

Parabolic Trough Technology Overview

Hank Price

NREL



Overview

- Technology Overview
- Historical Cost and Performance
- Cost Reduction Potential
- Relevance to Algeria



KRAMER JUNCTION SOLAR ELECTRIC GENERATING SYSTEM (SEGS) FACILITY III - VII

Five 30+ MW Hybrid Power Plants

- **SEGS III-V: Dual Inlet Rankine Steam Cycle**
- **SEGS VI-VII: Single Inlet Reheat Rankine Steam Cycle**

Annual Energy Input Entering Steam Turbine

- **75% Solar Energy**
- **25% Natural Gas Boilers**

Typical 30+ MW SEGS (VI) Characteristics

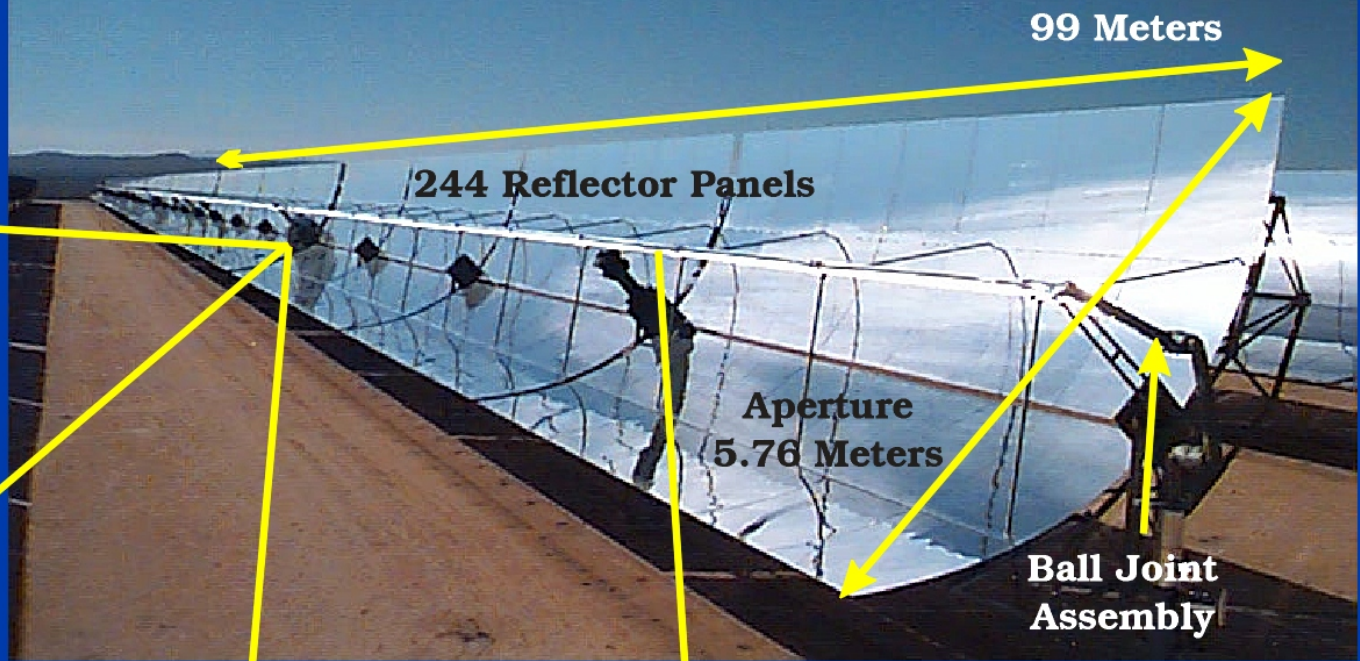
- **800 LS2 Solar Collector Assemblies (SCA)**
- **188,000 m² of Reflective Aperture Area**
- **96,000 Reflector Panels (RP)**
- **9,000 Heat Collection Elements (HCE)**



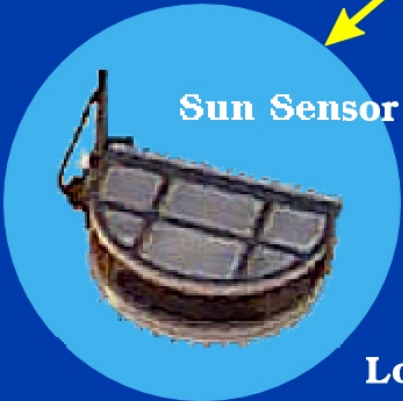
Rankine Steam Cycle Power Plant



Solar Collector Assembly LS-3 (545 M²)



