SAND2007-6735P

SOLAR ENERGY

Tom Mancini

Department 6337
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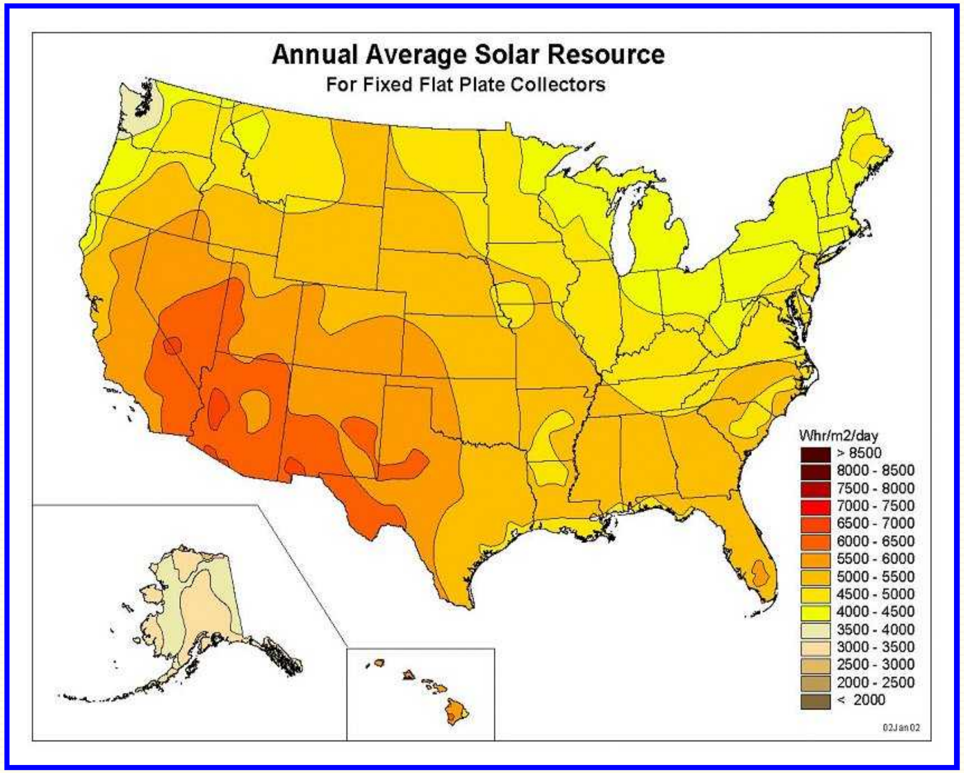
Solar Energy Applications



Applications include

Distributed uses

- **Heating and cooling**
- **Domestic hot water**
- **Roof-top PV electricity**

Larger-Scale uses

- **Utility Scale Power**
  - *Concentrating Solar*
  - *Concentrating Photovoltaics*

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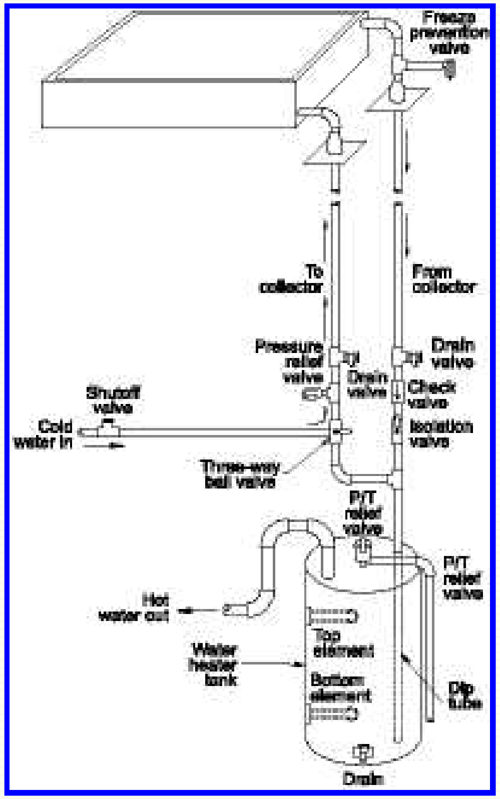
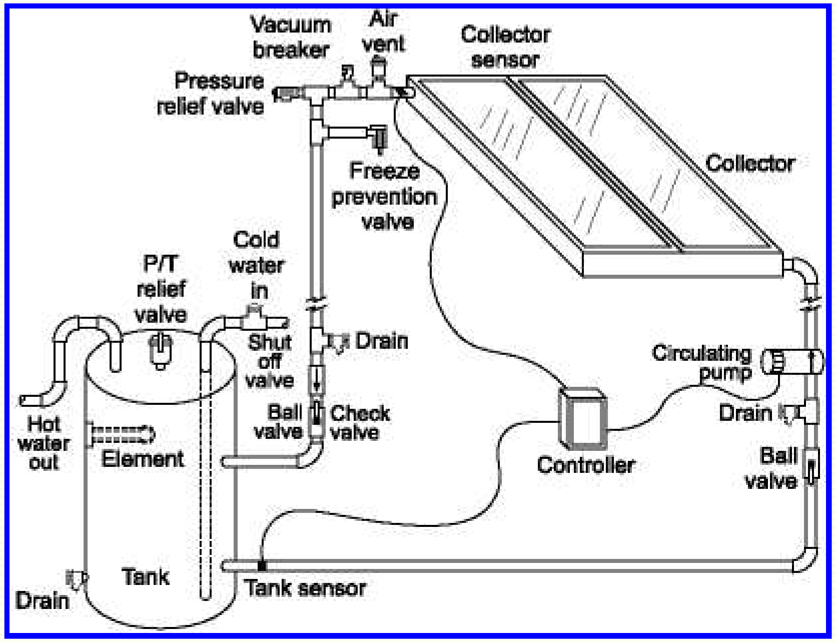
Solar Water Heating

Common System Types



Passive

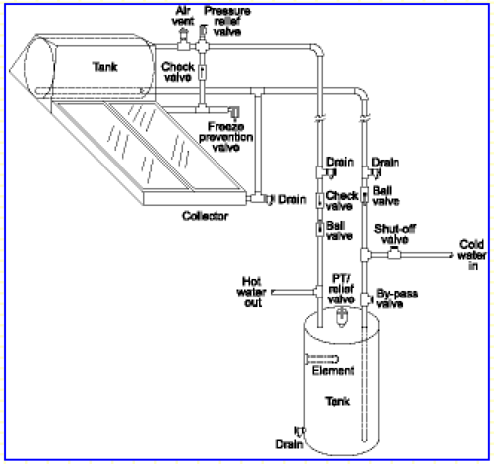


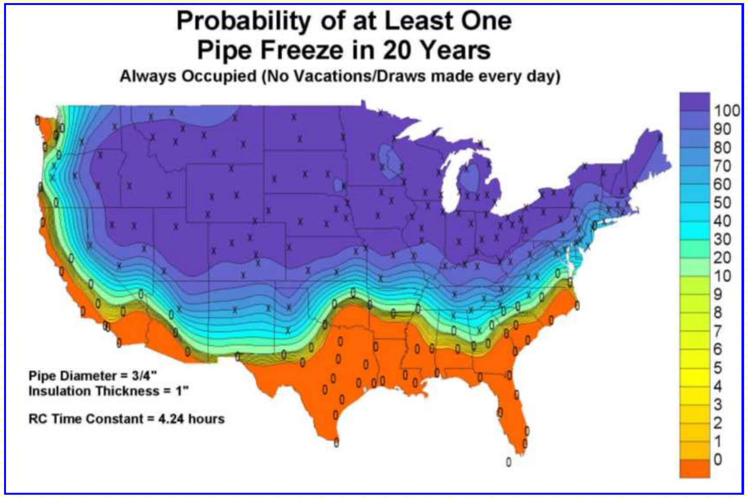
Active

Passive Solar Water Heating

Thermosiphon System

A solar water heater on a typical Australian suburban rooftop.





