The Potential of Solar Thermal to Substantially Replace Fossil Fuels for Electricity Generation in Israel

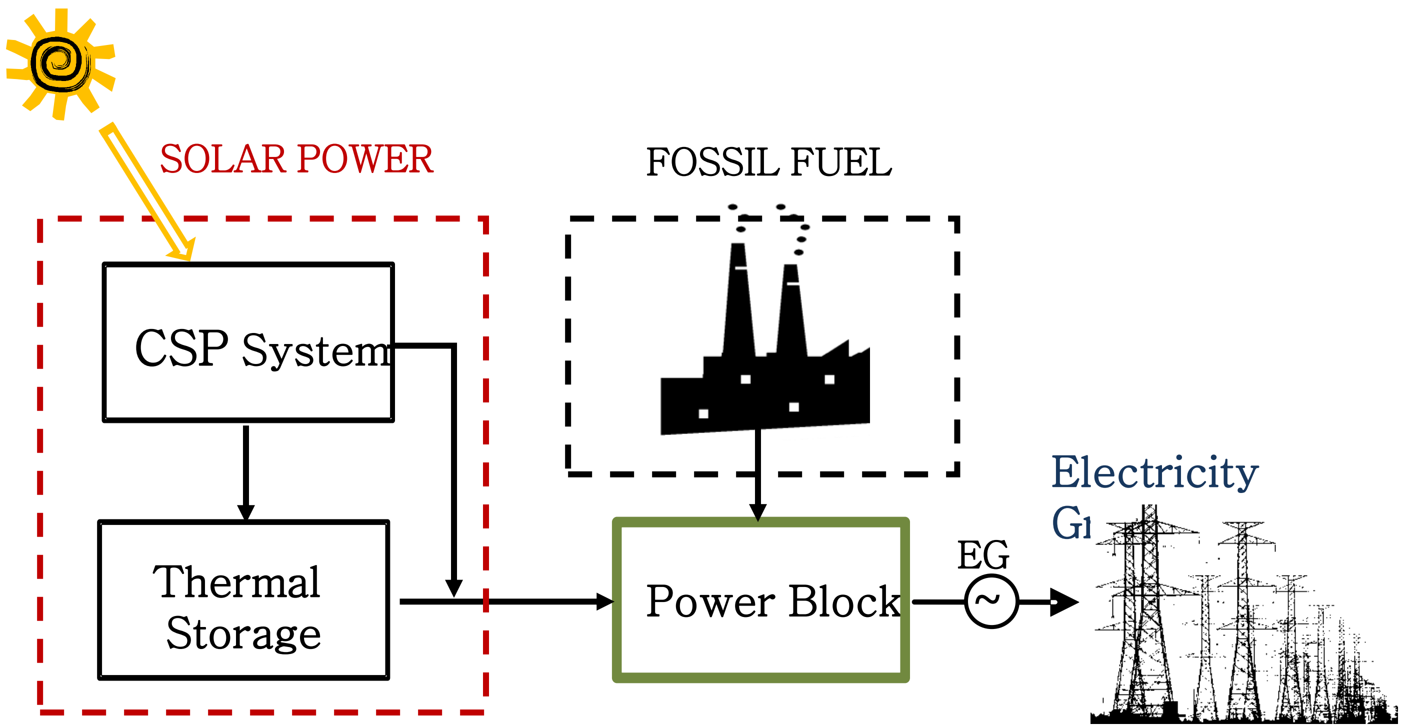
Roman Adinberg

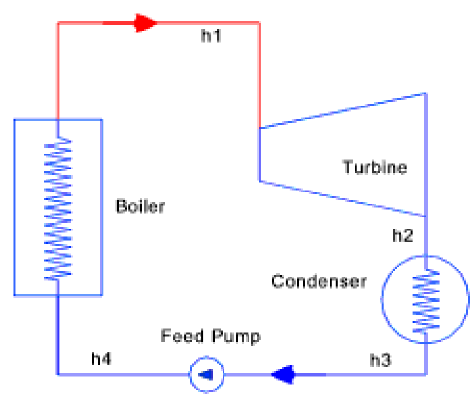
WEIZMANN INSTITUTE OF SCIENCE
Solar Research Facilities, Rehovot, ISRAEL