Drive System



Sun Sensor



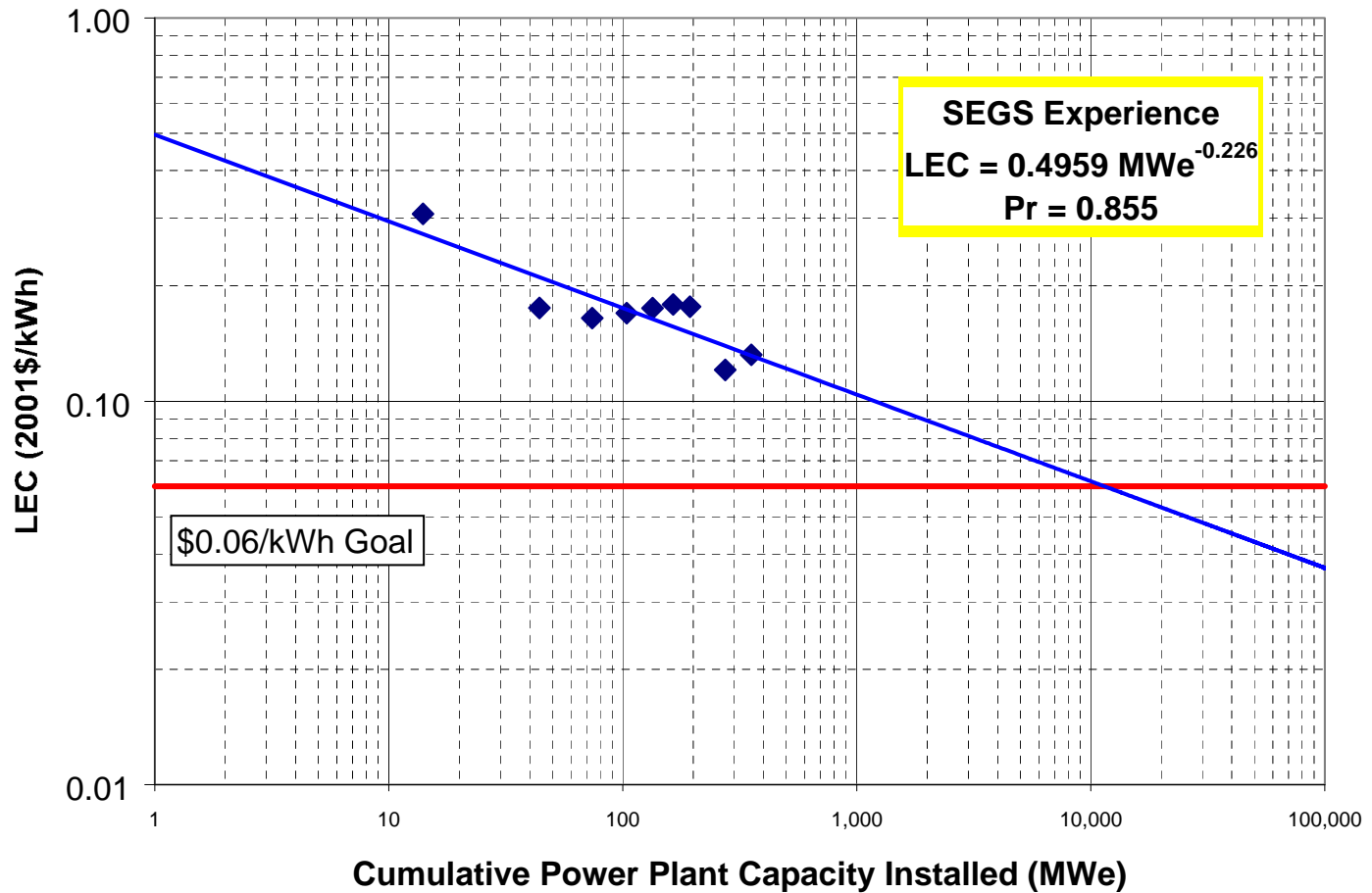
Local
Controller



24 Heat Collection Elements

Historical Cost

Based on Luz Projections



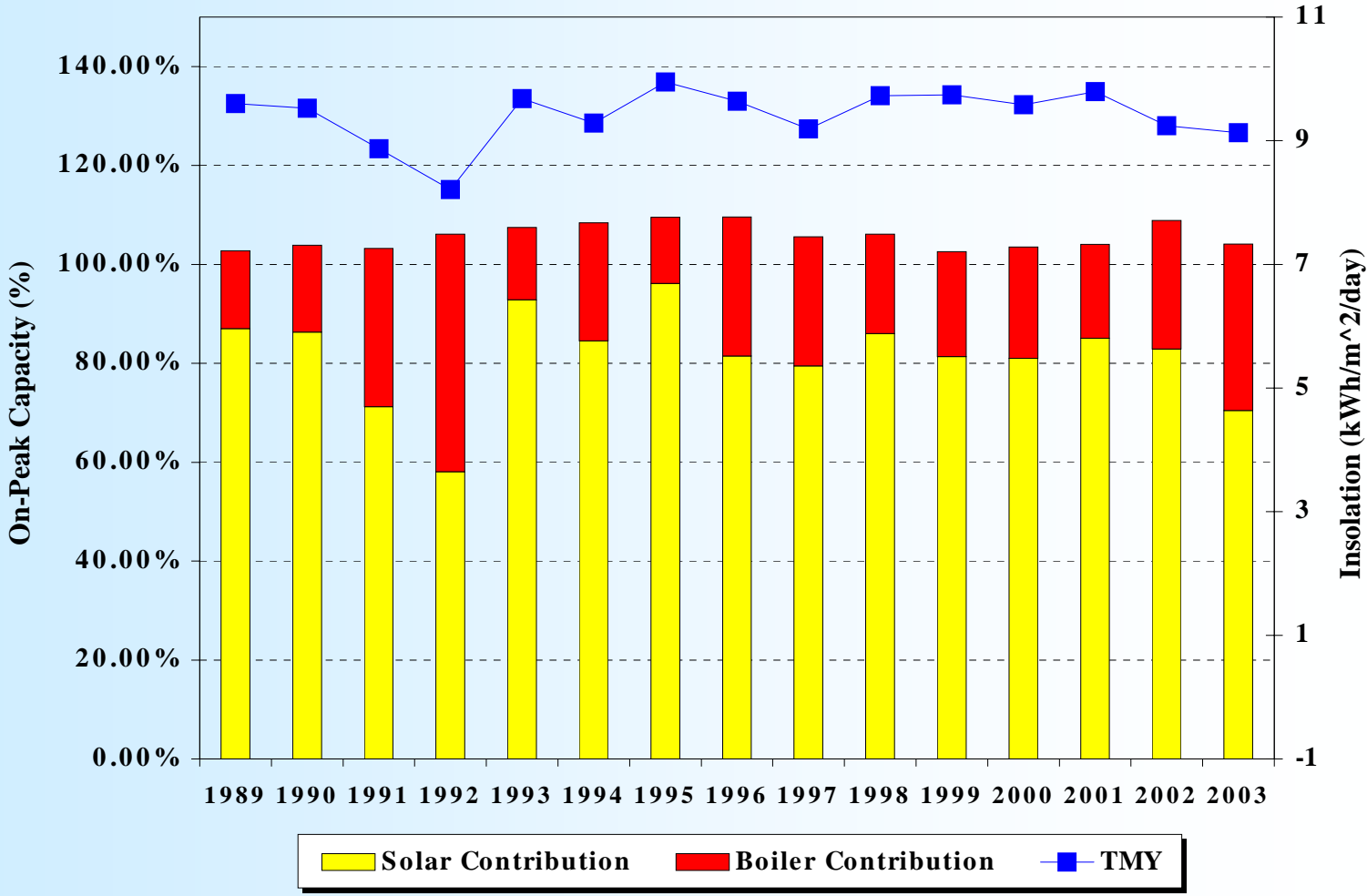
Source: Luz International Limited, 1990

Historical Operating Experience

- SEGS Track Record
 - Performance well established
 - Good operational experience
 - Low perceived technical risk (financial community)
- Technology Advances
 - Advanced receiver technologies
 - Next generation of trough concentrators
 - Thermal energy storage (TES)
- Additional Cost Reduction Opportunities