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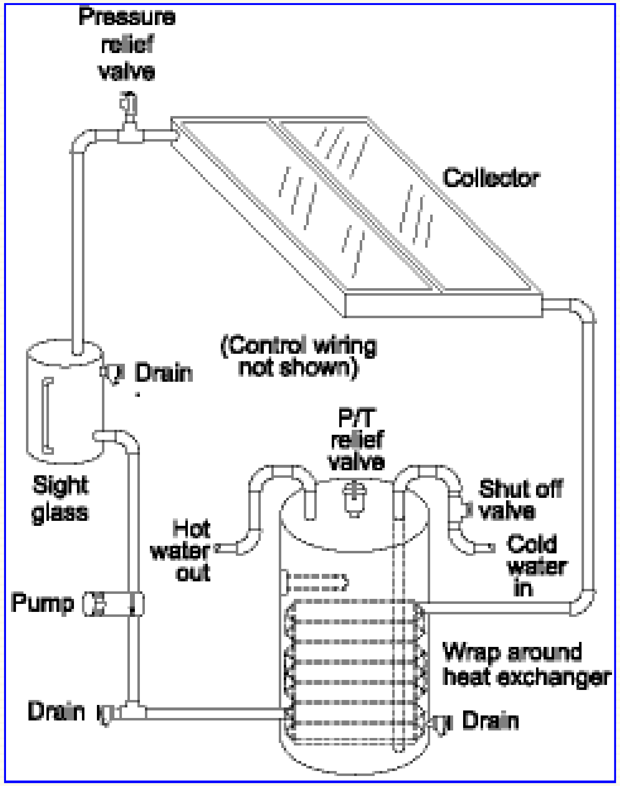
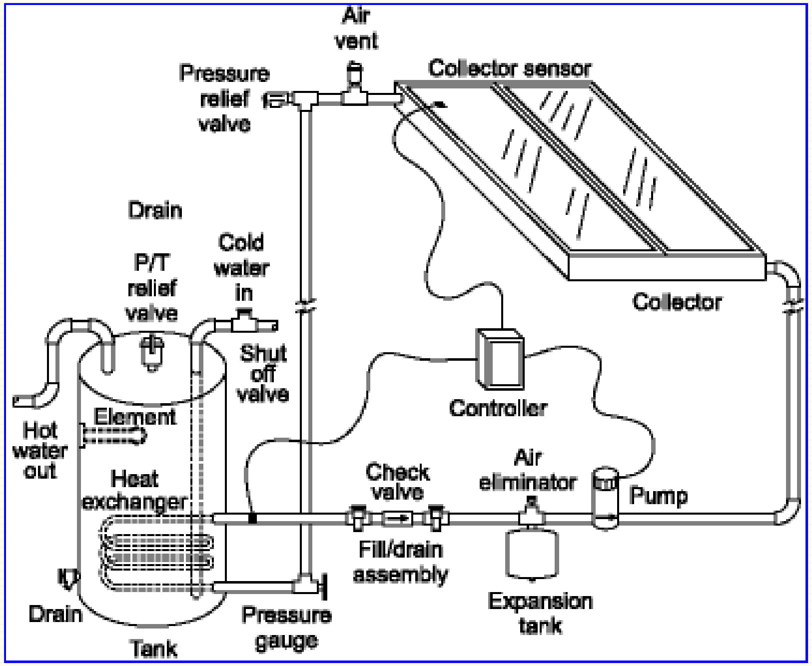
Active Solar Water Heaters

Drainback Indirect Circulation





Pressurized Glycol Indirect Circulation

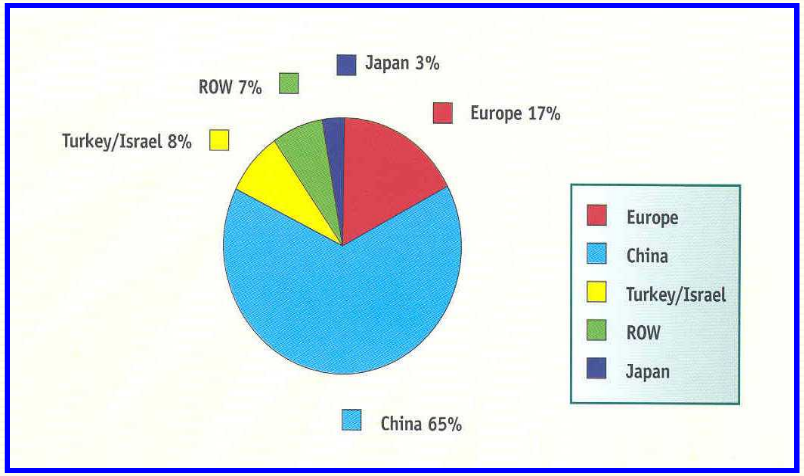
Solar Rating & Certification Corporation (SRCC)

- http://www.solar-rating.org/
- Administers a U.S. certification, rating, and labeling program for solar collectors and solar water heating systems
- 138 solar water heating system models have been approved for SRCC certification

Solar Water Heating Status

Solar Hot Water

- 1 million U.S. homes
- 4.5 million houses in the world
- Annual U.S. generation over 2 billion kilowatt-hours of energy equivalent.
- U.S. represent more than 1 Gigawatt of installed equivalent power capacity.



Over 100 million m^2 collectors worldwide

What is Concentrating Solar Power?

Utility-Scale Solar Power > 100 MW

354 MW Operating in South CA for 18 years

Wholesale Electricity Market

Electricity Generated using thermal- electric processes (heat engines)

Historically, has not included utility-scale photovoltaics

What are CSP technologies?

Concentrating Solar Power = Solar Thermal Power

Power Towers

Trough Electric Systems

Dish Stirling Systems

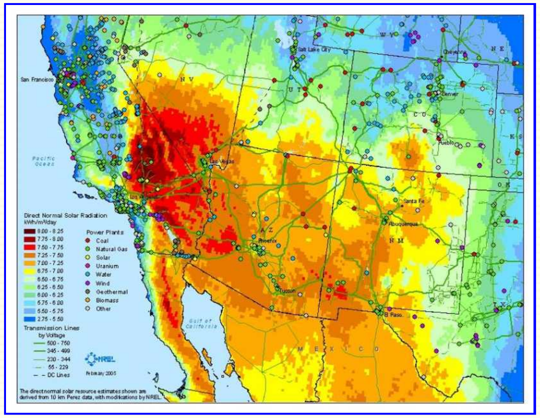
Concentrating Photovoltaics

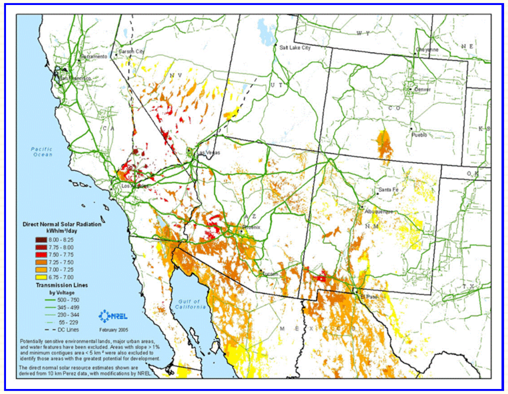
Project Costs

Not going into detail on costs today

- Sometimes represented as $/kW installed
- Sometimes represented as the Levelized Cost of Energy (LEC) from a plant (includes financing, O&M, profit, over the lifetime of the plant etc.)
- Project costs are complicated and are impacted by a number of things in addition to the cost of the technology.
  - *Financing terms*
  - *Plant ownership*
  - *Incentives*
  - *Proximity to/capacity of substation*
  - *Ownership/cost of land*
  - *Capacity of power lines*

Capacity in the Southwest





Filters applied:

- **Direct-normal solar resource.**
- **Sites > 6.75 kwh/m²/day.**
- **Exclude environmentally sensitive lands, major urban areas, etc.**
- **Remove land with slope > 1%.**
- **Only contiguous areas > 10 km²**

State	Land Area (mi^2)	Solar Capacity (MW)	Solar Generation Capacity GWh
AZ	19,279	2,467,663	5,836,517
CA	6,853	877,204	2,074,763
CO	2,124	271,903	643,105
NV	5,589	715,438	1,692,154
NM	15,156	1,939,970	4,588,417
TX	1,162	148,729	351,774
UT	3,564	456,147	1,078,879
Total	53,727	6,877,055	16,265,611

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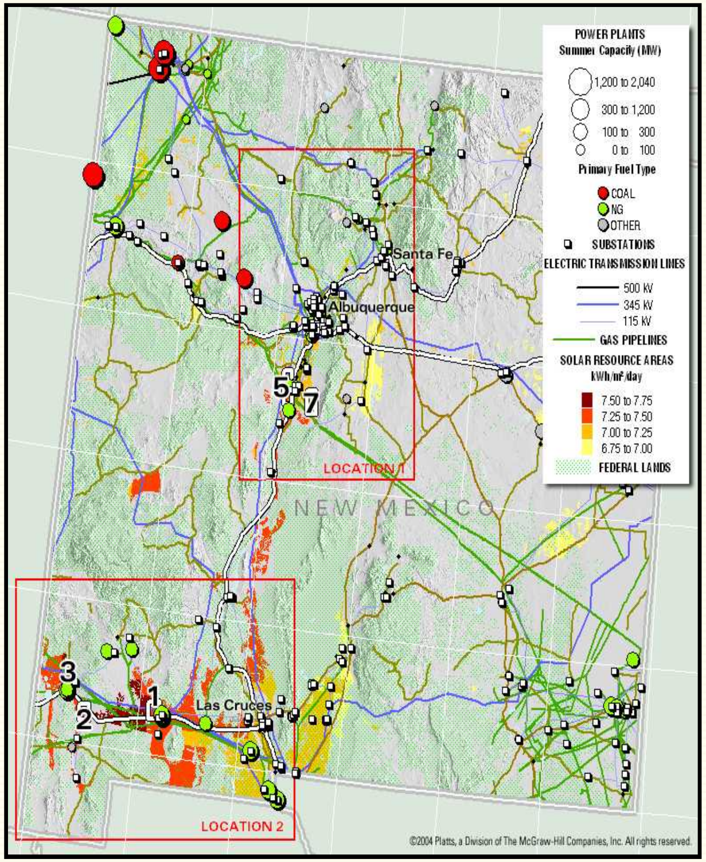
NM's Solar Energy Potential



The table and map represent land that has no primary use today, exclude land with slope > 1%, and do not count sensitive lands.