Discussion

- Solar-Fossil hybrid power systems for electricity generation via the conventional Rankine (steam turbine) cycle.
- Evaluation of the annual solar capacity fraction vs. thermal storage capacity.
- Exploring the ways to double the annual solar capacity of hybrid power systems from 35 to 70%.
- Conclusions

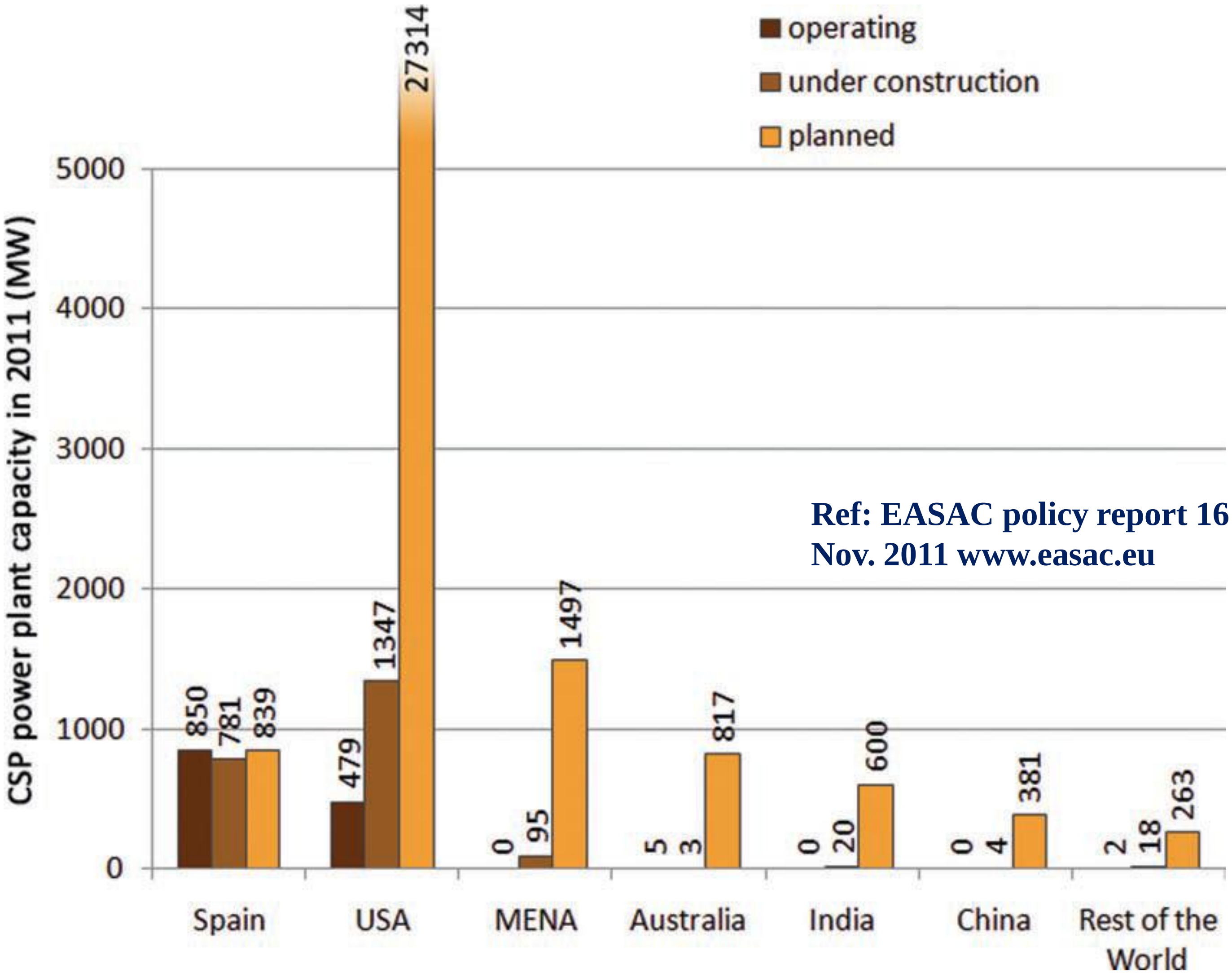
Solar-Fossil Hybrid Power System





Rankine Cycle
Steam Turbine

Worldwide in 2011, 1.3 GW of CSP were operating and a further 2.3 GW were under construction



