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Global CSP Library Archive for Improved Resource Access

Kenneth Armijo[1,a)], Ansel Blumenthal[1], Dimitri Madden[1], Aaron Rodriguez[1], Luis Garcia-Maldonado[1], Alice Parsons[1], Shannon O'Grady[1], Sandra Pacheco[1] and Margaret Gordon[1]

[1] Concentrating Solar Technology, Sandia National Laboratories, P.O. Box 5800, MS-1127, Albuquerque, NM 87185, USA

[a)] kmarmij@sandia.gov

1. Introduction

Proper documentation management of concentrating solar power (CSP) and thermal (CST) documents and media is critical for ensuring wide-spread information dissemination of previous work, as well as safeguarding one-of-a-kind documents that could be unintentionally degraded or destroyed over time. Sandia National Laboratories (SNL) National Solar Thermal Test Facility (NSTTF) and Sandia's Technical Library departments have been collaborating to establish and maintain the first and only digital collection in the world of Concentrating Solar Power (CSP) related historical documents. These date back to the CSP program inception here at Sandia in the early 1970's thru to the present. The unclassified, unrestricted (UUR) collection, comprised of internally generated Sandia documents as well as a significant number of external reports from global CSP groups, are now searchable via both the Sandia website, where some are also provided within the U.S. Department of Energy (DOE), Office of Scientific & Technical Information (OSTI) document repository. DOE is currently championing efforts for wide-spread dissemination of the collection to foster strong research and development within U.S. research institutions as well as to reduce the propensity of repeated research, which can impact strategic funding to needed work. This work is intended to further the development of the novel external-facing website for the archive and integration of other important historical CSP documents and media by both U.S. and international partners, including Australia, South Africa and Germany. This work is expected to also make the CSP collection accessible to the CSP and solar-thermal global R&D communities, which includes commercial groups who intend to promote the success of CSP in the U.S. and globally.

2. Archive Development

CSP and CST research has been facilitated over decades, which includes periods of time prior to the digitization of documents and media. These one-of-a-kind documents can have tremendous value for current research across many fields of scholarly study. This can be particularly true for understanding R&D, commercial best practices, as well as fundamental design techniques with respect to costs, measurement for uncertainty quantification and anxcillary environmental impacts. This work assessed documents and media originally at the SNL NSTTF, but was later extended to other reserach and commerical groups globally. Originally, there were a large number of paper-based documents in various physical document repositories at the SNL NSTTF that were identified internally to be digitized and provided to the CSP community and general public. During 2022 the outstanding paper-based documents that were previously determined documents were digitized and uploaded into the SNL SRN Library catalog for subsequent dissemination to the two digital repositories. The CSP Library Archive, which can be accessed online [1] was originally developed as a Structured Query Language (SQL) database, which included metadata that was manually registered for over 12 metadata tags. To ensure the documents collected (as well as any future documents and media) are collectively tagged appropriately within the context of the CSP archive and not affiliated with other SNL databases, a CSP file extension was added for efficient querying within the contruct of the database. A website was developed for users to interface with the database which was made outwardly facing from the National Laboratories servers.

The CSP Library Archive uses commercial off-the-shelf (COTS) software, LibraryThing to catalog items and uses Library Thing's product TinyCat Library Catalog to make the archive available and searchable to anyone who has access to the internet. Records in the catalog contain title, authors, report numbers, abstract, links to full text, tags and a unique identifier. TinyCat's capabilities are typical of library catalogs. Users can conduct a basic keyword search or do an advanced search to narrow to the title, author, report number and/ or abstract field. The TinyCat interface has customization capabilities which were used to optimize the detailed record display.

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Certain fields were used as a convenience to display records information, i.e, “Library Review” contains the records‘ abstracts. The CSP document and media records were batch loaded into LibraryThing. Exel data files containing metadata for each document were converted to MaRC files using a program called MaRC Edit and then imported in the catalog. This will be how future archive additions will be handled. This project digitized over 20,000 documents and associated media (e.g. videos, pictures, etc.) which were scanned for archiving and uploaded to the CSP Library Archive. After scanning, metadata was created for each respective document to support catalogue and tagging for the library digital archiving. CSP historical documents were collected from the SNL NSTTF, as well as those from the Australian Solar Thermal Research Institute (ASTRI), Stellenbosh University, the U.S. DOE where further are being considered for digitization and inventory, from the German Aerospace Agency (DLR), and Plataforma Solar de Almería. Additionally, this work also includes historical engineering drawing documents for various CSP systems, which will provide more detailed design information for CSP researchers and SolarPACES.