SUMMER ON-PEAK PRODUCTION CAPACITY





HISTORIC SEGS PRODUCTION

Gross Solar Production - MWh

	Daggett Facility		Kramer Facility					Harper Facility		TOTAL
	SEGS I	SEGS II	SEGS III	SEGS IV	SEGS V	SEGS VI	SEGS VII	SEGS VIII	SEGS IX	
1985	<i>19261</i>									19261
1986	22510	<i>25085</i>								47595
1987	25055	23431	49444	52181						150111
1988	16927	38914	61475	64762	62858					244937
1989	23527	43862	63096	70552	65280	48045	38868			353230
1990	21491	39156	69410	74661	72449	62690	57661	114996	5974	518487
1991	20252	35168	60134	64600	59009	64155	58373	102464	144805	608960
1992	<i>17938</i>	<i>32481</i>	48702	51007	55383	47087	46940	109361	129558	538458
1993	<i>20368</i>	<i>36882</i>	58248	58935	67685	55724	54110	130999	130847	613798
1994	<i>20194</i>	<i>36566</i>	56892	57795	66255	56908	53251	134578	137915	620354
1995	<i>19800</i>	<i>35853</i>	56663	54929	63757	63650	61220	133843	138959	628674
1996	<i>19879</i>	<i>35995</i>	64170	61970	71439	71409	70138	139174	141916	676091
1997	<i>19228</i>	<i>34817</i>	64677	64503	75936	70019	69186	136410	139697	674473
1998	<i>18686</i>	<i>33836</i>	70598	71635	75229	67358	67651	137905	119732	662631
1999	<i>11250</i>	<i>33408</i>	70689	71142	70293	71066	66258	135233	107513	636851
2000	<i>17235</i>	<i>31207</i>	65994	63457	73810	68543	64195	140079	128315	652835
2001	<i>17947</i>	<i>32497</i>	69369	64842	71826	67339	64210	137754	132051	657834
2002	<i>17402</i>	<i>31511</i>	66125	70313	73235	64483	62926	138977	137570	662542
Total	331550	549159	995686	1017283	1024444	878476	834986	1691773	1594852	8967123

Note: Numbers shown for SEGS I and SEGS II in italics are estimates.

9 TWhrs



Current State-of-the-Art

50 MWe Trough Plant

- **Current State-of-the-Art (Plant built today)**

- 50 MWe (~100 bar, 700F, 37.5% gross)
- LS-2 Collectors (391 C)
- Receiver – Solel UVAC
- Solar only or hybrid
- Solar multiple 1.5
- No thermal storage
- DNI 8.0 kWh/m²-day