Ref: EASAC policy report 16 Nov. 2011 www.easac.eu

Solar Thermal Electricity by CSP Technologies

Parabolic Trough Plants **50** to **300** MW
Proven utility scale technology
Commercial operation since 1984

Solar Tower Plants **10** to **20** MW in Spain
Large projects to be built in the USA
The Ivanpah complex of **3** plants **377** MW

Dish Stirling Systems **10** kW to **100** MW
High efficiency of **30**%

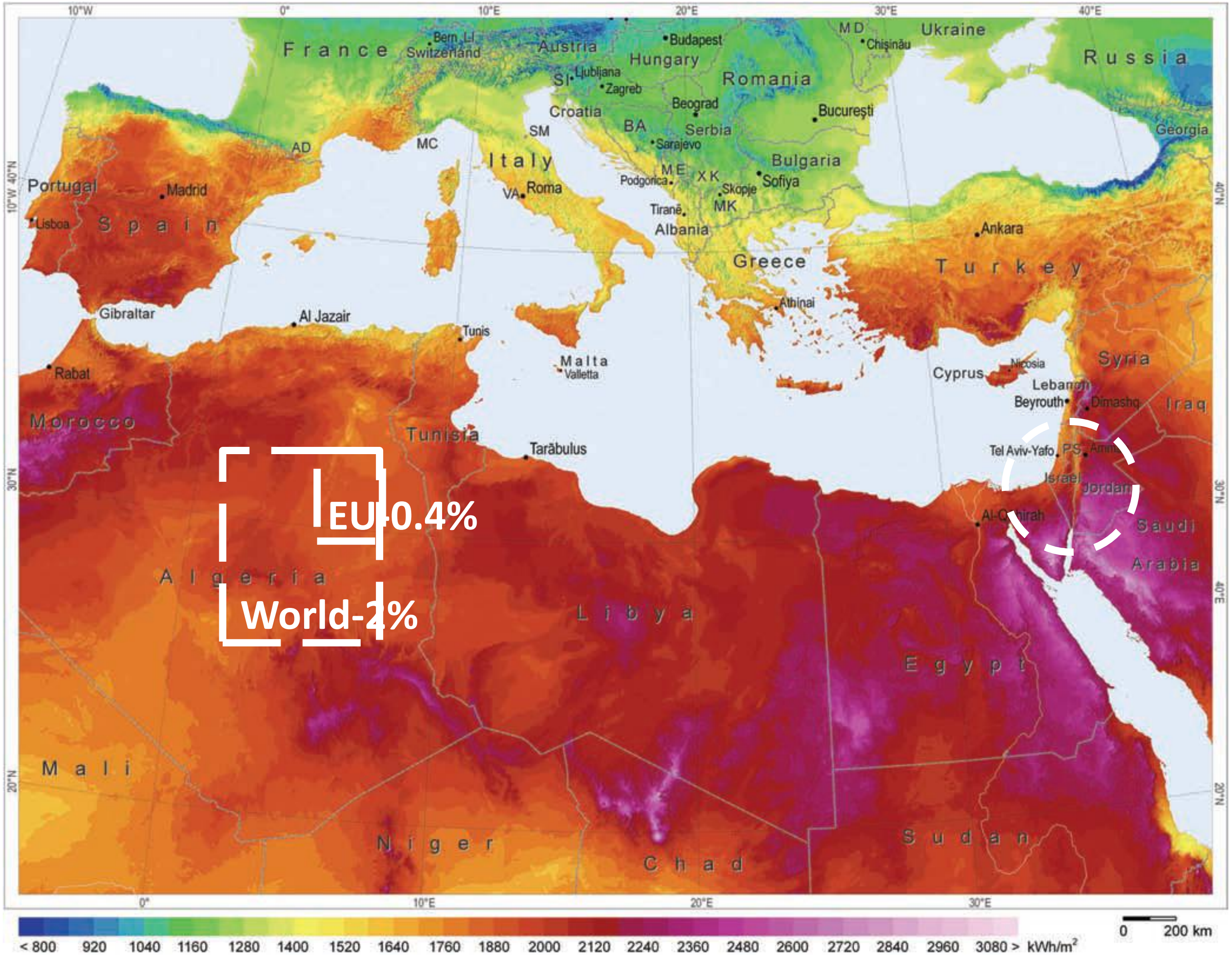
Linear Fresnel Systems up to **6** MW demo
Large plants under development

