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EuroTrough Collector Assembly

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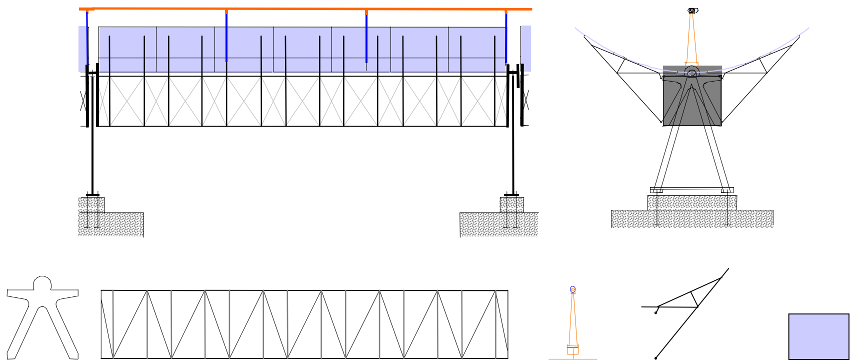
EuroTrough Structural Elements



a b c d e

EuroTrough collector element consisting out of

- *(a) 2 endplates*
- *(b) 4 simple steel frames screwed to a torque box*
- *(c) 3 HCE supports*
- *(d) 14 cantilever arms and*
- *(e) 28 mirror facets.*

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EuroTrough
Solar Collector Element - weights

EuroTrough Collector Component		*strong SCE*	*"field" SCE*
Glass mirrors	kg	747	747
HCE (incl. oil)	kg	73	73
Torque box	kg	597	597
End Plates	kg	186	130
Cantilever Arms	kg	384	231
HCE supports	kg	113	90
Torque Transfer	kg	32	32
Total weight steel structure only	kg	1,312	1,080
Specific weight steel only	kg/m²	19.0	15.6
Total weight incl. mirrors and HCE	kg	2,132	1,900
Specific weight kg/m²	kg/m²	30.9	27.5

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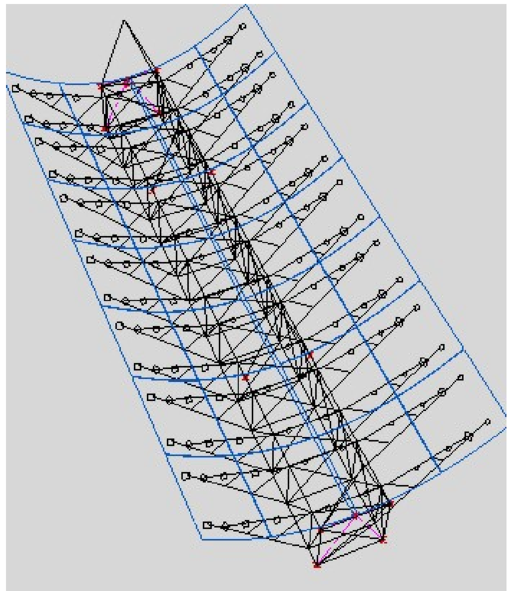
EuroTrough support structure



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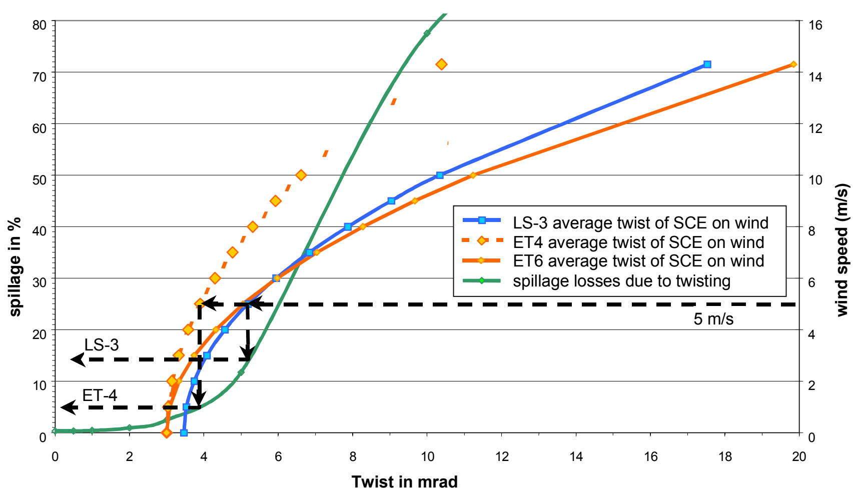
Optical Performance under Wind Loads



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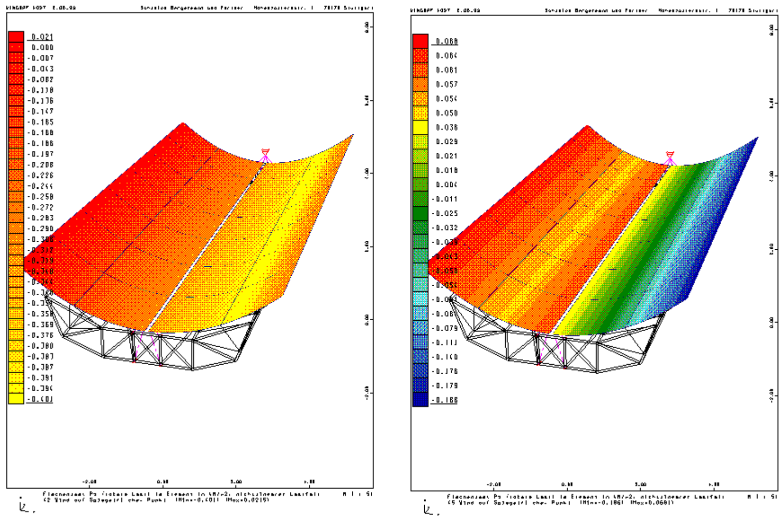
Wind-tunnel results: cp-values



pressures in kN/m² for max. bending (left), max torsion (right)