Solar Resource kWh/m^2/day

	> 8.0	7.0 – 8.0	6.0 – 7.0	Total
Available Area* (mi	923	8,234	25,060	34,217
Capacity (MW)	119,000	1,000,000	2,550,000	3,669,000
Generation (MWh/year)	282,020,000	2,367,297,000	6,036,258,000	8,685,575,000

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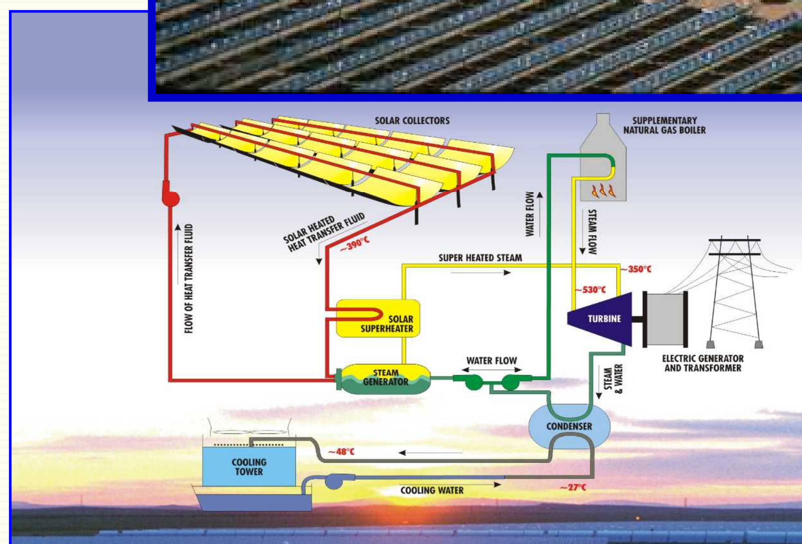
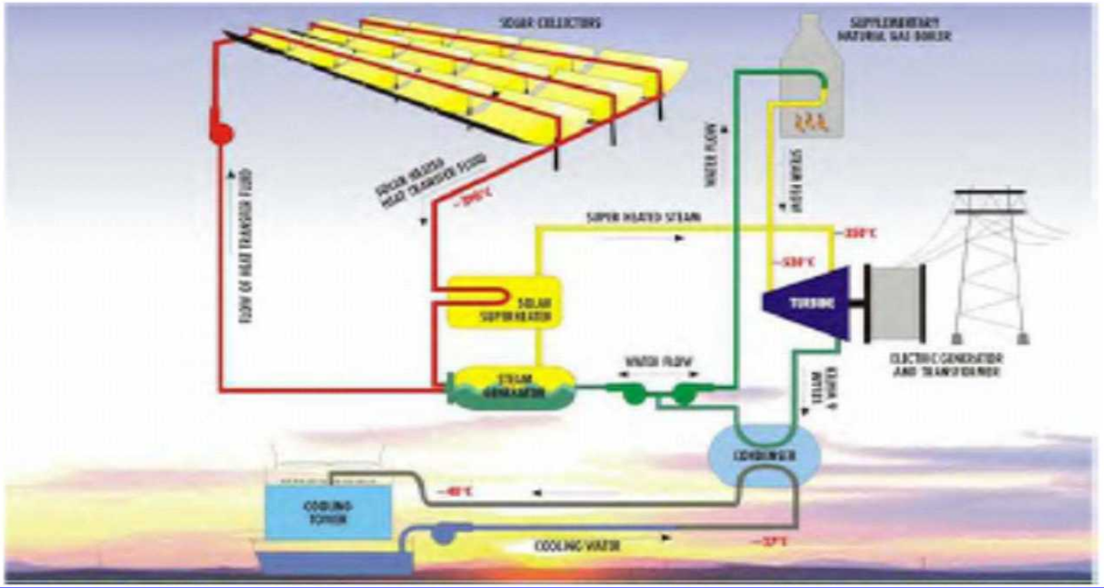
Trough Technology

Trough Technology

- Trough Collectors (single axis tracking)
- Heat-Collection Elements
- Heat-transfer oil (Therminol VP1)
- Conventional steam-Rankine cycle power block
- Steam generator



Nevada Solar One
Technical Characteristics



SOLAR FIELD

64 MW solar field – 30 Minutes Storage –No fossil fuel added

Solar Collector Assemblies:	760
Aperture Area (m^2/Sq.ft):	5.0 / 59
Length (m/ft):	100/328
Concentration Ratio:	71
Optical Efficiency:	0.77
# of Mirror Segments:	182400
# of receiver tubes	18240
Field Aperture (m^2):	357,200
Site area (Km^2/acres):	1.42/360
Field Inlet Temp.(°C/°F):	350/662
Field Outlet Temp. (°C/F°):	395/743

Annual electricity production estimated to be 140 - 150GWh

Turbine Generator Gross Output	75 MWe
Net Output to Utility	70 MWe
Solar Steam Conditions	
Inlet Pressure	102 bars/1480 psi
Reheat Pressure	17.5 bars/254 psi
Inlet Temperature	371 Deg.C / 700 Deg.F

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1-MW Organic Rankine Cycle Plant at APS

APS Saguaro Solar Plant

CLFR Linear Technology

Continuous Linear Fresnel Reflector

38 MWe Project In Construction Singleton, NSW Australia

Low-Cost Reflectors

Low Profile Flat Glass

- **Low wind load, low steel**

Air-Insulated Absorber

Subcritical Temps

38MWe now in construction

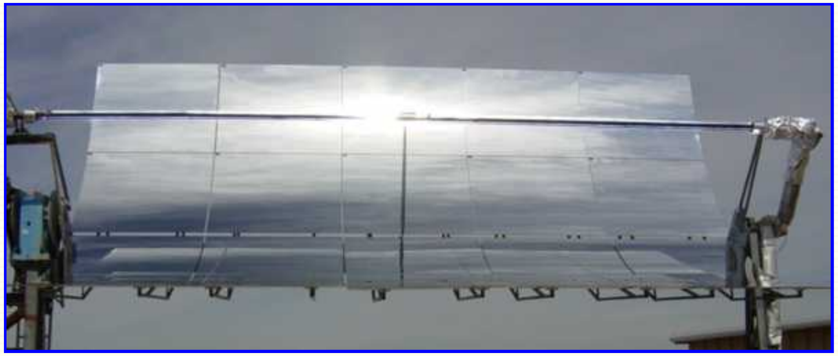
175MWe now in permitting in CA

Trough Components

Drive

Controller

Trough Collector



Receiver

Current Trough Design

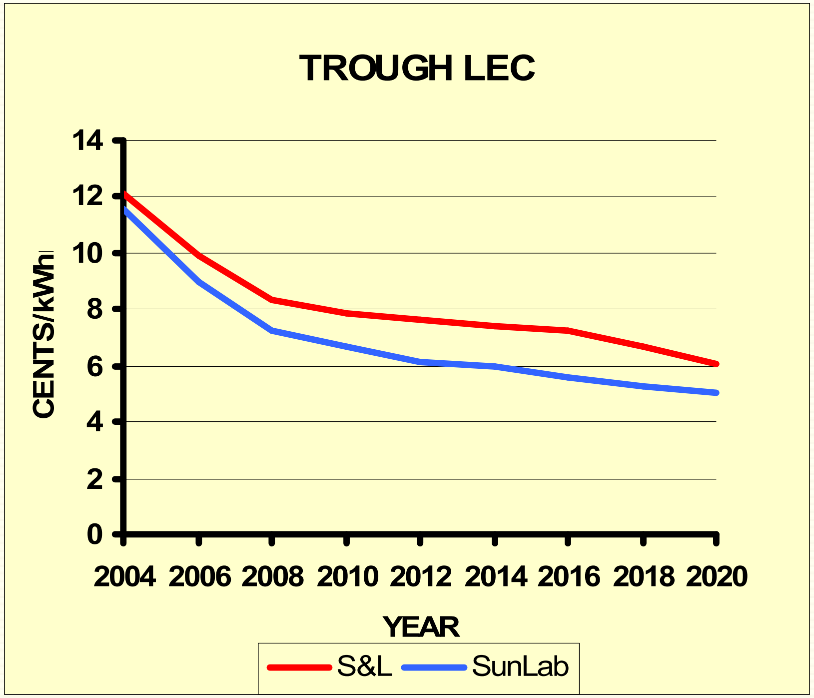
For a 100 MW Trough Plant

- E-W tracking collector, Area = 624,000 m^2
- No Storage, No hybrid operation
- Annual solar-to-electric conversion = 11%
- Annual Capacity factor = 29%
- Field operating temperature = 391 C
- Conventional Rankine steam turbine
- Water cooled (water is an issue in the West)

Trough Near-Term R&D and Electricity Cost

Near-Term R&D

- Concentrator Design to reduce cost
- Advanced Receiver Technology
- Thermal Energy Storage



Subject to a set of assumptions including: 3 GW deployed by 2020, storage utilized, incentives in place, etc.