3. Utilization of the CSP Library Archive

This work highlights the importance of digitization and archives within the public domain of previous research and its impact on current U.S. DOE-funded projects (Table 1), including that of the Gen 3 particle-pathway (G3P3) [2]. As an exemple for a current DOE HelioCon project, ongoing efforts at SNL to advance components and controls for CSP technologies significantly benefits from access to a global CSP library. Current research and development (R&D) to improve heliostat technology while reducing field implementation costs has shown control systems and lack of Standards documentation as crucial gaps in the industry requiring improvement [3]. Many useful documents that advance understanding of these gaps have been archived in the global library. In addition, documentation contained in the library provides useful information to SNL engineers about onsite equipment, such as original Winsmith documents pertaining to the drives used in SNL heliostats or assements of heliostat stretched membane mirrors for furnace applications. Expanding on examples of pertinent literature from Table 1 show information pertaining to integral parts of CSP research including site selection, static loading simulations, and research into both theoretical and practical costs/performance of CSP systems.

Table 1. CSP Archive Exemplar Components & Controls R&D Documents & Current Potential Impacts

Topic	Abbreviated Article Title	Lead Author	Year	Notable Reserach Finding
Drives	Development of a low cost drive tracking mechanism	Peerless-Winsmith	1981	Contains singnificant information on heliostat drive design
Controls	An Assessment of Heliostat Control System Methods	SERI	1986	Contains an excellent report of control system engineering as was once standard
Standards	A Standards Application and Development Plan for Solar Thermal Technologies	SERI	1981	One of the most complete documents on quality assurance and standards in CSP
Truss System	Assessment of second-generation stretched-membrane mirror modules	Albert A. Heckes	1990	Useful design information and background on stretched mirrors contracted for SNL

Practical Cost & Performance	Solar Thermal Process Heat and Electricity Generation Performance and Costs for 'Big Dish' Technology	Stephen Kaneff	1991	Contains detailed cost breakdowns for dish systems ranging from $50kW_e$-$100MW_e$
Theoretical Cost & Performance	Study of the Potential for a Solar Thermal Power Station in Victoria	David Wilson	1990	Theorectical cost analysis of a 6 MW, 90 MW, and 330 MW CSP facility
Mirror Structure	A Geometrical Study of Paraboloidal Mirrors and Focal Absorbers	L.C.F. Whyte	1974	Equations governing geometry of Mirrors for highest efficiency
CSP Credibility	Mass Utilization of Solar Thermal Energy	Stephen Kaneff	1992	Details comparing CSP with fossil fuels
Thermodyn-amic Equations	Theoretical Principles For Solar Energy Collector Studies	P.O Carden	1974	Equations governing incoming potential energy to work & losses
Thermal Energy Storage	Evaluation Material From Industrial Waste For Thermal Storage	Stephen Kaneff	1987	Experiments on sustainable materials for thermal energy storage
Aggregate Comparison of CSP Systems	Review of Existing Mirror Panel Concepts for Point Focus Concentrating Collectors	Applied Solar Pty. Ltd.	1999	Highlights features of unique CSP systems from across the world
R & D	Prefeasibility Study Two Designed Systems Using 400m Apature Big Dishes	Stephen Kaneff	1997	Detailed information for entire $400m^2$ solar collector system
Site Selection	Site Selection Guide For Solar Thermal Electric Generating Plants	J.C. Grosskre-utz	1974	CSP plant requirements, site selection, and site criteria for CSP