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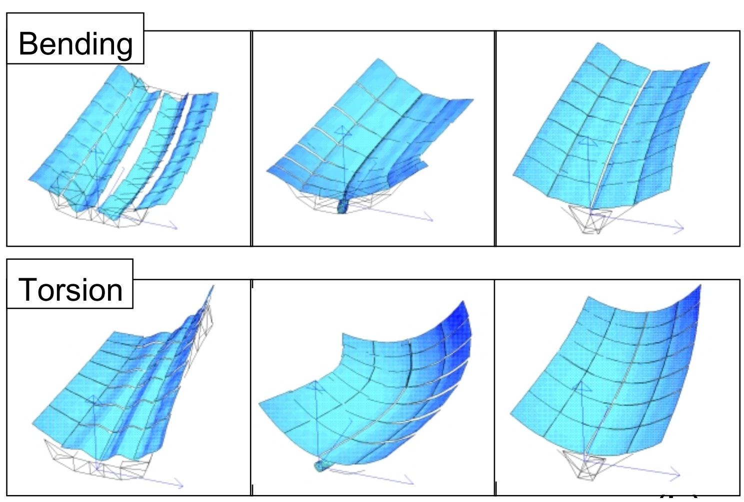
Wind tunnel testing + finite elements structural analyses



EuroTrough Characteristics

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Layout	parabolic trough collector
support structure	steel frame work, pre-galvanized, three variants; light weight, low torsion
collector length	12 m per element; 100 - 150 m collector length
drive	hydraulic drive
max. wind speed	operation: 14 m/s, stow: 40 m/s
Tracking control	clock + sun sensor, <2 mrad
parabola	$y = x^2/4f$ with f = 1.71 m
aperture width	5.8 m
Reflector	4 glass facets
optical efficiency	0.80 (design)
absorber tube	evacuated glass envelope, UVAC® or other, application dependent
Fluid	oil, steam, application dependent
cost	< 200 Euro/m^2

so what is new?

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The EuroTrough Prototype

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EuroTrough Project Start

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in the nineties:

- a vision
- a group of visionaries

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ENGINEERING SERVICES AND CONSULTANCY
Schlaich Bergermann und Partner
DLR
Deutsches Zentrum für Luft- und Raumfahrt e.V.
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
FLABEG
CRES
Miner
The European Commission
bmb+f

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EuroTrough project results

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- various design studies
- many design details addressed
- collector drawings available
- prototype collector started up
- cost estimations for series production
- performance models
- market analyses
- design review and continuation
- world-wide exploitation opportunities
- project consortium established

EuroTrough results cost reduction aspects

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- following cost reduction potentials have been identified:
  - cost reduction by improvement of the optical performance of the collector
    - rigid support structure --> frame work torque box
    - manufacturing
    - assembly accuracy
  - cost reduction by simplification of the design
    - less different profiles, parts
    - better transportation
    - assembly concept
  - cost reduction by weight reduction of the structure
    - frame work structure, closed profiles
    - finite element method for structural design calculations
    - wind analyses for proper definition of the load cases
  - Further cost reduction achieved in additional steps towards inclination of the collector and extension of collector length per drive unit (EuroTrough II).

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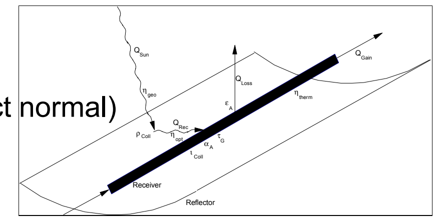
EuroTrough performance

<u>thermal testing at PSA</u>

- with oil loop up to 390°C
- in east-west orientation
  (normal incident radiation once a day)
- influence of
  - fluid temperature
  - solar radiation (direct normal)
  - incidence angle



- photogrammetry
- mechanical analyses

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Summary

- European solar parabolic trough collector
- known geometry
- wind loads analysed
- improved support structure
- cost reduction achieved
- prototype testing at Plataforma Solar

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The DISS project: Direct Steam Generation in parabolic troughs

Operation and Maintenance experience. Update on project status

Eduardo Zarza

Klaus Hennecke

The DISS (DIrect Solar Steam) Project

➢ ***PROJECT OBJECTIVES:***

DISS is a complete R+D program aimed at developing a new generation of Solar Thermal Power Plants with improved parabolic trough collectors and Direct Steam Generation (DSG) in the solar field, thus reducing costs while increasing the efficiency. There are two main items in DISS:

- *Development of improved components for parabolic trough collectors*
- *Development of the Direct Steam Generation (DSG) technology*

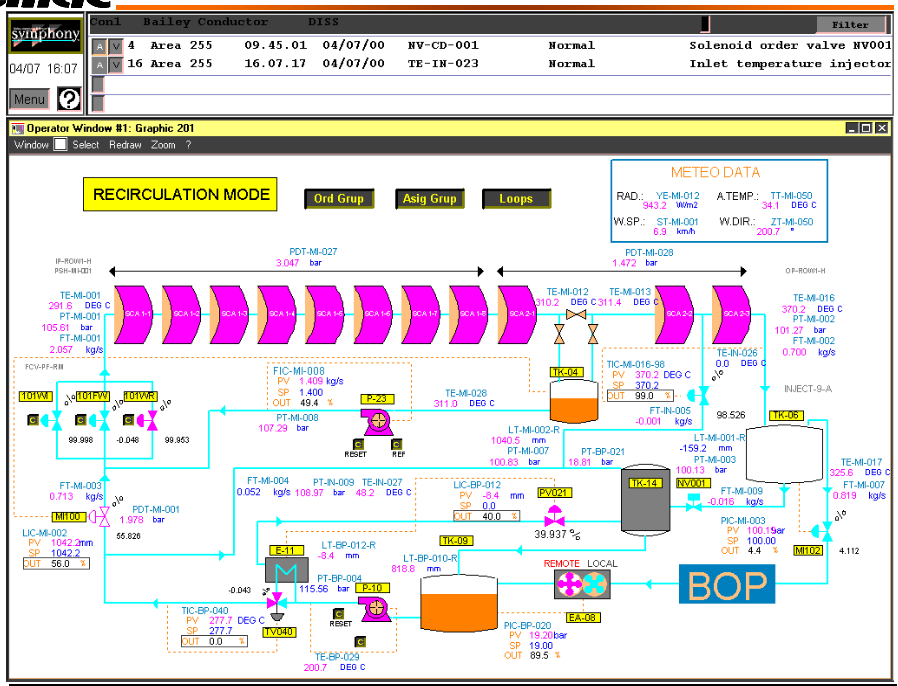
➢ ***PROJECT PHASES AND PARTNERS:***

- **DISS-phase I** (with E.U. financial support under JOULE contract JOR3-CT95-058)
  Duration: from January 1996 to November 1998
  Partners: CIEMAT, DLR, ENDESA, IBERDROLA, INABENSA, PILKINGTON, SIEMENS, U.E.F., ZSW
- **DISS-phase II** (with E.U. financial support under JOULE contract JOR3-CT98-277)
  Duration: from December 1998 to August 2001
  Partners: CIEMAT, DLR, ENDESA, IBERDROLA, INABENSA, INITEC, FLABEG, ZSW