State of the art Thermal Storage Technology

Andasol, Spain Solar Power Plant **50** MWe

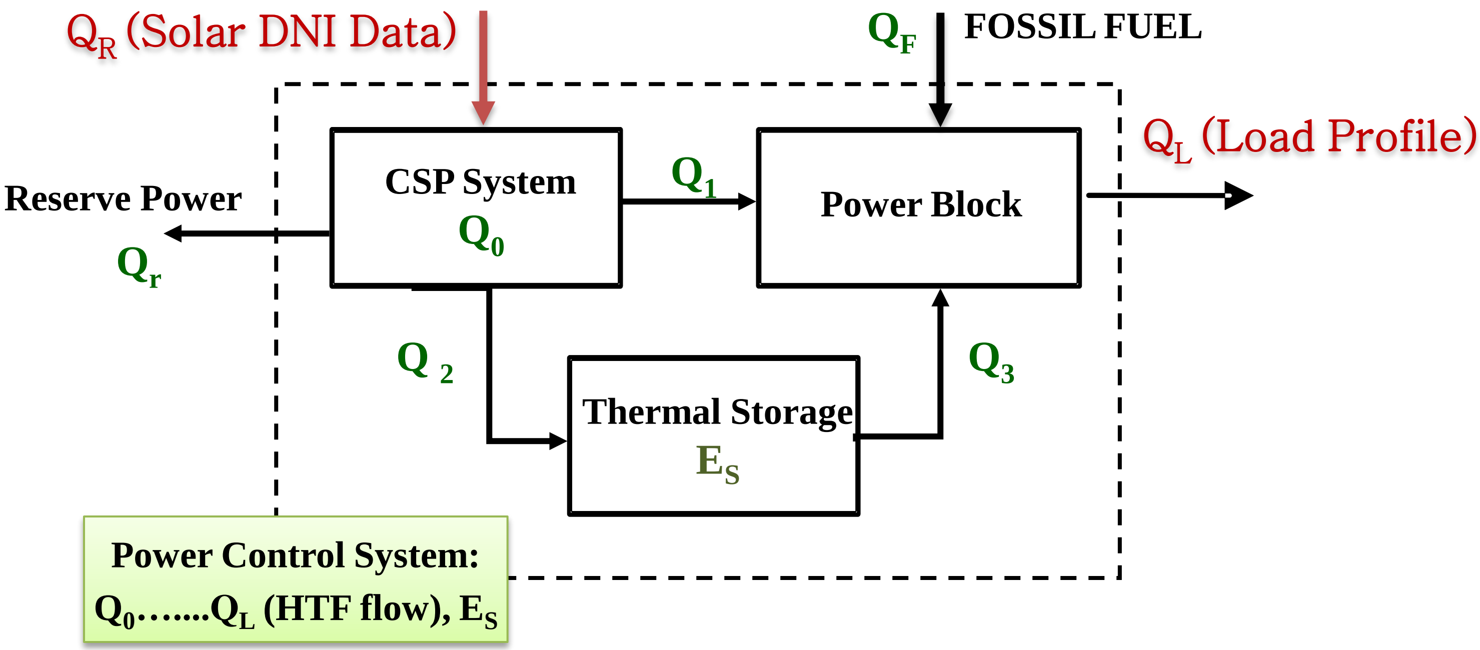
2-tank Molten Salt System	
Tanks Size	**14** m height
	38 m diameter
Molten Salt	**K/Na nitrates**
Amount	**28,500** tons
Storage Capacity	**1010** MWh = **7.5** h
Annual Solar Fraction	~ **35-37%**