As an example of the utilization of the archive, the report “Site Selection Guide For Solar Thermal Electric Generating Plants" [4] found details of potential locations for CSP systems in the Southwest United States, with the top four sites occuring in California. This research hypotheized a 1,000 MW_e system. Figure 1**Error! Reference source not found.** displays four sites seriously considered during that time: Blythe, Inyokern, Manix, and Searles. The report takes a multitude of factors into consideration and performs detailed analysis on insolation, meteorological conditions, water supply, access, land use, land ownership, topography, and electric transmission. Required land area showed 15-20 acres necessary per megawatt, so for a base load generating a daily average of 1,000 MW_e over a year, approximately 25 square miles would be required. This research also showed typical water requirements for a 1,000 MW generating plant operating at 0.5 capacity factor being 14,100 GPM peak and 7,200 GPM average. Although the cost breakdowns will have changed since the report was written through inflation and technological advancements, the data for what is required in CSP applications is a helpful reference for today‘s projects. For the study, cost estimates for constructing plant access roads and railroad spurs were made on the basis of $74,000 per mile for roads and $200,000 per mile for railroad. The cost of transporting water was based on piping and pump costs of $264,000 per mile, and the cost for transmission lines for a 1,000 MW load was $3.1 million, $4.8 M, $10.0 M, $28.1 M. The detailed considerations of the factors listed above returned an overall economic comparison of each site with confidence on why certain locations would be desirable. These desirable site features hold true for today’s potential projects and should be considered when preparing for new CSP facilities in the United States.

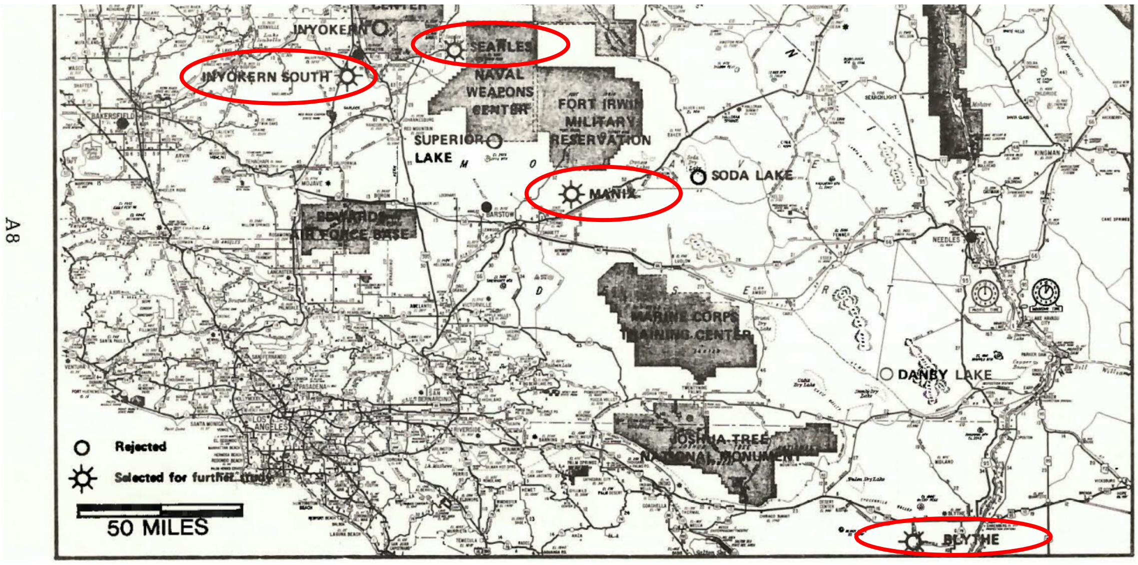

Figure 1. Potential Site Locations for 1,000 MW CSP System

Also, included in the archive are over 700 schematics from projects developed through the Australian Solar Thermal Research Institute (ASTRI). These projects include the White Cliffs Solar Power Station with collaboration with the Australian National University (ANU), the first commercial solar power plant built, which consisted of fourteen 20 m^2 dishes in operation from 1982 to 2004. These previous paper-based detailed schematics provide an array of information from initial research, to fabrication, to operational data and range from bolt specs to electrical diagrams to hydraulic diagrams as shown in Figure 2. Practical application data sometimes is lacking in the field of CSP, and with the archive now expanded to include information for the entire build-out of multiple CSP facilities, this information is now digitially accessible for the first time. Regarding the White Cliffs Solar Power Station, the operational longevity gives insight into operational requirements over the lifetime of the system that can heighten our knowledge about levelized costs of industrial scale projects.