The PSA DISS Test Facility

Technical Characteristics of the PSA DISS Test Facility

No. of parabolic-trough modules	40
Module aperture/length:	5.76 m /12 m
No. of solar collectors	11
Total row length:	550 m
Inclination of the tracking axis:	0º,2º,4º,6º,8º
Orientation:	North-South
Absorber pipe inner/outer diameter:	50/70 mm
Mass flow per row (once-through configuration)	1 kg/s
Max. recirculation rate:	4
Max. outlet steam temperat./pressure:	400ºC/100 bar



Main operation and maintenance problems

Temperature measurements at the absorber pipes

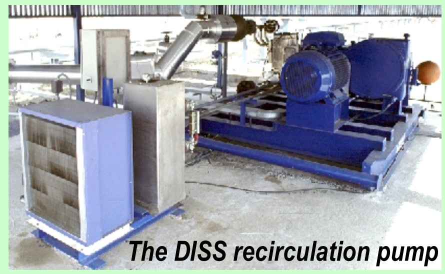
- Concentrated solar radiation onto the absorber pipes caused a measurement error. This problem was successfully solved in 2000

D.A.S. System

- Since the Elsag&Bailey Simphony DAS System implemented at the DISS facility was the first one in Spain, it required a long time for tunning and set up. Additionally, the rate of electronic circuit cards that have to be replaced every year is extremely high (≅5%)

Water Recirculation pump failure

- The DISS water recirculation pump is a positive-displacement pump provided with three plungers. A wrong design of the packing has caused frequent failures of the pump since June, 1999. The pump manufacturer (National Oil Well, USA) has not been able to solve the problem yet



The DISS recirculation pump

Operation and Maintenance experience

- The DISS solar field has a great thermal inertia due to the length of the piping (>2400m) and the amount of steel parts (>26 Tons), while the length of the absorber pipes is 480m only. This problem will not affect to a DSG commercial power plant
- The open-loop sun-tracking system implemented at the DISS collectors shows a small seasonal error in summer time (<4 mrad). Investigation of this problem is still underway
- No O&M problem has been found with the 100bar/400ºC ball-joints installed at the solar field
- Efficient control pressure was implemented at the solar field to avoid vacuum condition due to steam condensation overnight
- Thermal insulation and piping lay-out were improved. The start-up time was thus reduced in more than 50%
- The number of data channels (600) and the short sampling period (<1sec.) demanded the optimisation of DAS and Control system parameters to avoid undue interruptions and communication failures in the internal data transfer network

The PSA DISS Test Facility

Main test results

➢ The pressure drop in the DISS solar field is 25-30% lower than predicted by simulation computer codes. Power required for pumping is therefore much smaller than in SEGS plants.

Steam pressure (bar)	Steam flow (kg/s)	Overall ΔP (bar, approx.)
30	0.55	4.8
60	0,55	3
100	0.55	1.2

➢ Temperature gradients at the horizontal absorber pipes of the solar collectors are rather similar to those predicted by simulation computer codes, and they are not dangerous

Measured ΔT in a cross section of the absorber pipe
(Heat flux onto the absorber: 38 kW/m^2, steam flow: 0.5 kg/s)

water pre-heating:	15ºC
Water evaporation:	25-30ºC
Steam superheating:	40ºC

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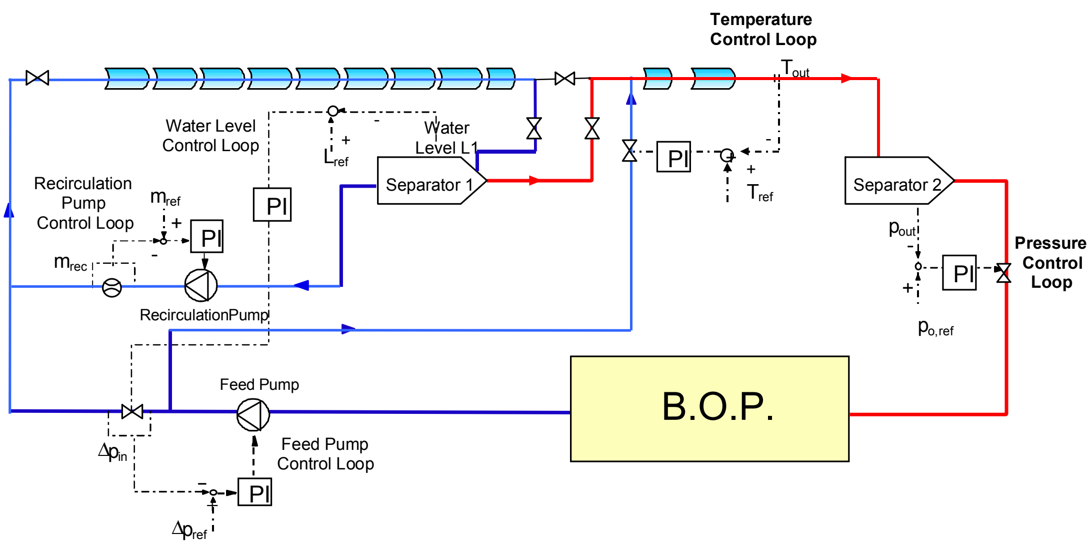
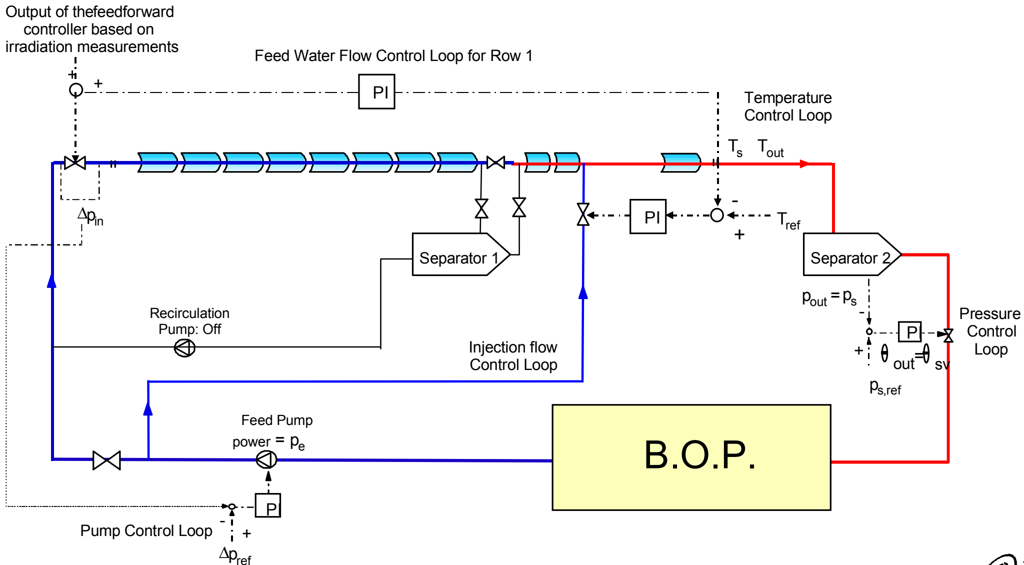
The PSA DISS Test Facility