Direct Normal Irradiation Map (*solargis.info*)



The solar resource in NEGEV is quite good, >2000 kWh/m^2/Yr,
for clean electricity generation from sun

Solar-Fossil Hybrid Model



System Basic Definitions

Solar Fraction α (0-100%): $$\int_0^{yr} Q_0(t)\,dt = \alpha \int_0^{yr} Q_L(t)\,dt$$

Solar Collector Factor β (> 1 w/storage): $$\int_0^{yr} Q_0(t)\,dt = \beta \int_0^{yr} Q_1(t)\,dt$$

Thermal Storage Energy (Wh/m²): $$E_S(t) = \int_0^t [Q_2(\tau) - Q_3(\tau)]\,d\tau$$

Control Logic Model

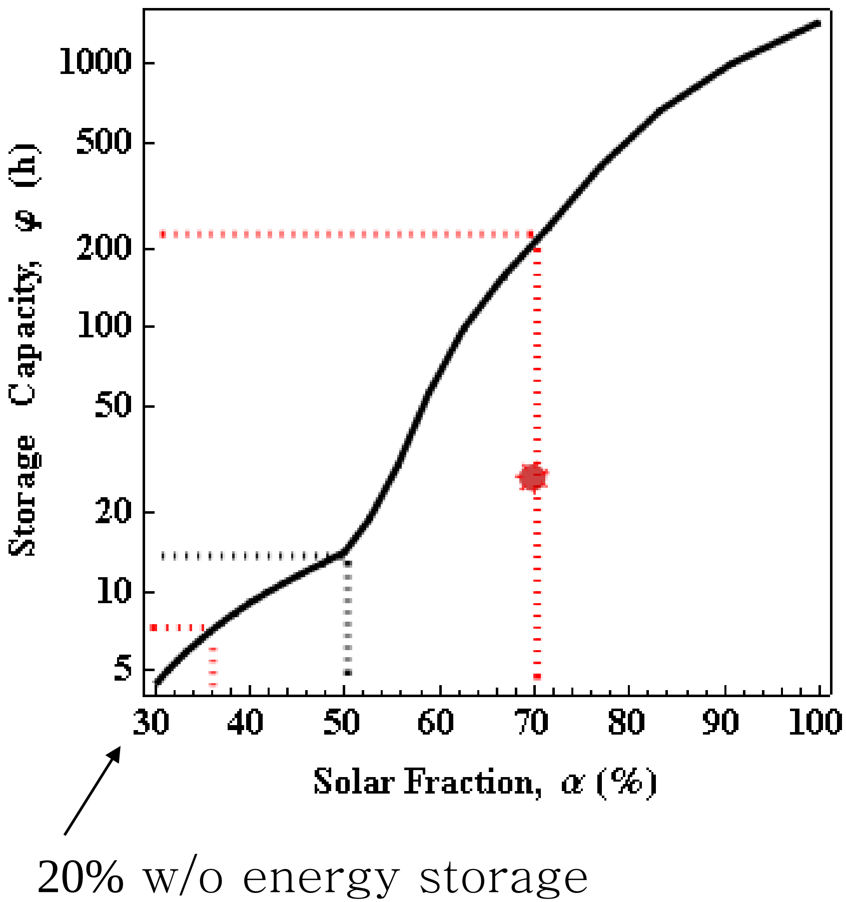
CSP Input	Q_R	DNI time series data	
Base Load	$Q_L =$	$Q_1 + Q_3 + Q_F = \text{Const.}$	
CSP Output	Q_0	$> Q_L$	$< Q_L$
Direct Power Input	$Q_1 =$	Q_L	Q_0
Storage Charge	$Q_2 =$	$Q_0 - Q_1 \; V \; \mathbf{0}$	$\mathbf{0}$
Storage Discharge	$Q_3 =$	$\mathbf{0}$	$Q_L - Q_0$
Fossil Fuel Input	$Q_F =$	$\mathbf{0}$	$Q_L - Q_1 - Q_3$
Reserve Power	$Q_r =$	$\mathbf{0} \; V \; Q_0 - Q_1$	$\mathbf{0}$