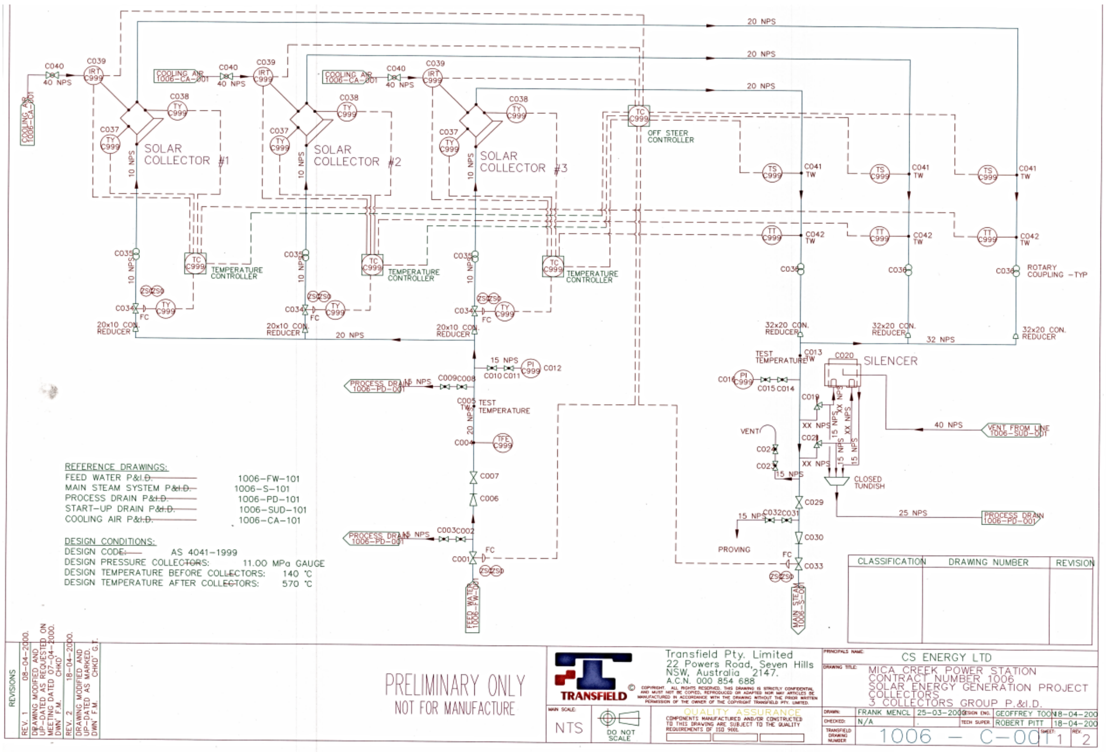

Figure 2. Hydraulic Schematic for Mica Creek Power Station

Research papers in the archive also include work performed at ANU with large paraboloidal dish technology, culminating in a 400m^2 50kW$_e$ prototype built in 1994. Figure 3 shows the wind loading conditions on a single 400 m^2 Power Dish in a specified orientation with 60 MPH winds applied. Additional schematics show differing orientations of the same dishes with the same wind loading conditions. This analysis is one example of hundreds available that can be refenced to help reduce engineering modeling costs for future projects.

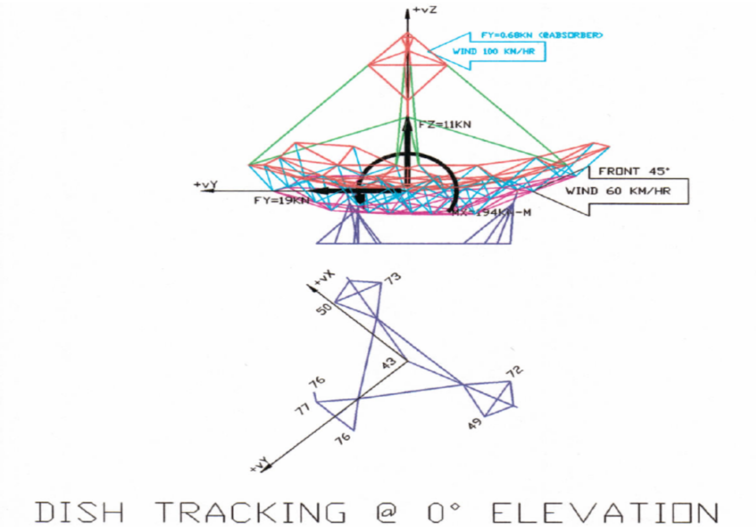

Figure 3. Mica Creek Wind Loading Conditions

Additonal research through ASTRI provided information for power output, efficiency, process heat, and cost breakdowns interpolated for 200kW, 1MW, 10 MW, and 100 MW systems. Figure 4 shows how scaling CSP systems effect efficiency, power output, and life cycles. With this data, Figure 5 shows a cost breakdown alongside electrical generation of each system. Each of the item lines in the tables are expanded upon in the full report to give detailed and accurate knowledge on how the values provided were generated.