Control Scheme for *Recirculation* process



The PSA DISS Test Facility

Control Scheme for *Once-through* process



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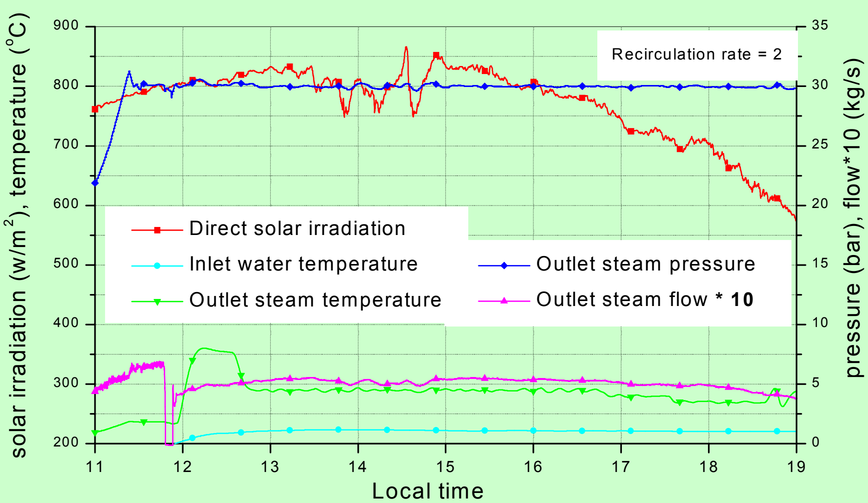
The PSA DISS Test Facility

Control test in *Recirculation* mode



Control test performed on June 22, 2000 (Recirculation mode)

Update of project Status

- The test facility has been operated for more than 2700 hours. 100bar, 60bar and 30 bar superheated steam was produced at 390ºC in Recirculation and Once-through modes
- The PSA DISS facility has proven its usefulness to evaluate the DSG process under real solar conditions and to identify the critical issues for the design of DSG commercial plants
- It has been proven that Direct Steam Generation is feasible in horizontal absorber pipes
- Technical problems and the long initial training to operate the facility delayed the fulfilment of the planned DSG tests campaign. Nevertheless, main problems were not related to the DSG process itself, but to standard equipment (i.e., recirculation pump, electronic cards,)
- Recirculation process with low recirculation rate is a promissing candidate for a commercial DSDG plant. Nevertheless, completion of the tests in Injection mode and the implementation of a multi-row DSG facility is essential to draw final conclusions
- Testing of optimised water/steam separators, design of a pre-commercial DSG power plant and production of superheated steam at 500ºC will be the main objectives of next phase

U.S. DOE CSP Program
Parabolic Trough Technology R&D
Industry & SunLab Activities

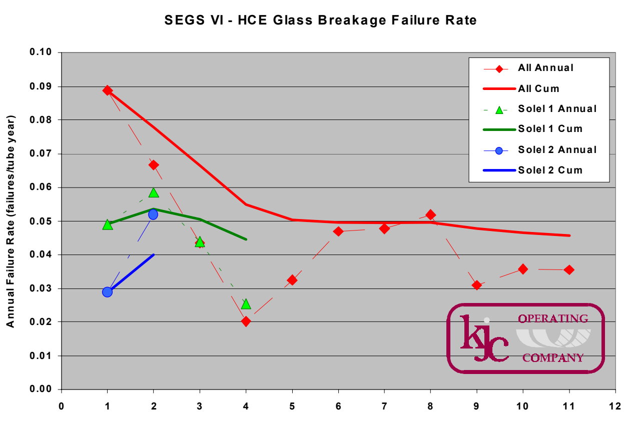
Dr. Thomas Mancini

for

Hank Price

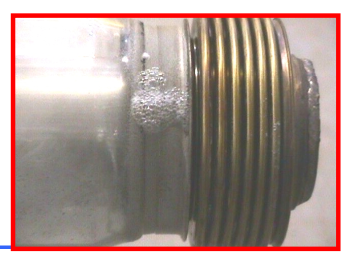
MWE USA Trough Phase I Work
Trough Receiver Reliability

Key Issues:
- Failure of the glass to metal seal
- Durability of selective coating in air