** ASSESSMENT OF PARABOLIC TROUGH AND POWER TOWER SOLAR TECHNOLOGY COST AND PERFORMANCE FORECASTS, SL-5641 MAY 2003.*

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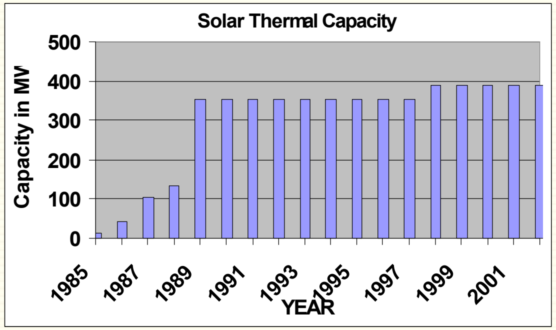
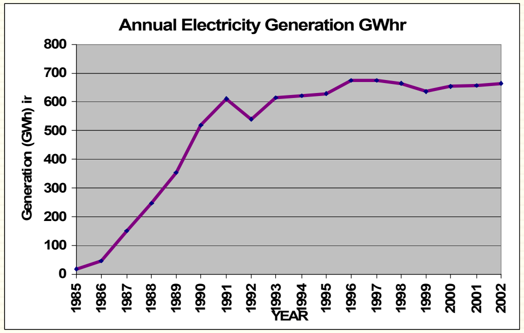
Status of Trough Plants

SEGS Plants

- 354+ MW operating in Mojave Desert since 1989
- Total reflective area > 2.3 Mill. m^2
- More than 117,000 HCEs
- 30 MW increment (PURPA reg power block size)
- Producing > 650 GWhrs annually





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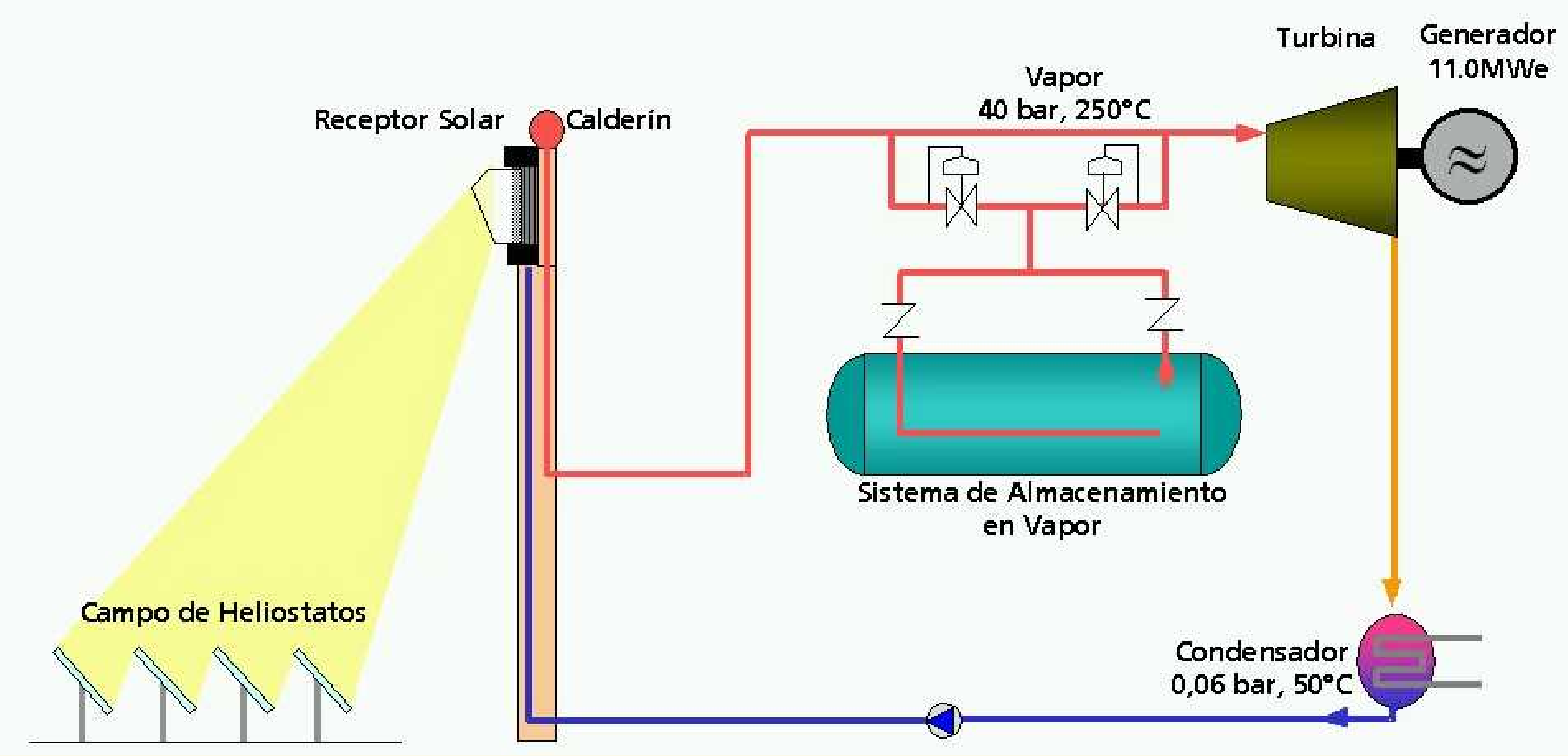
PS 10 Power Tower

PS 10 Plant Operational Nov 2006. Construction started on first PS 20 Plant.

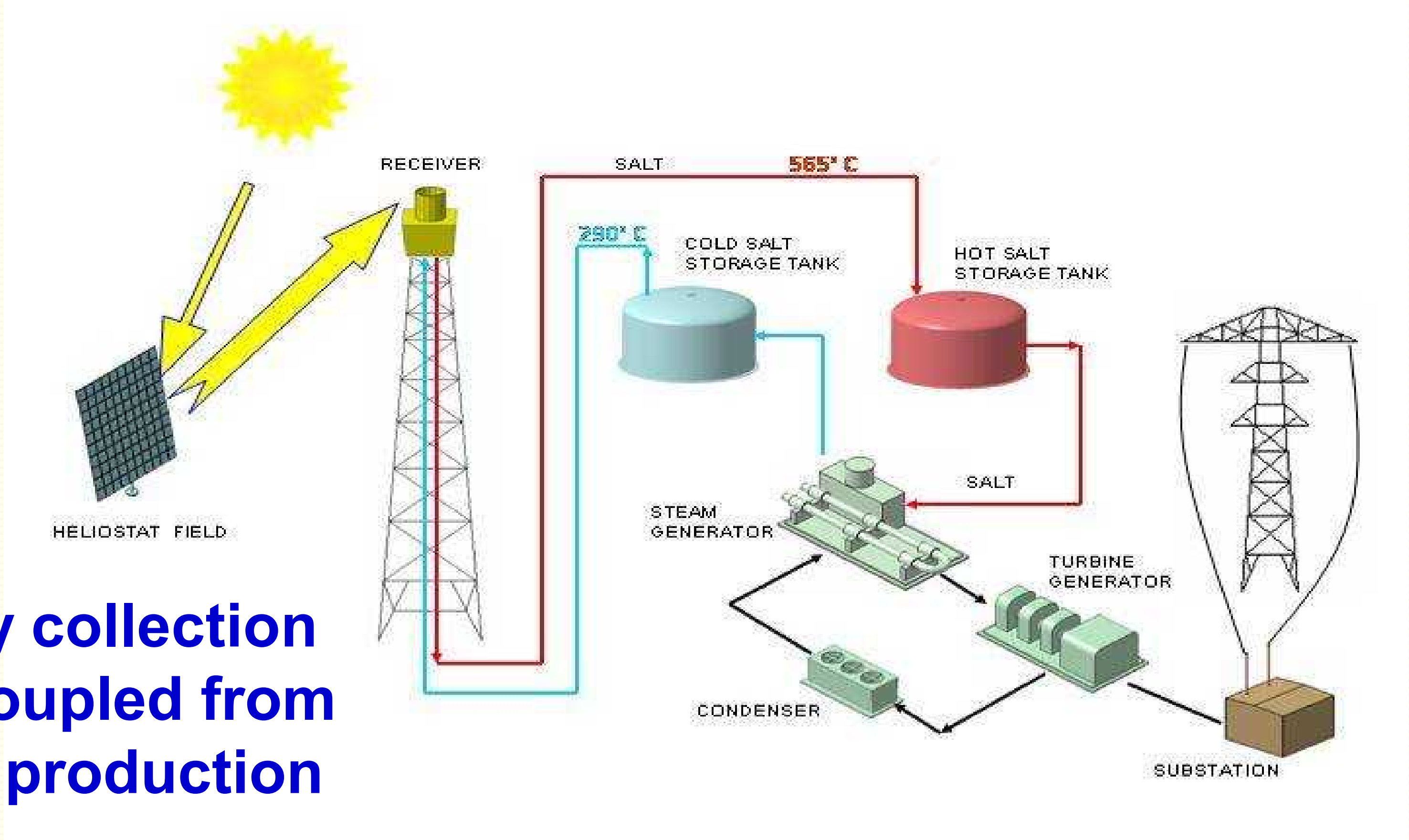
PS 10 Steam Cycle



Once-through steam boiler similar to Solar 1

Molten-Salt Power Tower

Power Tower or "Central Receiver"