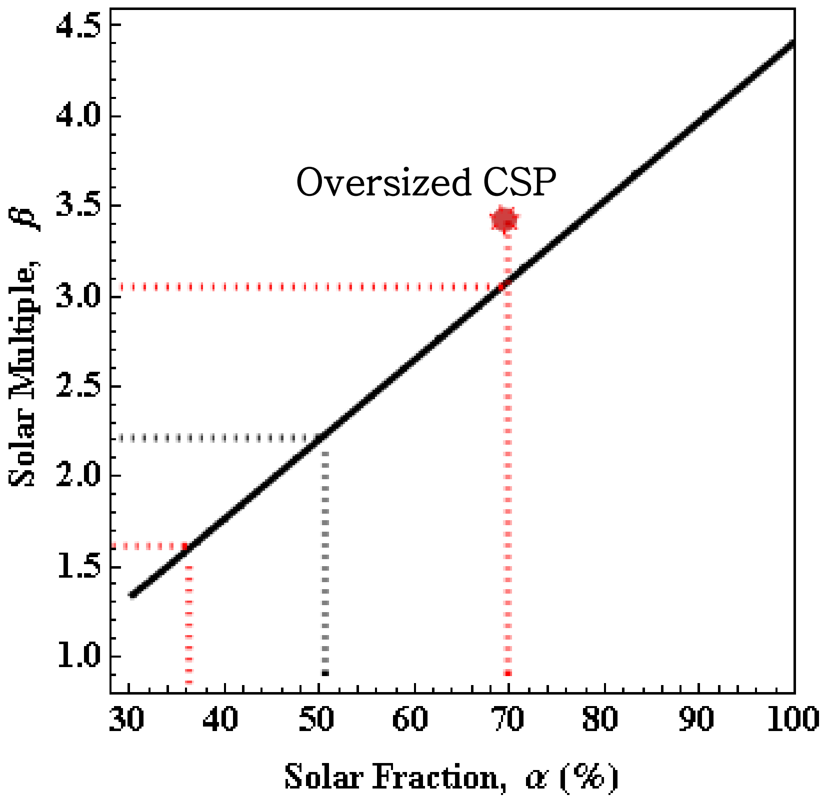
Nominal Storage Capacity $=$ Max[$E_S(t)$] over year

Initial Conditions: $E_S(\mathbf{0}) = E_S(yr) = \mathbf{0}$	Annual Cycle: 8760 hours