Coating failure

Glass to metal seal failure



KJC Operating Company & Solel

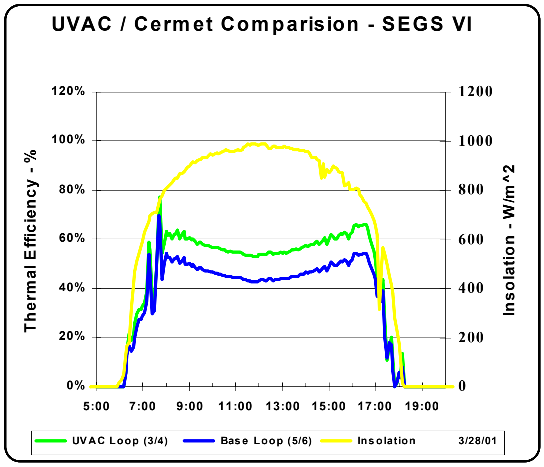
HCE Reliability Test

KJC Operating Company Test

- Test a loop of Solel UVAC HCEs on LS-2 Collectors at SEGS VI
- Compare performance and failure rates to existing HCEs

Solel UVAC HCE Specifications

- Cermet stable in air
- Improved glass to Metal Seal
- Absorptance 97% vs. 95.5%
- Transmittance 97% vs. 96%
- Emisivity 0.07 vs. 0.18 @ 400C



Initial Performance Data Shows ~ 20% Increased Performance

Duke Solar USA Trough Phase I Work

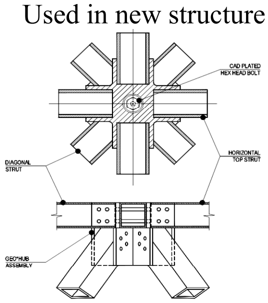
Advanced Concentrator Development

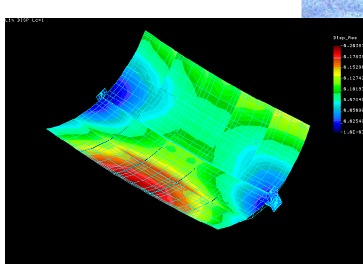
Phase I Work

- New concentrator structure
- Secondary Receiver
- Optimized Primary
- Stationary Receiver Trough