Energy collection is uncoupled from power production

Power Tower Technology

Power Tower

- Heliostats (two axis tracking)
- Air or Molten-Salt Working Fluid
- Thermal Storage
- Conventional steam-Rankine cycle power block

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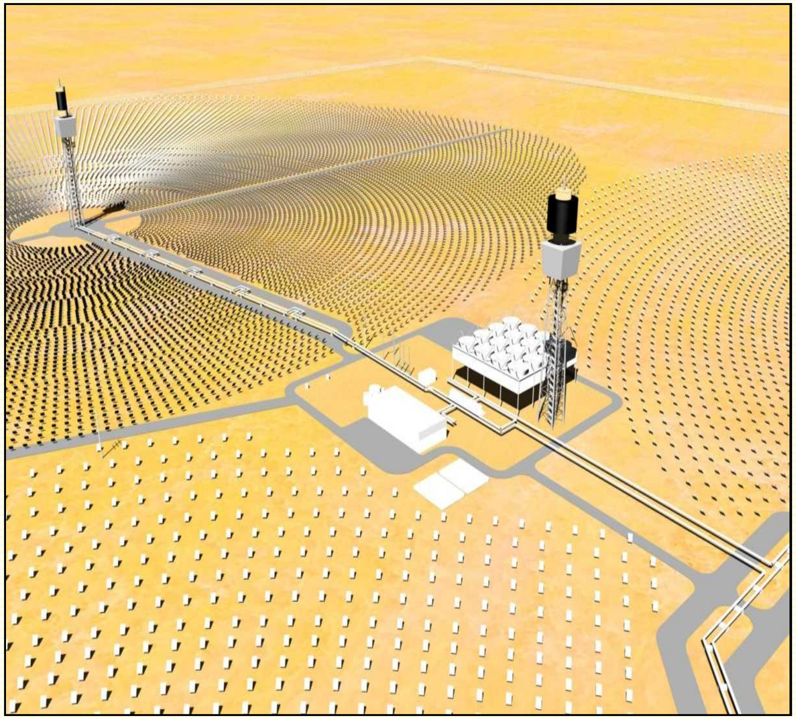
Distributed Power Tower (DPT)



Dual axis tracking heliostats focus sunlight onto solar boilers atop towers

Steam can be piped to high efficiency standard power block to generate electricity

Typical plant size is 100 MWe

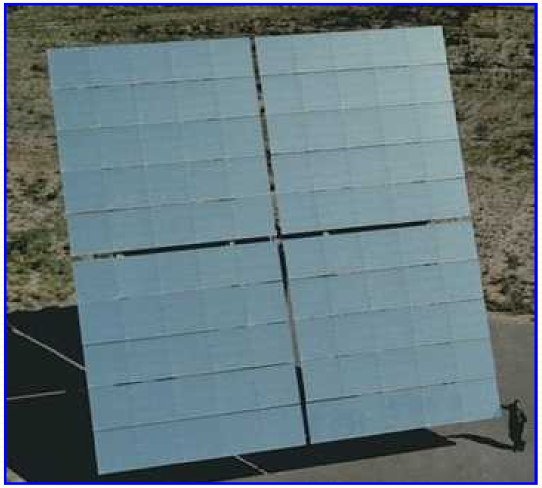
Small, low cost heliostats

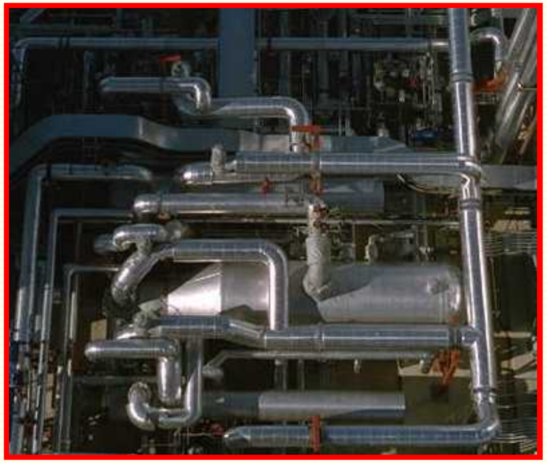
Power Tower Components

Receiver

Storage Tanks

Heliostat





Steam Generator

Current MS Power Tower Design

For a 100 MW MS Power Tower Plant

- Collector Area = 144,000 m^2
- 13 hours of thermal storage
- Annual Solar-to-electric conversion = 15%
- Annual Capacity factor = 65%
- Field operating temperature = 565 C
- Conventional Rankine steam turbine
- Water cooled

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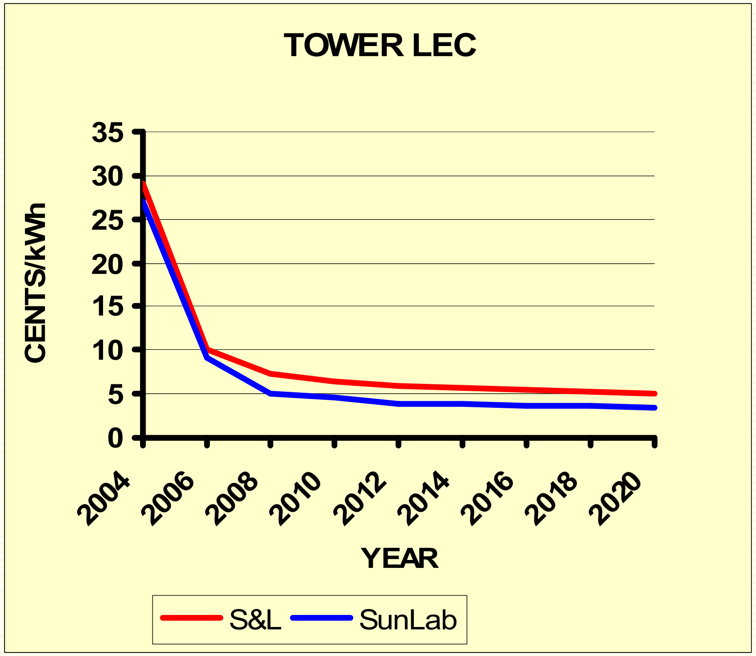
Tower Near-Term R&D and Electricity Cost

Near-Term R&D to

- Heliostat Design to reduce cost
- Receiver Cost and Operational Strategy
- Receiver reliability
- Steam Generator design/operation



Subject to a set of assumptions including: 3 GW deployed by 2020, storage utilized, incentives in place, etc.

** ASSESSMENT OF PARABOLIC TROUGH AND POWER TOWER SOLAR TECHNOLOGY COST AND PERFORMANCE FORECASTS, SL-5641 MAY 2003.*

Dish Stirling Technology

Dish Stirling Technology

- Dish (two axis tracking)
- 10 and 25 kW Stirling Engines
- Thermal receivers
- Distributed generation or bulk power
- 8 different systems built and tested over the last 20 years

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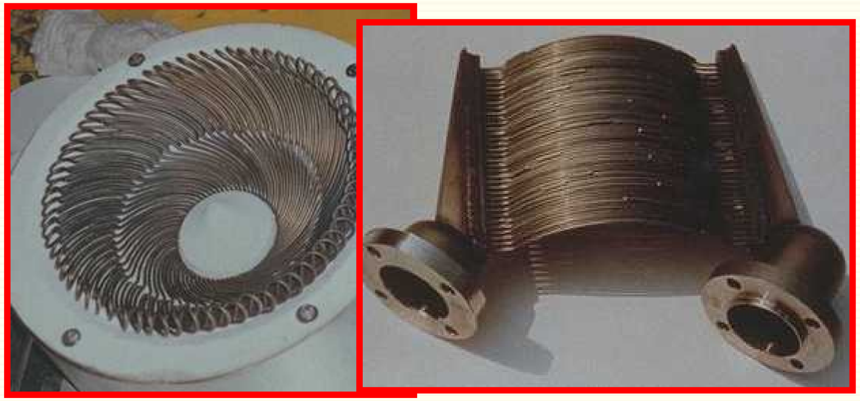
Dish Stirling Components

Receiver



Dish

Engine/Generator

Current Dish Stirling Design

For a 50 MW Dish Stirling Plant

- Require 2,000 25-kW systems
- Modularity at single unit size
- Hybridization is possible (NG, H_2, LFG, etc.)
- Annual Solar-to-electric conversion = 22 %
- Annual Capacity factor = 29% (solar only)
- Field operating temperature = 750 C
- 25 kW Kinematic Stirling engine
- Closed-radiator cooling system

Dish Near-Term R&D and Electricity Cost

Near-Term R&D

- Dish design/cost reduction
- Engine/receiver Cost and Operational Strategy
- Engine/receiver reliability

Current cost estimated to be 25 - 30 ¢/kWhr

Projects in SW U. S.

