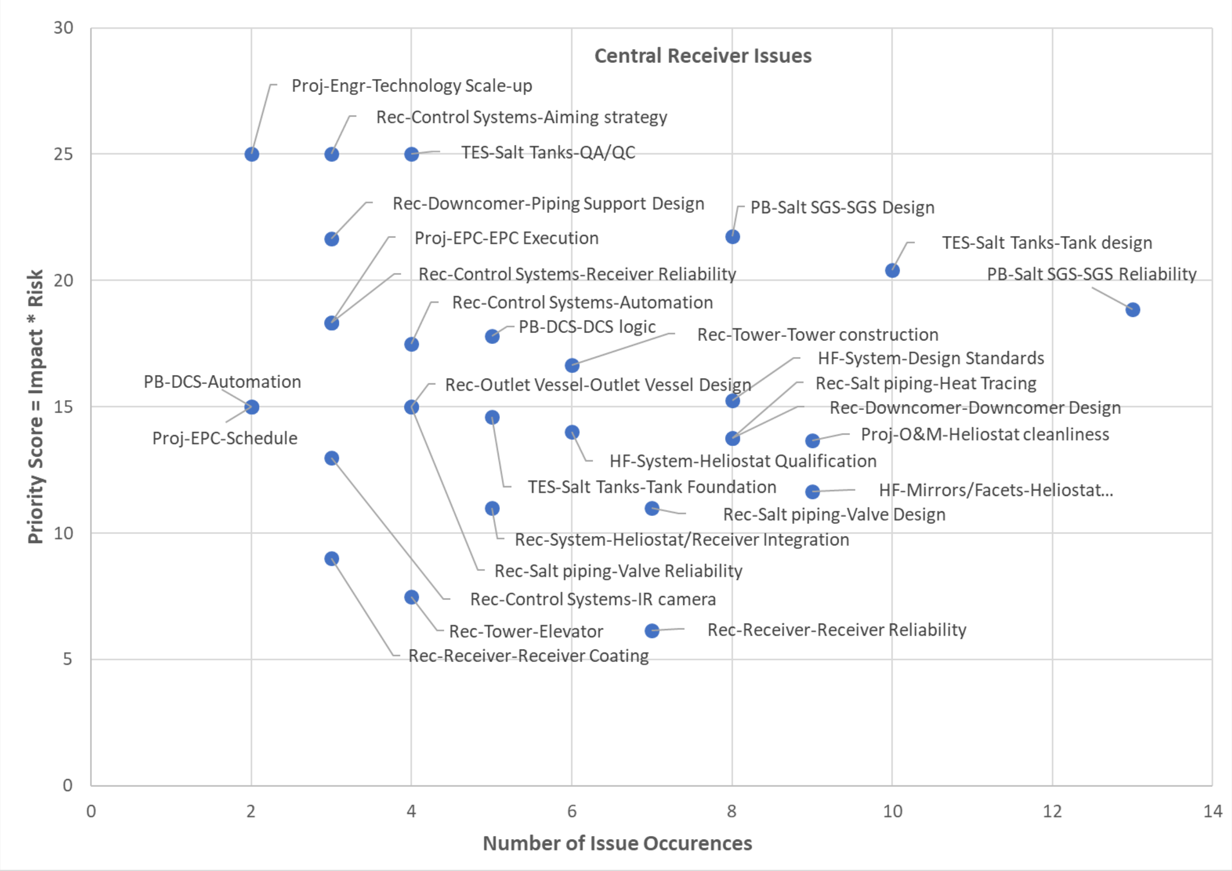
Trough plant technology experience

- **Areas where issues remain (Cont.)**
  - Heat exchangers for SGS and TES
    - Robust designs/good control system
    - Designing plants for transient operation
  - DSC System:
    - control logic
    - alarm management
    - automation
  - Standards need development:
    - structural design for wind loads
    - collector optics
  - Rethink process design for future applications