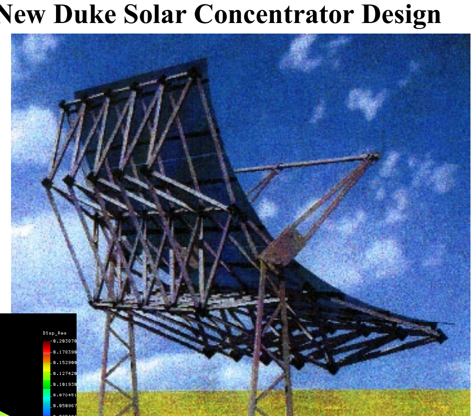
Starnet GeoHubs

Used in new structure





New Duke Solar Concentrator Design

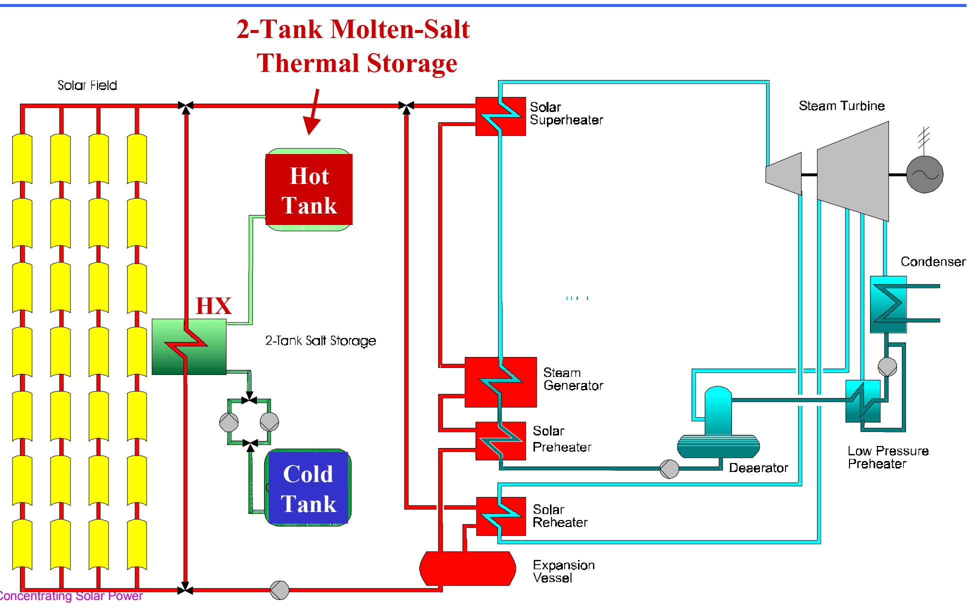


Estimated Installed Structure Cost

- LS-3 $47/m2

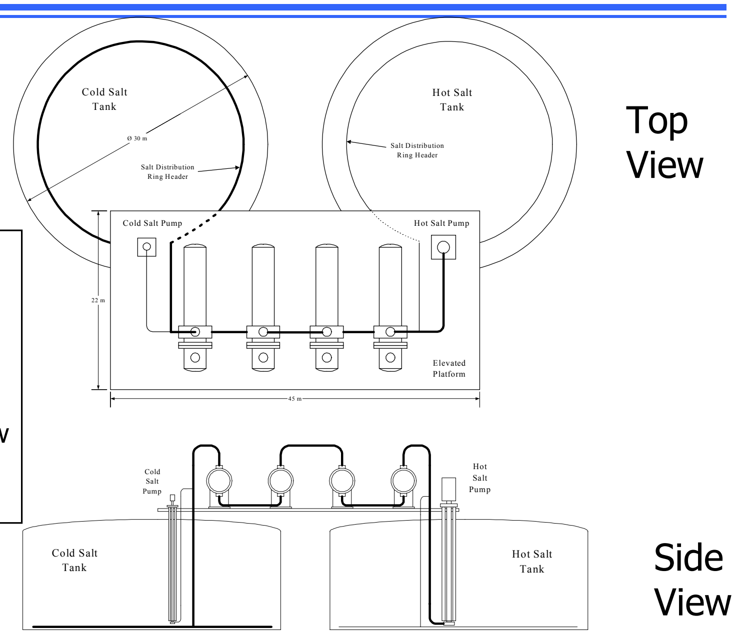
- Duke $49/m2

Thermal Storage
for Parabolic Trough Power Plants



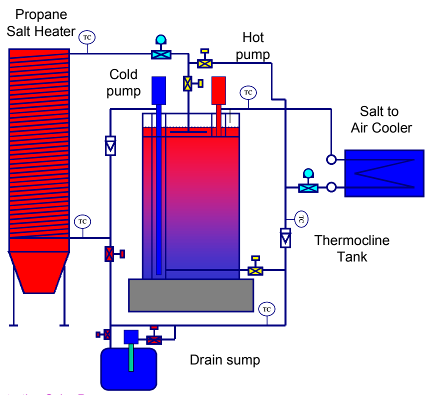
Nexant Thermal Storage Design
2-Tank Indirect Storage

Nexant Study
- -80 MWe SEGS
- -2 hrs storage
- -470 MWht
- -15,600 M tons salt
- -Tanks 12.2m h, 30m w
- -4 HXs (30,000m^2)
- **-$40/kWht**



Sandia Molten-Salt Thermocline Storage Test for Parabolic Troughs

Molten-Salt Thermal
- Isothermal test of filler material
- Thermal cycling tests of filler materials
- Engineering-scale thermocline test



Test Results:
The thermocline system has the potential to reduce the cost of thermal storage by ~ 35%

Univ. of Alabama & SunLab

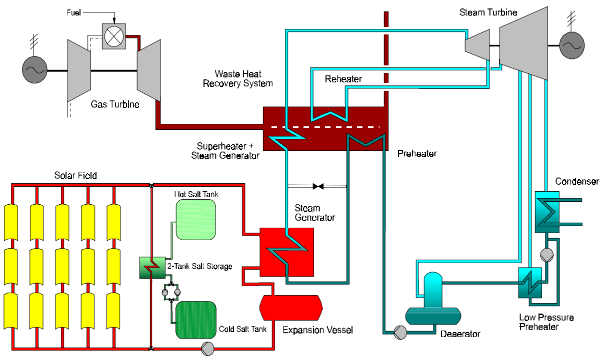
Developing a new class of HTF: Ionic Liquids

Typical Properties of Ionic Liquids (Organic Salts)
- Low melting-point solvents
- High ionic concentration
- Wide temperature range for liquid
- Non-volatile and non-toxic solvents

Ionic liquid	Melting point,°C	Decomposition point, °C	Viscosity at 25°C, mPa s	Density at 25°C, kg/m^3
[C_{10}mim][PF_6]	34	390	--	--
[C_8mim][PF_6]	-75	416	--	1400
[C_4mim][PF_6]	4	390	312	1370
[C_{10}mim][BF_4]	-77.5	--	--	--
[C_4mim][BF_4]	-75	407	219	1119
[C_4mim][$CF_3(SO_2)_2N^-$]	-89	402	54.2	1429

Nexant/Flabeg USA Trough Phase I Work

ISCCS Optimization Study



Low Impact ISCCS

- 2.5% Solar Contribution
- 38% Solar to Electric Efficiency

High Impact ISCCS

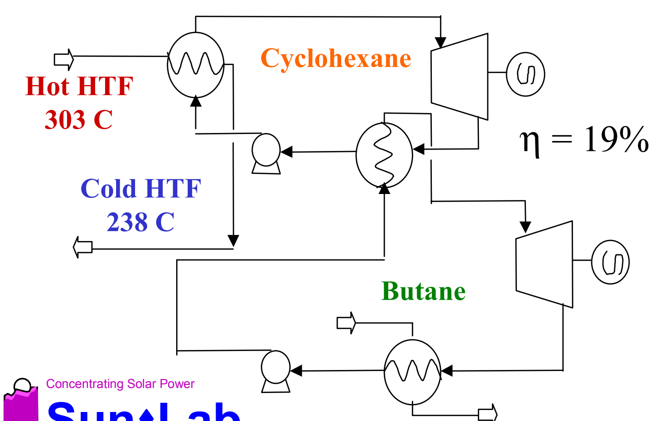
- 12.9% Solar Contribution
- 29% Solar to Electric Efficiency

Reflective Energies USA Trough Phase I Work

Solar Trough Organic Rankine Electric System

STORES
- 10 MWe Cascade ORC
- Air Cooled
- Uses Caloria HTF for Thermal Storage
- ORC Optimized for Trough Temperatures

Reflective Energies

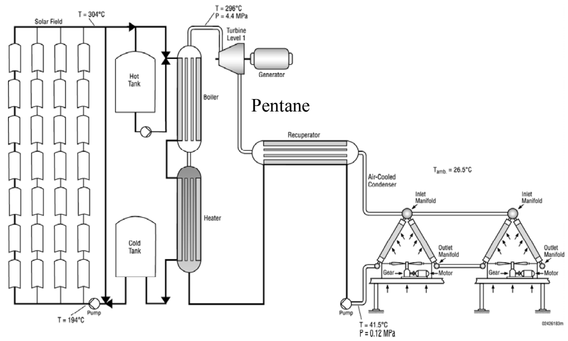


Results
Capital Cost $4500/kWe
LEC 22-31 ¢/kWh

SunLab Trough ORC Analysis

2nd Plant Economics

- **Power Cycle:**
  - 1 MWe organic Rankine cycle
  - recuperated
  - air cooled
  - 22.5% efficiency
  - \$1700/kW$_e$ (Barber Nichols)
- **Solar Field:**
  - 20,000 m^2 parabolic trough
  - 193-304C operating temperature
  - non-evacuated Cermet receiver
  - \$200/m^2
- **Thermal Storage:**
  - 2-Tank Caloria HT-43
  - 9 hours of thermal storage
  - \$10/kWht
- **Annual Performance:**
  - capacity factor @ 1 MWe: 53%
  - solar to electric efficiency: 8.4%