- 1 MW trough/ORC in Arizona (APS, Solargenix) operating
- 64 MW trough electric project in Nevada (Nevada Power, Solargenix) commissioned June 2007
- 500 (option to 850 MW) Dish Stirling plant in Southern California (SCE, SES). (Agr. signed Aug 2005.)
- 300 (option to 900 MW) of Dish Stirling plants in Southern CA (SDG&E, SES). (Agr. signed in Sep 2005.)
- PG&E 553MW (PPA w/Solel) (July 23, 2007)
- ~ 250 MW SW Utility Consortium in planning
- 300 MW AUSRA and FPL (Sept. 25, 2007)
- Other RFPs issued by not announced (SCE, PG&E, LADWP, SMUD, SDG&E, APS, etc.)

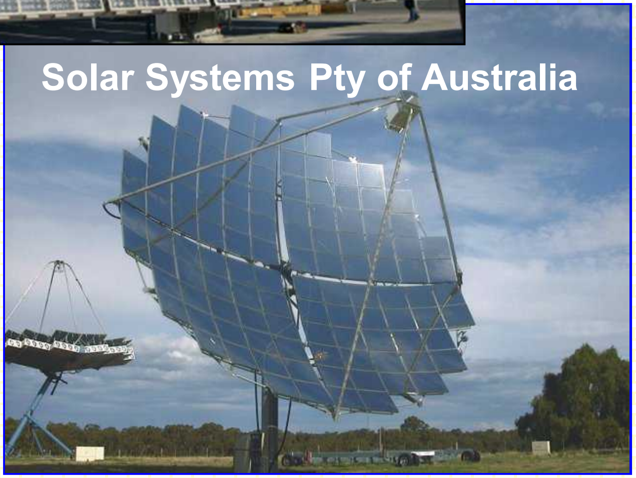
Projects Around the World

- Algeria: Abener, 30 MW trough fuel saver; €75M and it must provide 5% solar fraction annually.
- Egypt: Bids for the 150 MW Kuraymat trough plant are due November 2006.
- South Africa: ESKOM in Phase V of molten-salt power tower development; currently performing an EIA.
- Israel: SOLEL signed a contract for a 150 MW trough plant.
- Mexico: Bids expected in December 2006 for the 30 MW solar trough project at Agua Prieta in Sonora.
- Spain: Estimates are that 2 GW or more of CSP plants are in the planning stages. SOLUCAR started operation of PS 10 power tower and construction of the 20 MW PS 20; the first of three 50 MW ANDASOL trough plants with 7.5 hours of molten-salt thermal storage is under construction.

Concentrating PV Technology

Amonix CPV Technology

- 25-kW CPV Module
- Two axis tracking structure
- 350 m^2 concentrator
- 3M Acrylic lens concentrator at 250X
- Silicon solar cells



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Current CPV Design

For a 50 MW Power Tower Plant

- Require 2,000 25-kW systems
- Modularity at single unit size
- Annual Solar-to-electric conversion = 16%
- Annual Capacity factor = 26%
- No cooling water requirement

CPV Near-Term R&D and Electricity Cost

Near-Term R&D

- Reliability validation
- Module cost reduction (packaging)
- Advanced cell technology 3-5 multi-junction technology

Current cost estimated to be 25 to 35 ¢/kWhr

Planned CPV Deployments

Contracted Deployments

- AMONIX with Guascor in Spain to install 10 MW
- An 80 MW plant was announced in California

Proposed/planned Deployments

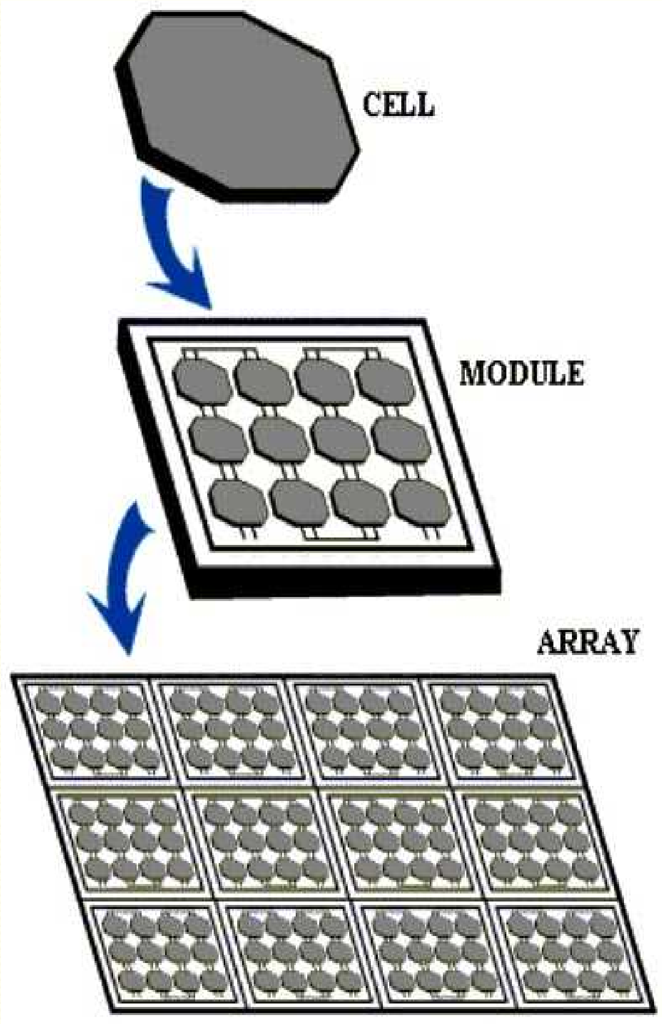
- APS 5 MW over the next couple of years.
- AMONIX is rumored to have plans to install a plant in Portugal
- Sharp has announced a CPV module

Photovoltaic Basic Building Blocks

Cell—a single unit, typically polycrystalline silicon wafer, capable of producing dc voltage (≈.6V) and current (≈1 ampere/ 50 cm^2 in 1000 W/m^2 sun)

Module—multiple cells connected together in series-parallel configurations to attain higher level dc voltage and current (10-300 Watt packages)

Array—multiple modules connected together in series-parallel configurations to meet user dictated voltage/current/power needed (KW's-MW's)



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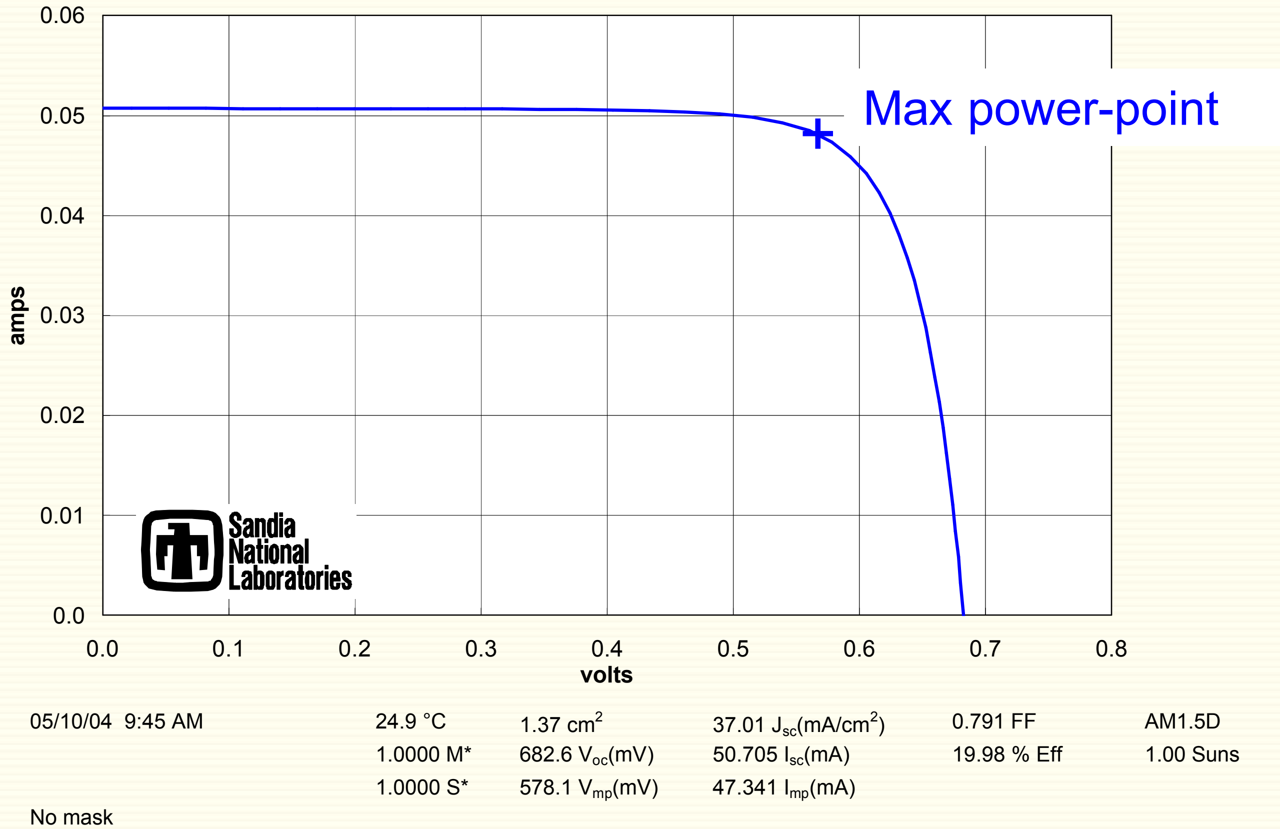
Electrical Characteristics of PV Cells