Key Parabolic Trough Issues

Ranking	Syst	SubComponent	Issue Type	Occur	Priority	Weight
1	SF	Receivers	Hydrogen	14	22.86	320
2	HTF	Interconnect	Ball Joint Vapor	9	22.78	205
3	PB	HTF SGS	SGS Design	11	16.64	183
4	HTF	Ullage	Ullage System Design	8	21.75	174
5	HTF	Interconnect	Ball Joint Stress	9	18.78	169
6	HTF	HTF Pumps	Seal Leakage	11	14.45	159
7	PB	STG	Turbine Start-up	11	12.64	139
8	SF	Structure	Wind load design	9	14.11	127
9	Proj	O&M	Mirror Cleanliness	8	14.75	118
10	PB	DCS	DCS logic	6	18.33	110
11	PB	STG	Turbine Reliability	9	11.00	99
12	HTF	Piping	Valve Design	6	16.33	98
13	PB	HTF SGS	Heat Exchanger Reliability	6	15.67	94
14	PB	STG	Turbine Blade Failure	5	17.00	85
15	HTF	System	Flow Balance - Loops	6	14.00	84
16	HTF	Piping	Valve Reliability	4	20.00	80
17	PB	DCS	DCS Design	6	13.33	80
18	HTF	Instrumentation	HTF Flow Meter Reliability	5	15.00	75
19	HTF	Piping	Piping Support Design	5	15.00	75
20	PB	Electrical	Generator Step-Up Transformer	5	15.00	75

Central Receiver Issue Ranking



Molten-salt tower technology experience

- **Successes**
  - Long-shafted salt pumps have proven to be reliable
  - Receiver performance has met expectations
  - Heliostat reliability appears to be acceptable
- **Areas where issues remain**
  - Heliostat accuracy
    - Optical errors are higher than guarantee levels
    - Receiver spillage, or receiver peak flux, values are higher than design values
    - Don't install heliostats with worsened optic parameters after receiver has been designed
  - Hot Salt tank inlet distribution piping
    - Single distribution header may not provide adequate mixing, particularly during transient conditions
    - Local gradients in the floor and the wall temperatures may reduce the low cycle fatigue life of the tank

Molten-salt tower technology experience

- **Areas where issues remain (continued)**
  - Hot Salt tank design specification
    - Under transient conditions, the thin (~7 mm) floor of a very large hot tank (40 m) can experience non-uniform stresses
    - Floor design must provide adequate resistance to buckling and have a uniform coefficient of friction at interface with foundation
    - Very large hot tanks (40 m) should be considered a high risk component
      - Reduce risk by following accepted scale up rules (i.e. factor of 3 between generations)
      - Reduce risk by using multiple smaller hot tanks
      - Reduce risk by installing hot-tank bypass line to allow plant to operate without storage
  - Hot Salt tank foundation
    - Perimeter of the foundation must be a rigid material to mitigate bowing of floor
    - A continuous drip pan must be provided to isolate the foundation from a tank leak
  - Steam generator operation
    - Process design must maintain the rates of temperature change to the vendor limits, and maintain stable operation at the 1 percent load case
    - Water chemistry must be strictly enforced

Molten-salt tower technology experience

- **Details matter**
  - The number of salt valves must be held to the absolute minimum
  - Bellows stem seals on salt valves are required
  - Diligent supervision of the installation of the heat trace equipment is required
  - O&M staff must understand the plant