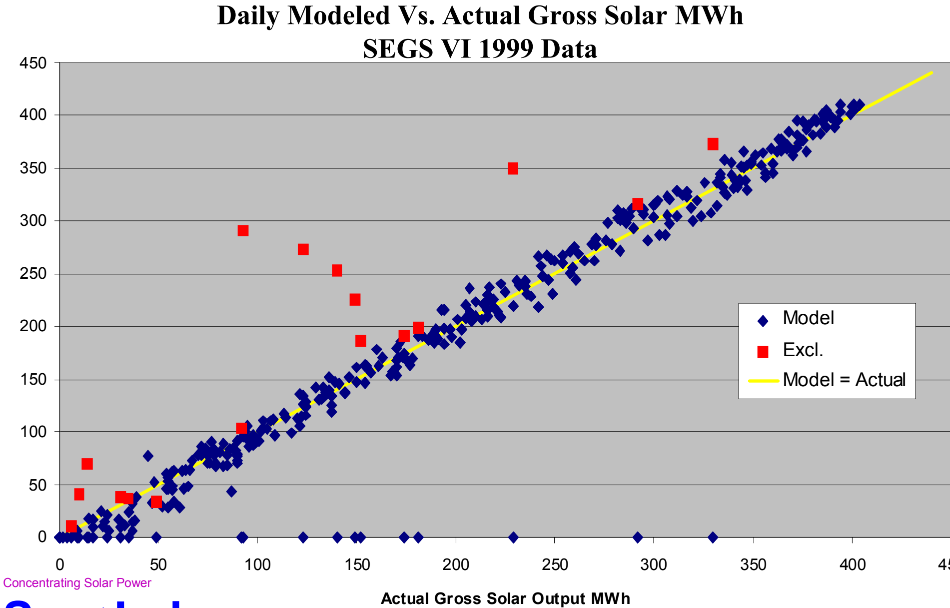
- **Economic Assumptions:**
  - 20 year lifetime
  - 10% discount rate
  - Insurance: 0.5% of capital cost
  - O&M cost: 2.5¢/kWh
- **Levelized Energy Cost: 21¢/kWh**

USA Trough Phase II
Industry Trough R&D in 2001

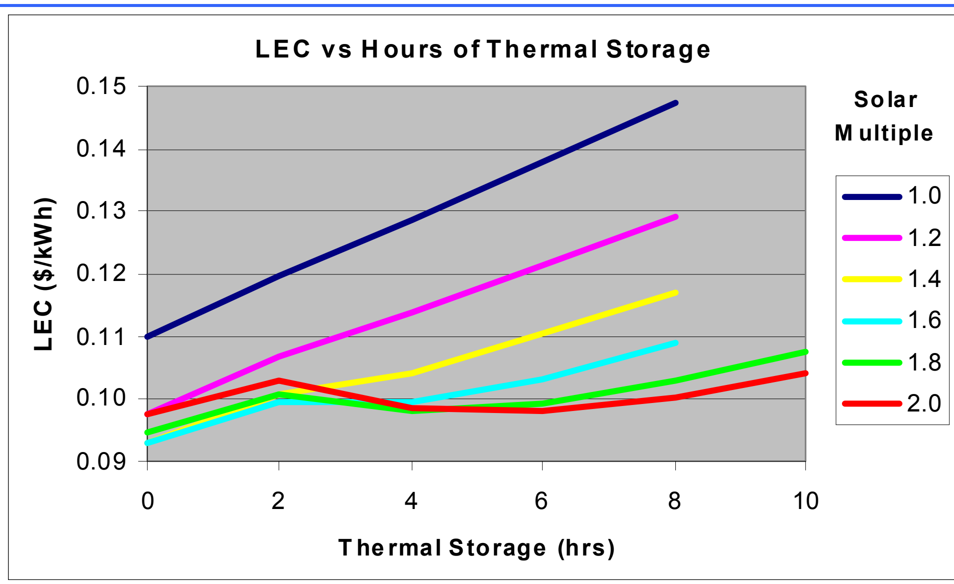
- Industrial Solar Technology
  - Concentrator Development
- SUNY Albany
  - Satellite DNI Mapping
- Augustyn & Company
  - Improved Low-Cost DNI Measurement System
- Kearney & Associates
  - Assessment of Molten-salt HTF for trough plants
- Reflective Energies
  - ORC Trough Plant Detailed Design (Follow-on)
- Duke Solar
  - Trough collector Development (follow-on)
  - Small ORC System Assessment

SunLab Excelergy Model

Trough Performance Simulation Model



Excelergy Model Output
100 MWe Trough Plant

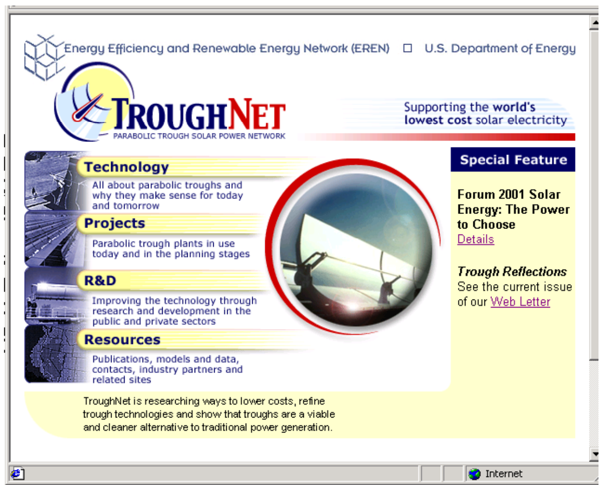


Current California Financial Environment

SunLab/DOE Parabolic Trough Activities

for more info…

Check out the TroughNet website for more info:
http://www.eren.doe.gov/troughnet/



FORUM 2001

Solar Power Tower Design Innovations To Improve Reliability & Performance, While Reducing Technical Risk & Cost

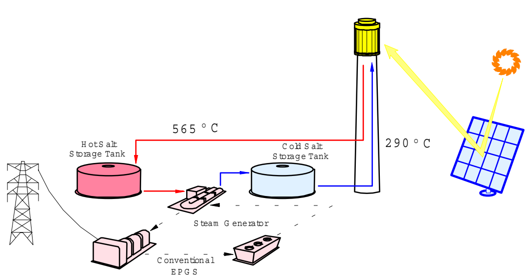
Alexis B. Zavoico
Bechtel National Inc.