TABLE H — SUMMARY OF ANU DISH-BASED SYSTEMS — PARAMETERS AND COSTS

Site Insolation:	2360 kWh/m^2/annum	
Dish Parameters:	Aperture Area	334 m^2
	Reflectivity	0.94
	Rated Insolation (to gain nett rated output)	950 W/m^2
	Receiver absorptivity at rated insolation	0.94
	Energy collection and transport efficiency (to fixed base of dish) at rated insolation	0.88
	Annual heat supplied at fixed base of dish	660 MWh$_{thermal}$/annum

System Rated Output at 950 W/m^2		50 kWe Demo Plant	50 kWe	200 kWe	1 MWe	10 MWe	100 MWe
Assessed Output at 950 W/m^2		52.9 kW	52.9 kW	241 kW	1.02 MWe	10.5 MWe	100.4 MWe
Collector Aperture	m^2	334	334	1 336	5 680	42 420	316 630
Number of Collectors		1	1	4	17	127	948
Nett Annual Heat Energy delivered to engine or turbine (a)	MWh$_{th}$ per annum	660	660	2 640	11 220	83 840	619 400
Number of engines (e)/turbines (t)		1e	1e	1e	5e*	1t	1t
Nett enthalpy to engine/turbine at rated output (950 W/m^2)		279.5 kW	279.5 kW	1 118 kW	4.74 MW	35.3 MW	262 MW
Gross engine/turbine efficiency of conversion at rated output	%	21.5	21.5	23.5	23.5	32.5	42.0
Auxiliary Power at rated output	kWe	2–4.2	2–4.2	4–8	20–42	700	8 000
Nett Electrical Output		52.9 kWe	52.9 kWe	241 kWe	1.02 MWe	10.5 MWe	100.4 MWe
Engine/Turbine-Alternator Efficiency at rated output	%	18.9	18.9	21.6	21.6	29.7	38.8
Efficiency of Overall System Nett electrical output/solar input at rated output	%	16.7	16.7	19.0	19.0	26.1	33.4
Nett Annual Electrical Output (b)	MWhe per annum	124	124	558	2 360	24 140	234 800
Annual Average Overall Collection and Conversion Efficiency solar to electricity	%	15.7	15.7	17.7	17.6	24.1	31.4
Process Heat							
System Installed Costs	$million	0.1649	0.1132	0.439	1.848	11.74	76.61
Heat supplied/annum [see (a)]							
Life Cycle Cost at 8% nett interest rate	¢/kWh$_{th}$	2.74	1.86	1.77	1.77	1.42	1.27
Electricity Generation							
System Installed Costs (total)	$million	0.2362	0.1775	0.6556	2.398	20.1	136.06
Installed Costs	$/kWe	4 465	3 355	2 720	2 350	1 910	1 355
Nett Electricity Produced per annum [see (b)]	MWh$_e$ per annum	124	124	558	2 360	24 140	234 800
Life Cycle Cost at 8% nett interest rate	¢/kWhe	23.0	16.5	13.7	11.7	9.5	6.6

* Alternatively a 1 MW turbine could be employed instead of 5 engines.

Figure 4. Summary of Power Generation & Requirements for Multiple Dish Systems

System Details	Total System Cost $	Output per Annum MWh_e	Cost/kW Installed	Life Cycle Costs*	
				i*=10% ¢/kWhe	i*=5% ¢/kWhe
50 kWe Demonstration Unit (1 dish)	236 200	124	4 465	26.0	18.3
50 kWe Commercial Unit (1 dish)	177 500	124	3 355	18.5	13.5
200 kWe Commercial Unit (4 dishes)	655 600	558	2 720	15.6	11.0
1 MWe Commercial Unit (17 dishes)	2.398 m	2 360	2 350	12.7	8.9
10 MWe Commercial Unit (127 dishes)	20.1 m	29 140	1 910	10.9	7.5
100 MWe Commercial Unit (948 dishes)	136 m	234 800	1 355	7.3	5.1