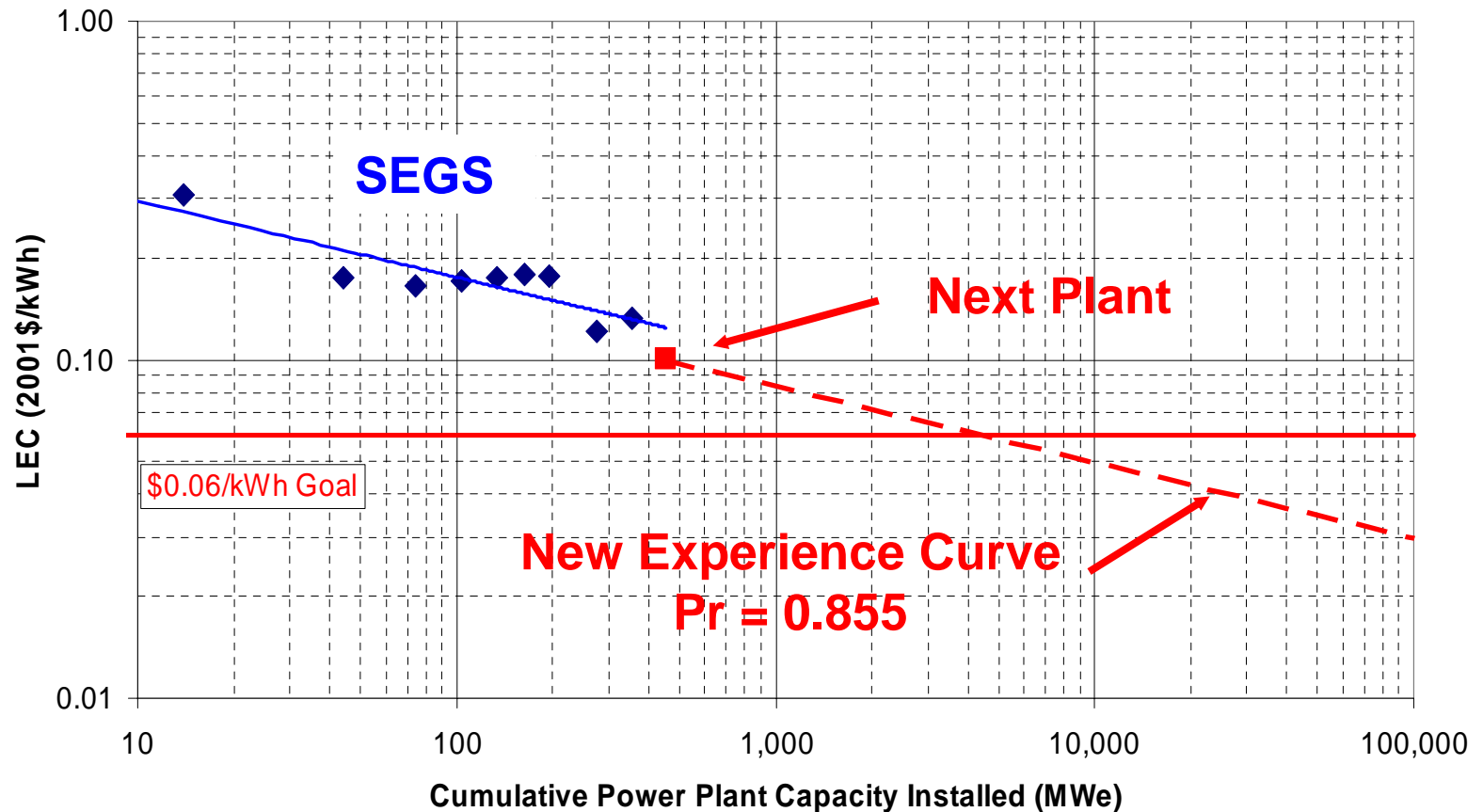
Enabling Technologies

- Improved Receiver
- Ball Joints
- O&M lessons from SEGS

Site: Kramer Junction	Solar Only	Hybrid (25%)
Plant size, net electric [MWe]	50	50
Collector Aperture Area [km ²]	0.312	0.312
Thermal Storage [hours]	0	0
Solar-to-electric Efficiency. [%]	13.9%	14.1%
Plant Capacity Factor [%]	29.2%	39.6%
Capital Cost [\$ /kWe]	2745	2939
O&M Cost [\$ /kWh]	0.024	0.018
Fuel Cost [\$ /kWh]	0.000	0.010
Levelized Cost of Energy [2002\$/kWh]	0.110	0.096