William R. Gould
Nexant Inc.

Bruce D. Kelly
Nexant Inc.

Ignacio Grimaldi Pastoril
Ghersa

Solar Power Towers



Components:

- Heliostats
- Molten Salt Receiver
- Thermal Storage Tanks
- Steam Generator
- Conventional Turbine / Generator

Background

- 10 MWe Solar Two **demonstration plant** operated from April 1996 - April 1999
  - Dagget California (near Barstow)
  - Cost shared between Government and Industry
- 15 MWe Solar Tres **commercial plant** under development
  - Near Cordoba Spain
  - 3 x scale up from Solar Two
  - Financed by power premium rate, tax credits, and grants
  - 30 year design life

Background (continued)

- SIII benefits from SII
- Design Basis Document is project design criteria and is based upon:
  - Lessons Learned
  - Application of new technology
  - Sandia National Laboratory Test Programs
- Concept Design Baseline incorporates:
  - New qualified equipment and components
  - State-of-the-art technology

Solar Two (SII) vs. Solar Tres(SIII)

	SII	SIII
Plant Rating	10 MWe	15 MWe
Capacity Factor	22-25%	60-65%
Storage	3 hours	16 hours
Plant Efficiency	6% Improvement in Overall Efficiency	
Receiver Efficiency	3% Improvement Thermal Efficiency	

Solar Two (SII) vs. Solar Tres(SIII)

	SII	SIII
Heliostats	1818- 39.1 m^2 108 - 95.2 m^2	2740 -96.3 m^2
Receiver Tube Metallurgy	316 H SS	High Nickel Alloy
Max. Incident Solar Flux on Receiver	850 kW/m^2	1.5 MW/m^2
RS & SGS Pump shafts lengths	3 - 4 m	14 -15 m

SIII Innovations

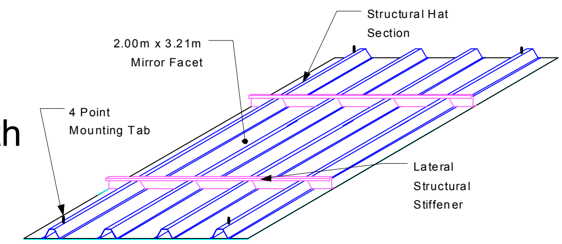
- Receiver Tube Metallurgy
- Heliostat Design
- Plant Physical Arrangement
- Simplification of Plant Molten Salt Systems
- Improved Instrumentation

Receiver Tube Metallurgy

- High nickel alloy tube metallurgy
- Accommodates higher incident solar flux
- Eliminates chloride stress corrosion problem
- Smaller receiver and simplified design
- Improved thermal efficiency

Heliostat Design

- Off-the-shelf components
- Simplified design
  - 4 point support
  - Planetary gear azimuth drive
  - Jack screw elevation drive
  - State-of-the-art controller technology
- 45% reduction in cost



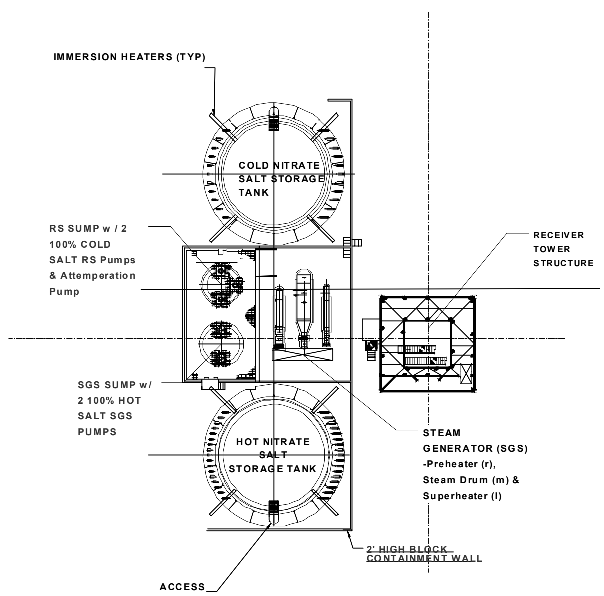
Plant System Simplification

- Hot and cold pump sumps eliminated
- New long-shafted submerged bearing molten salt pumps - 13 m
- All systems are passive self-draining back to tanks
- Over 50% reduction in the number of valves & control valves

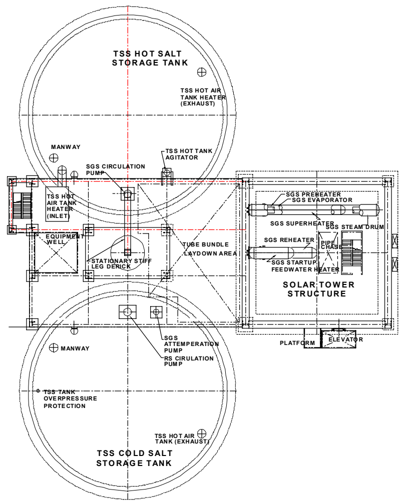
Plant System Simplification (Continued)

- Elimination of complex piping manifolds, drains and vents
- Reduction in electric heat tracing
- Elimination of RS inlet vessel high pressure air receiver and compressor system

SII Plan - Salt Systems



SIII Plan - Salt Systems



Improved Instrumentation

- Off-the-shelf & compatible with molten nitrate salt service:
  - Pressure - Transducers using NaK filled capillaries and diaphragms are now available for services up to 538 °C
  - Level (Tank and Vessel) - Radar based instruments suitable for service up to 400°C and 100 bar (1000°C with active cooling system)
- Improved reliability and reduced risk

Conclusion

- Using SII experience & lessons learned SIII has:
  - Improved reliability and availability through design innovation
  - Lowered technical risk using proven commercial technology
  - Substantially lowered overall system cost

SOLAR TRES

QUESTIONS