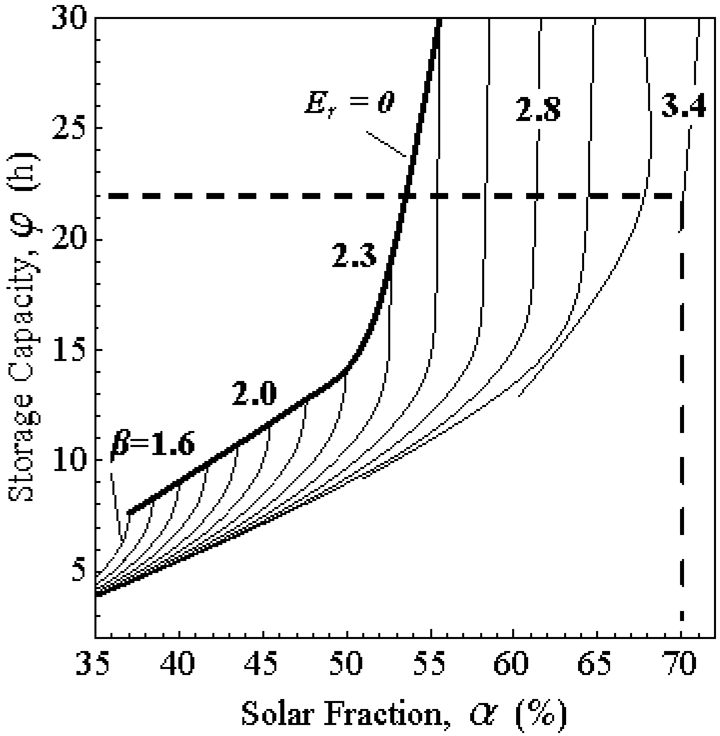
The Model is solved numerically using Mathematica 8

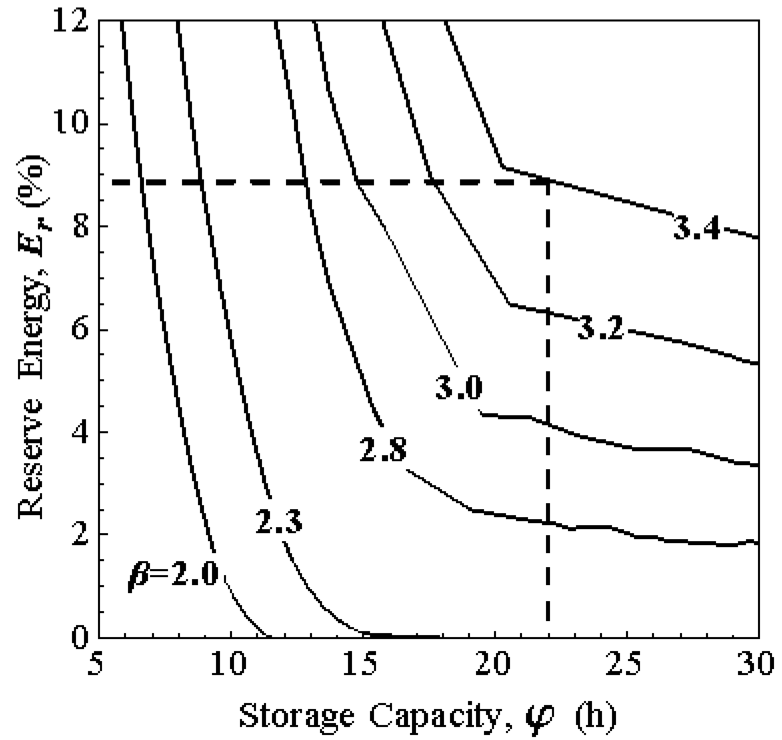
Thermal Storage Capacity vs. Solar Fraction DNI for Mitzpe Ramon, Israel (2005)





Base Load Solar Power Plant





Solar power plant 50 MWe	Solar collector factor β	Storage capacity φ (h)	Solar/Fossil fractions (%)	Daily operational period (h)	Reserve energy E_r (%)
Referent e.g. Andasol	1.6	7.5	37/63	9	0
Model	3.5	22	70/30	17	9

SUMMARY

For the target value of annual solar capacity factor

70%,

as compared to the referent **37%**

Solar Parabolic Trough Plants need:

- x**2** Solar collector size (**3.4**)
- x**3** Thermal storage capacity (**22 h**)
- about **10%** of the available solar energy is reserved

Comparative Advantage:

2 times reduced (**63 to 30%)** fossil fuel consumption

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- The Weizmann Institute of Science

Global CSP Market Players Survey
by EuPD Research, 2008

R&D
- CIEMAT/PSA
- CNRS
- CERTH
- DLR
- DOE
- Fraunhofer ISE
- IDAE
- IEA Solar Paces
- INETI
- NREL
- PSI
- SANDIA
- Weizmann Institute