Electrical Characteristics—current, voltage, power, efficiency…

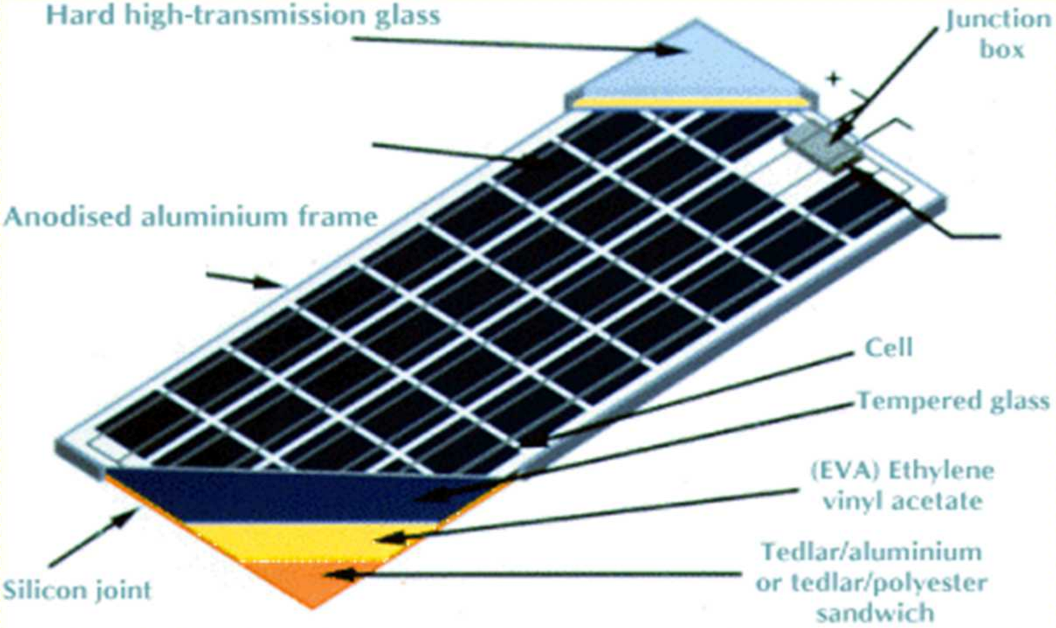
Module Construction

Super and/or substructure—typically tempered glass

- Cell string(s)— tinned flat wire soldered to cell metallization
- J-box or pigtails
- Backsheet—typically a tri-layer for tedlar/polyester/tedlar (Al sometimes)

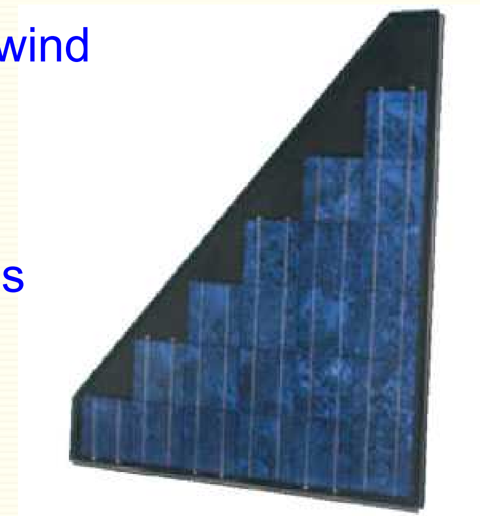
Encapsulant—polymer for adhesion of layers (ethylenevinylacetate)

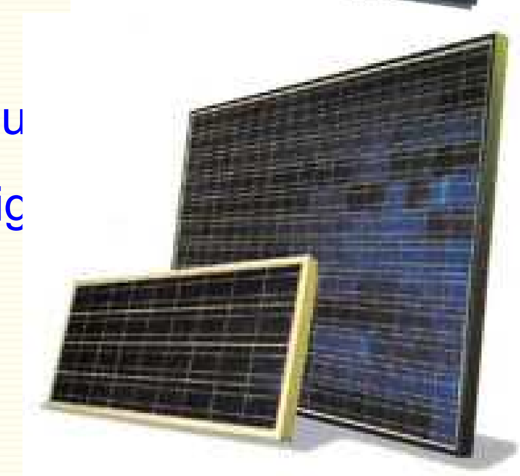
Frame—aluminum for edge protection and mounting

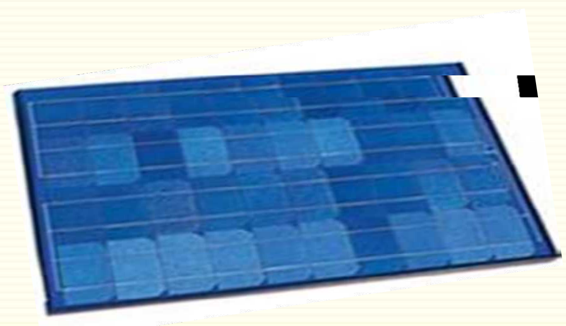


PV Module Characteristics

- Typically rigid to handle structural loads/mounting-requirements
- Packaged to withstand UV, temperature, humidity, hail, and wind stresses
- Packaged to meet high-voltage bias configurations
- Packaged to meet UL (fire) tests, safety, NEC, building codes
- 15-25 Year manufacturers warranties
- ≈ 1% per year performance degradation predicted
- Packaged to meet architectural needs
- Packaged for easy connection into strings for array configu
- 10-300 Watt configurations—specific voltage/current config for specific markets