Current Cost
11¢/kWh

Future Trough Cost Reduction Potential



Cost Reduction Opportunities

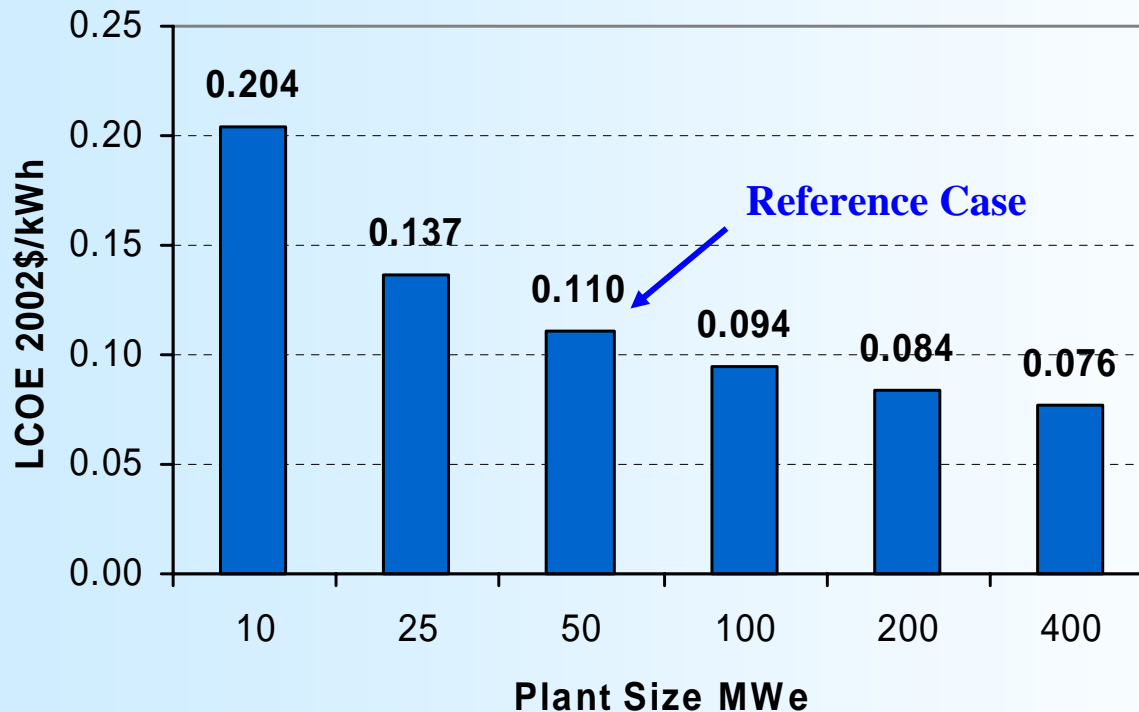
Parabolic Trough Technology

- **Plant Size**
- **Concentrator Design**
- **Improved Receiver Technology**
- **Thermal Energy Storage**
- **New Power Cycle Integration**
- O&M
- Design Optimization/Standardization
- Power Park
- Competition
- **Financial**

Plant Size

Impact on Cost of Energy

Near-Term Trough Plant



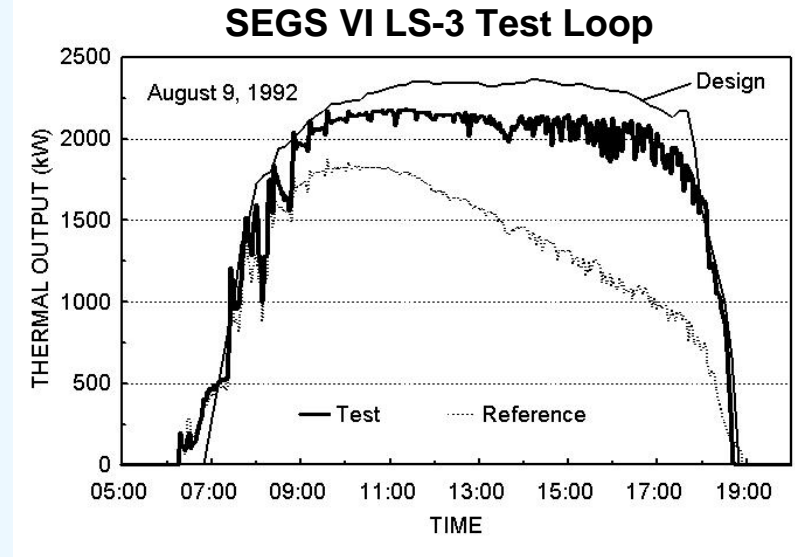
Enabling Technologies

- Ball Joints
- Salt HTF

Trough Concentrator

Cost Reduction Opportunities

- Luz LS-3 Baseline
- Reduce Costs
 - Competition
 - Optimized Structure
 - Increase Size
 - Reduced Shipping & Assembly Cost
- Improved Performance
 - Increased torsional stiffness
 - Improved Optical Accuracy & Alignment