Key Central Receiver Issues

Ranking	System	Subsystem	Issue Type	Occurrence	Priority	Weight
1	PB	Salt SGS	SGS Reliability	13	18.85	245
2	TES	Salt Tanks	Tank design	10	20.40	204
3	PB	Salt SGS	SGS Design	8	21.75	174
4	Proj	O&M	Heliostat cleanliness	9	13.67	123
5	HF	System	Design Standards	8	15.25	122
6	Rec	Downcomer	Downcomer Design	8	13.75	110
7	Rec	Salt piping	Heat Tracing	8	13.75	110
8	HF	Mirrors/Facets	Heliostat Optical Quality	9	11.67	105
9	Rec	Tower	Tower construction	6	16.67	100
10	TES	Salt Tanks	QA/QC	4	25.00	100
11	PB	DCS	DCS logic	5	17.80	89
12	HF	System	Heliostat Qualification	6	14.00	84
13	Rec	Salt piping	Valve Design	7	11.00	77
14	Rec	Control Systems	Aiming strategy	3	25.00	75
15	TES	Salt Tanks	Tank Foundation	5	14.60	73
16	Rec	Control Systems	Automation	4	17.50	70
17	Rec	Downcomer	Piping Support Design	3	21.67	65
18	Rec	Outlet Vessel	Outlet Vessel Design	4	15.00	60
19	Rec	Salt piping	Valve Reliability	4	15.00	60
20	Proj	EPC	EPC Execution	3	18.33	55
21	Rec	Control Systems	Receiver Reliability	3	18.33	55
22	Rec	System	Heliostat/Receiver Integration	5	11.00	55

Operation & Maintenance

- **Having an O&M team with strong prior CSP experience is highly desirable**
  - This group will be the end user of the plant

- **Having O&M Subject Matter Experts involved in the design, construction and commissioning of the plant is highly recommended**
  - Assist with QC – obtain familiarity
  - Optimize Operational Processes (Start up/Transients) / Equipment Protection and Reliability
    - DCS System / Control Logic & Schemes (Automation) / Gradients
  - Ensure the Workability of Equipment
    - Efficient and safe equipment isolation and access
  - Ensure quality documentation is provided by EPC
    - O&M Manuals / Procedures / P&IDs

Operation & Maintenance

- **O&M costs are often not budgeted correctly in financial projections.**
  - Consider equipment degradation
  - Consider pay structures of O&M personnel from rates of regional CSP and power-generation facilities. Understand regional labor conditions.
  - Consider and factor in service providers experience and availability

- **The O&M organizations must be prepared to take over at COD**
  - Important that projects invest appropriately in the O&M quality, mobilization, preparation, and training.
  - EPCs typically provide some training for the O&M team, but depth and timeliness is critical. Projects need to realize that the training provided by the EPC is only a portion of the overall training program required to fully mobilize the O&M organization
  - Participate in O&M Manual/Procedure development process - review / approval
  - Ensure Plant Systems are in place and appropriately functional for O&M needs:
    - Safety / Environmental Programs
    - Spare parts and inventory
    - Maintenance Programs (CMMS – Preventative and Predictive Maintenance)

Operation & Maintenance

- **Further O&M Considerations**
  - Additional operational and engineering experienced SMEs should be considered for the early operational period of the project while the control/automation and staff experience is being developed and proven
  - Project O&M KPIs are important to define, be monitored, and used throughout the organization.
  - Rigorous and continuous training of plant O&M personnel is essential
  - Continued adherence to quality O&M maintenance systems/programs
  - Maintaining Plant Water Chemistry is IMPORTANT!

Key O&M Issues

Ranking	Subcategory	Issue Type	Count	Priority	Weight
1	O&M	O&M Staff Quality	10	15.40	154
2	O&M	O&M Training	8	16.00	128
3	O&M	O&M Labor Costs	7	14.14	99
4	O&M	Water Chemistry	5	19.00	95
5	O&M	O&M Provider Quality	8	11.00	88
6	O&M	Service Groups	6	14.67	88
7	O&M	O&M Costs	6	14.00	84
8	O&M	Spare Parts	5	14.60	73
9	O&M	O&M Systems	5	13.40	67
10	O&M	O&M Procedures	4	14.50	58

Conclusion

- We believe the few remaining technology issues for parabolic trough and molten-salt tower projects are really design issues that can be resolved by appropriate engineering and equipment selection.
- Plants and equipment must be designed for the transient behavior that they will see.
- CSP projects are complex, they need to be properly managed. Best to work with experienced team with good track record.
- Desirable to have an experienced O&M team and to get them involved early.
- Accurate solar and wind resource assessment of the site is essential.
- Based on our finding, we are confident that future tower and trough plants can be built on time and budget and to perform as expected.

Thank you

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