Figure 5. Summary of Costs Associated with Scaled Dish Systems

Understanding fabrication and operational costs for CSP industrial projects is paramount to make sure the project is profitable. A 1999 report on point focus concentrating collectors titled "Review of Existing Mirror Panel Concepts for Point Focus Concentrating Collectors" studied 44 "Realized and Proposed Collector Systems" from 1978 to 1998. Figure 6 depicts information on the 400 m^2 50 kW_e prototype mentioned above, one of 44 collectors studied in the report. This example was chosen for congruency of overlap in research at CSP facilities. Other systems worldwide have similar parallelisms within the archived literature. The ease of viewablity of information, including optical efficiency, weight, focal ratio, and cost allows each of the 44 collectors studied to be easily compared for pros and cons.

Energy Research Centre 400 m^2 'Big Dish' 1988-94

Location of Organization: **ANUTECH, Canberra**

Overall Configuration: **See Figures 45a, 45b, 45c, 45d, 45e 45f, 45g**

Status: **Prototype**
Numbers Built: **2 comprising SG3 in Canberra and SG3 Mark 2 at Israel National Solar Energy Centre, Sede Boqer**
Heated Fluid: **Water/Steam**
Focal Ratio F/D: **0.57**
Optical Configuration: **Paraboloidal structure carrying paraboloidal mirror panels**
Mirror Details: **SG3: 2 mm back-silvered glass mirrors glued to steel sheet frame; SG3 Mark 2: 1 mm low iron glass glued to fibreglass scored substrate**
Optical Aperture Area/Diameter: **400 m^2; Hex. aperture dia. 22.7, 25.5 m**
Reflector Elements: **SG3 - 54; SG3 Mark 2 - 216**
Optical Efficiency: **SG3 - 0.86; SG3 Mark 2 - 0.96**
Reflector Slope Error: **SG3: Average 6 mrad. SG3 Mark 2; ?**
Intercept Factor: **1.0**
Geometric Concentration Ratio: SG3 - 260; SG3 Mark 2 - ?
Peak Conc. Ratio: **SG3- 1800 suns; SG3 Mark 2, not yet measured, >4000 by design**
Reflector Panel Construction: **Mirrors glued to substrate held in paraboloidal form by wire frames**
Thickness of Reflective Panels: **SG3 ~ 75 mm; SG3 Mark 2 ~ 20 mm**
Weight of Reflective Panels: **SG3 ~ 8 t. total; SG3 Mark 2 ~ 5.5 t. total**
Mirror Support Structure: **Rigid steel tubular frame**
Mounting and Actuation: **Elevation: SG3: Curved beam with 'walking' hydraulic ram; SG3 Mark 2: Twin direct-acting Rams. Azimuth: SG3 - single 'walking' hydraulic ram; SG3 Mark 2: two 'walking' rams**
Drives: **Elec. Pump driven hydraulic system**
Foundations: **Circular concrete ring with integral hub foundation**
Maximum Tracking Wind Velocity: **SG3: and SG3 Mark 2: 80 km/h**
Survival Wind Velocity: **SG3: 130 km/h; SG3 Mark 2: 180 km/h**
Natural Collector Vibration Frequency: **SG3: ~ 4 Hz; SG3 Mark 2: 3 Hz**

Costs: **Mirror Panels: SG3: $AUD 107,000 (1994). SG3 Mark 2: $158,000**

Comments: **SG3 is an experimental prototype. SG3 Mark 2 is an experimental facility with which to conduct experiments of many kinds and has accordingly strict demands on concentration ratio and accuracy generally. References: Kaneff (1990a,b,c; 1991 a,b,c,;1992 b; 1993 a,b; 1994 a,b,c; 1995 a; 1997/98; 1999 a,b). Kaushika and Kaneff (1988,1993)**

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Figure 6. Collector System Highlights for 400 m^2 Dish.

4. Conclusions

A comprehensive digital library archive was developed as a repository of paper-based documents dating back to the start of significant CSP R&D over the last 50 years. This archive, with over 20,000 documents, spans work produced from multiple countries, including the United States, Australia and South Africa, among others. Research is included to illustrate how these one-of-a-kind, previously paper-based-only documents can directly impact current CSP projects/programs as well as the inclusion of media (e.g. videos, pictures), and engineering drawings which provide more value of the archive to CSP researchers and SolarPACES.

5. Acknowledgements

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