Arrays--multiple modules in a series/parallel configurations

- Form voltage/current requirements—typically 12V to 300V configurations

Latitude-tilt

Horizontal

Tracking

Concentrator

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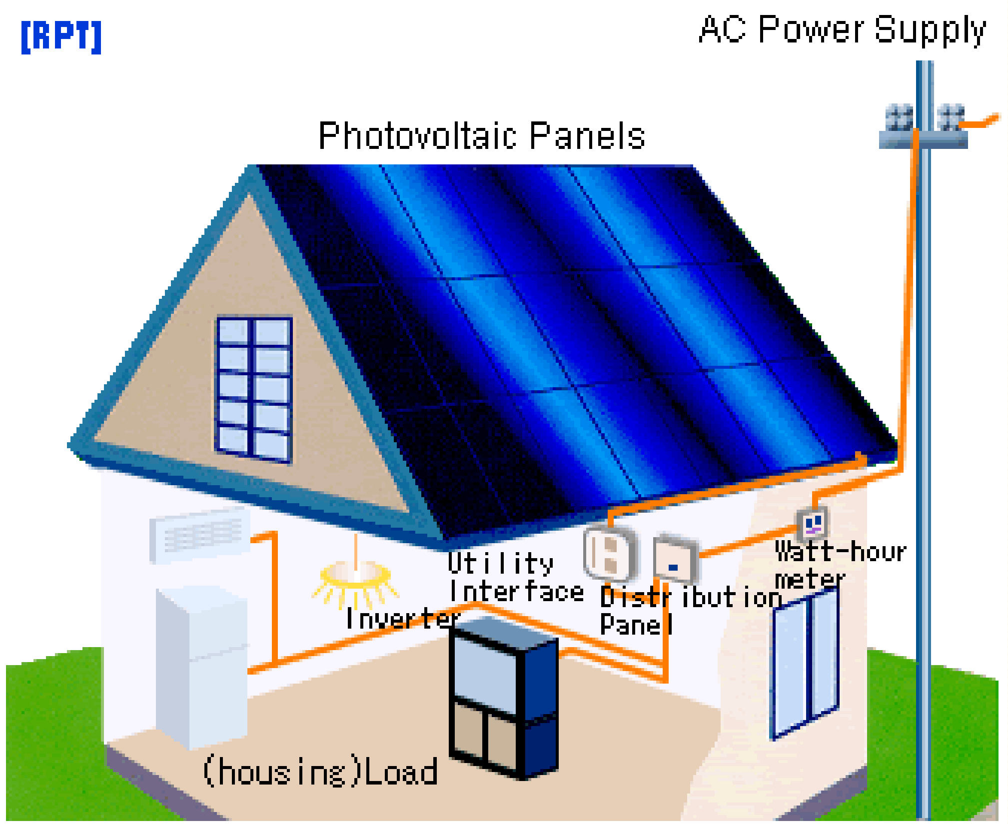
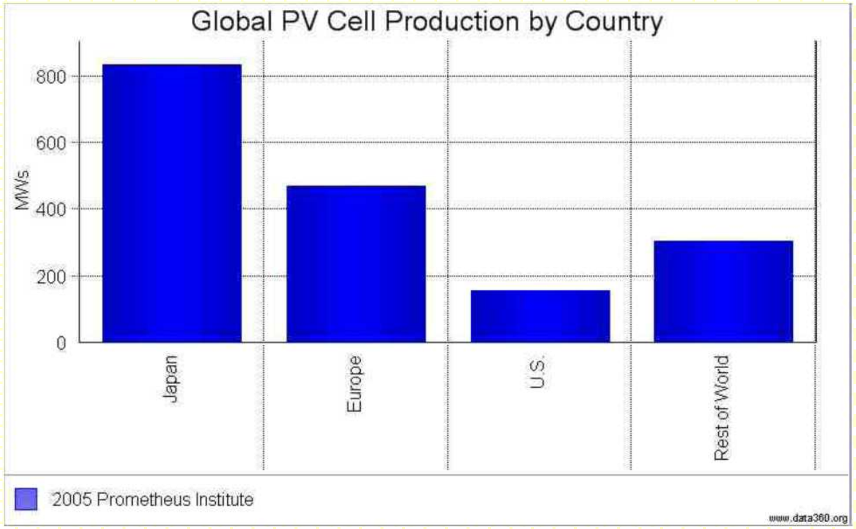
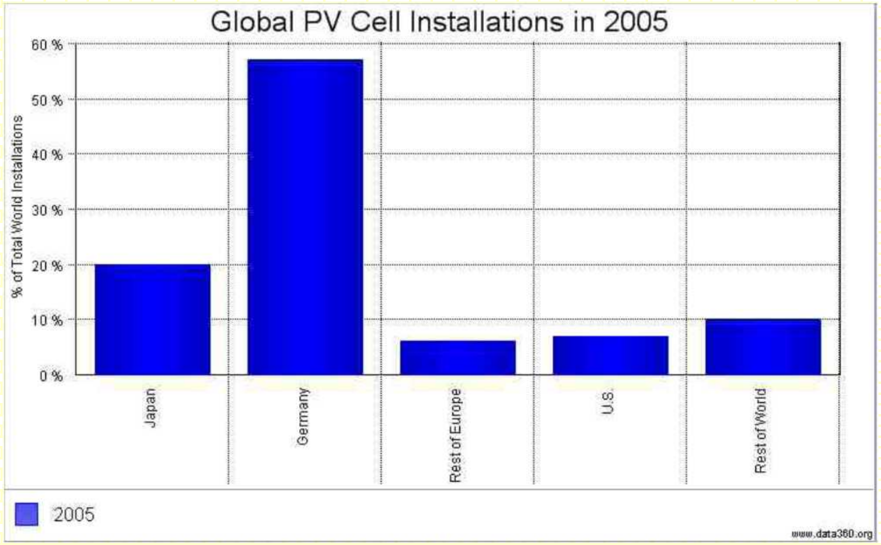
Photovoltaic Systems

- Photovoltaic arrays produce dc electricity
- Inverters convert dc electricity to ac electricity and interface to the utility grid
- Balance of System components make installation complete
- Energy storage—typically lead-acid batteries with a charge controller



PV Cell Production





2002 – 2805 DG pv installations in U. S.

2006 – 7446 DG pv installations in U. S.

2007 predictions are > 11,000 installation

2005 – 1.7 GW of pv cells produced globally

2010 predicted to be > 10 GW

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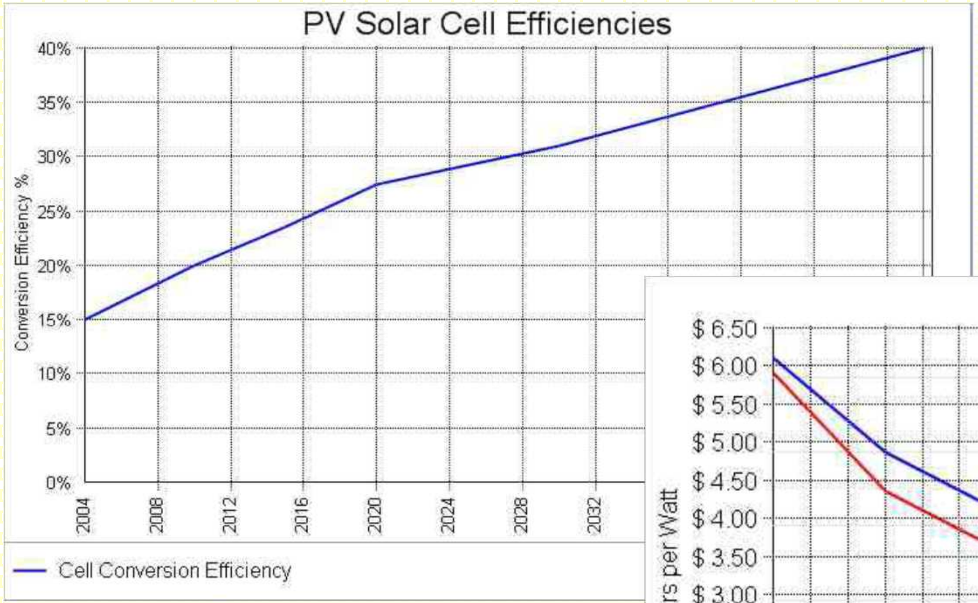
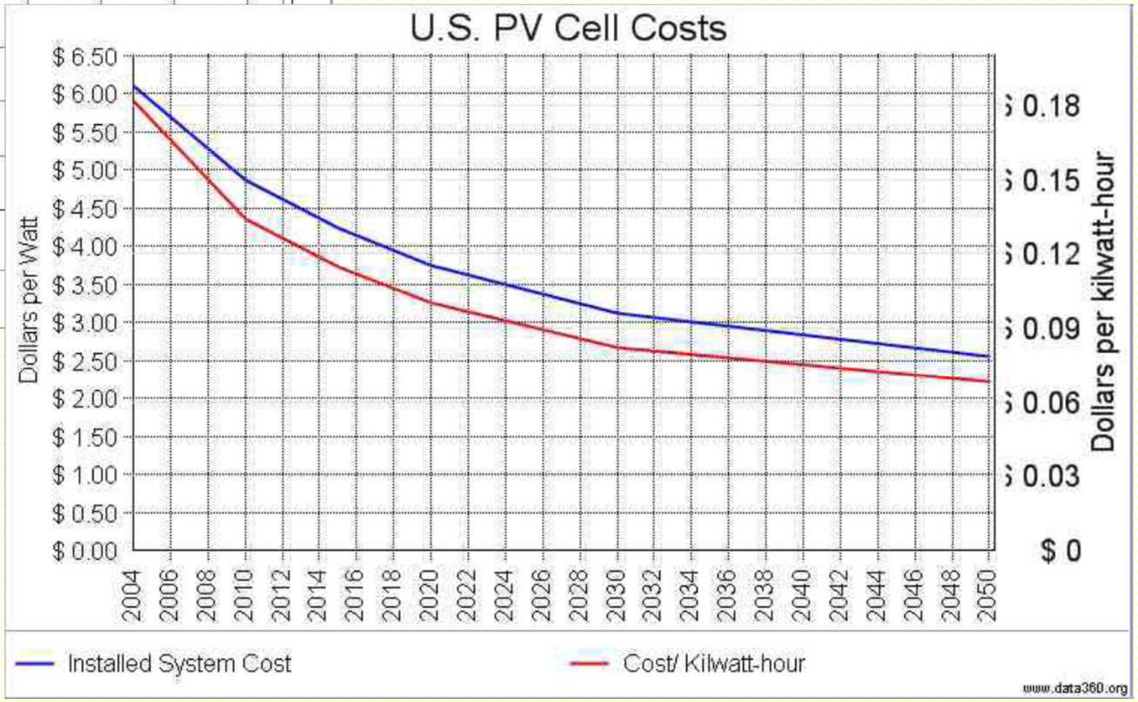
PV Cell Costs



These are cell efficiency and cost not system efficiency and cost.



Current system costs are $5 -- $6 per watt

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