Manu-facturers
- 3M
- Alstom
- Balcke-Dürr
- Dèfi Systémes
- Flabeg
- GE
- GEA Ibérica
- Guardian
- Kraftanlagen München
- MAN Turbo
- Novatec Biosol
- Rioglass
- Saint-Gobain
- Schott Solar
- Siemens
- Solel
- SPX Cooling
- Thermodyn

Project developers
- Abengoa
- Acciona
- ACS
- Albiasa Solar
- Aries
- Ausra
- Brightsource
- Enerstar
- esolar
- Iberdrola
- Ibereólica Solar
- Novatec Biosol
- SES
- Skyfuel
- Solar Millennium
- SolarReserve
- Torresol
- Valoriza

Investors/ Creditors
- ADB
- Banc Sabadell
- Banesto
- Caja Madrid
- Calyon
- CAM
- Cofides
- Commerzbank
- EIB
- Fidelity
- ING
- JBIC
- KfW IPEX
- Lupus Alpha
- Masdar
- Natixis
- Piraeus Bank
- Santander
- SI Capital
- Société Generale
- Swisscanto
- Ubibanca
- UBS
- Union Invest
- West LB
- World Bank/GEF

EPC
- Abener
- Acciona
- Aries
- Astrom
- Babcock Montajes
- Cobra
- Duro Felguera
- Elecnor
- Fichtner
- Flagsol
- FPL Energy
- Iberese
- Iberinco
- Isolux
- Kraftanlagen München
- MAN Solar Millennium
- M+W Zander
- sbp
- Sener

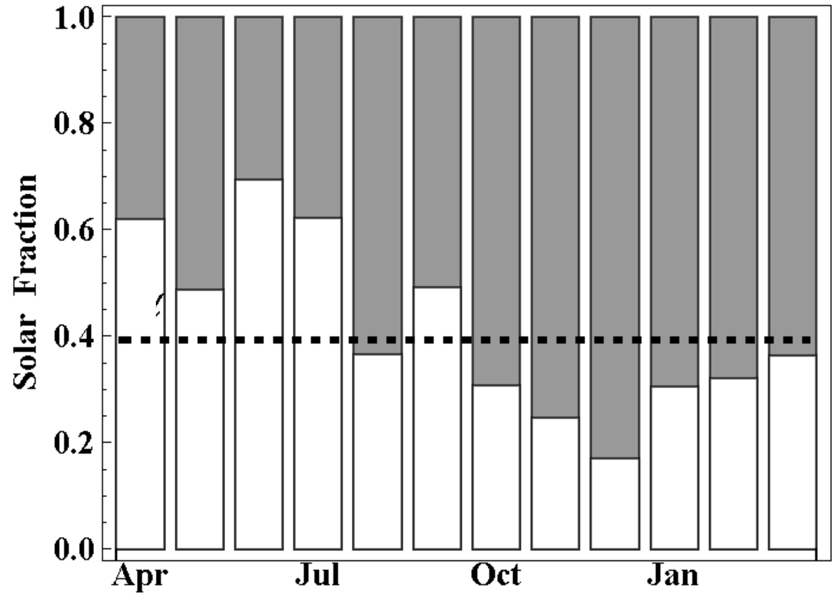
Operators/IPP
- Abengoa
- Acciona
- ACS
- Aries
- Enerstar
- FPL Energy
- Iberdrola
- Ibereólica Solar
- Masdar
- Solar Millennium
- Valoriza
- Sener

Utilities
- APS
- Endesa
- Iberdrola
- NEAL
- Nevada Solar
- ONE
- Sierra Pacific

Legend:
- Glass/Mirrors
- Receivers
- Collectors
- Turbines
- Cooling equip.
- Others

- Engineering/ consulting
- Just engineering
- Just construction

Monthly Change of Solar Fraction



Seasonal Variation of Thermal