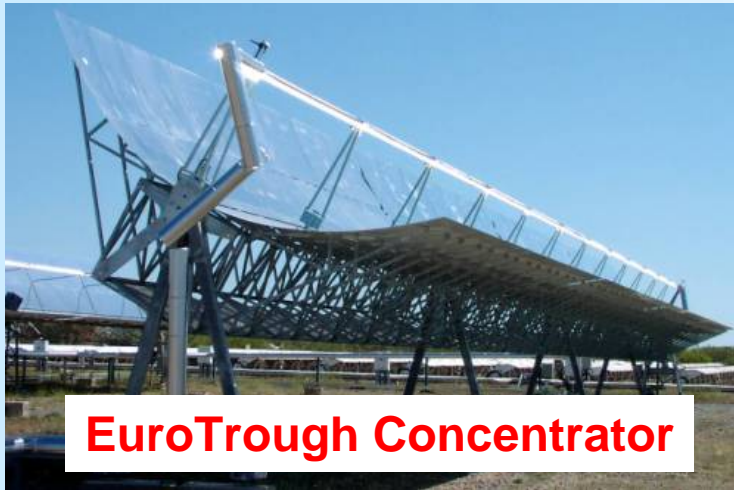
Trough Concentrator

Current Developments



Solel LS-3

- Three Suppliers of Next Generation Collectors



EuroTrough Concentrator



SolarGenix Concentrator

Trough Receiver Developments

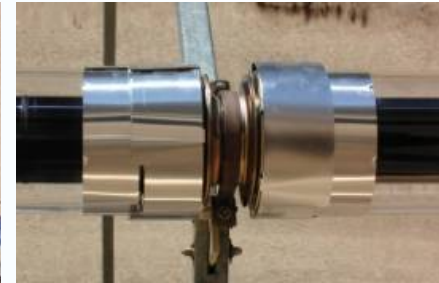
- Improved Reliability
 - Reduced Breakage (G/M Seal)
 - Durability in Air at Temperature
- Improved Performance
 - Thermo/Optic Properties
 - Higher Temperatures
- Reduced Cost
 - Selective Coating Process
 - Design Changes
 - Competition

New Bellows Shields

KJC Operating Company

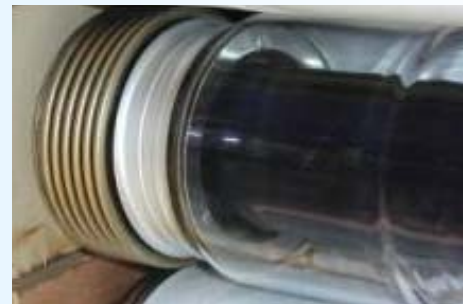


Solel Solar Systems



New Receiver Tubes

Solel UVAC Receiver



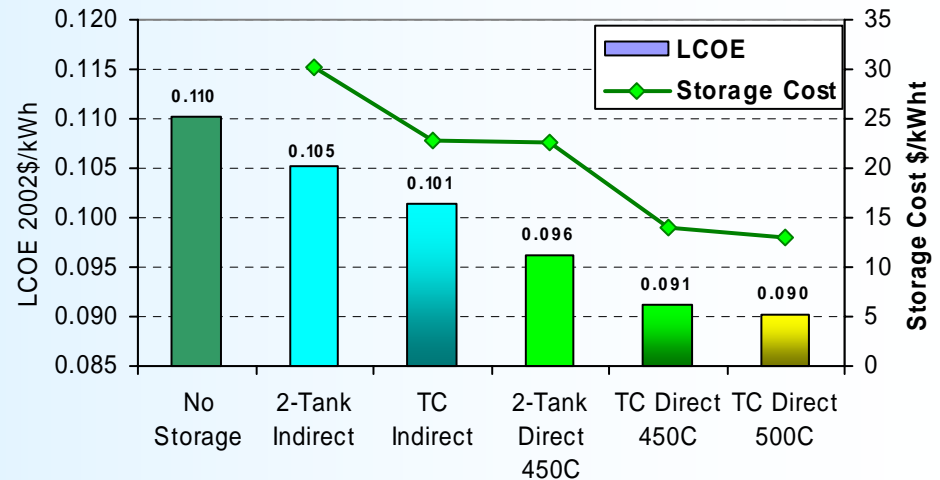
Schott Receiver



Thermal Storage Technology

- Provides dispatchability
- Lowers cost of energy
- Near-term options developed
- Advanced options being developed
 - Concrete
 - Molten-salt HTF
 - Organic-salt HTF
 - Thermocline storage tanks

Near-Term 50 MWe Trough Plant



New Power Cycle Integration

Integration with Combined Cycle Power Plant (ISCCS)

New Power Cycle Options

- ISCCS
- Direct steam generation
- Organic Rankine cycles
- Dry & hybrid wet/dry cooling

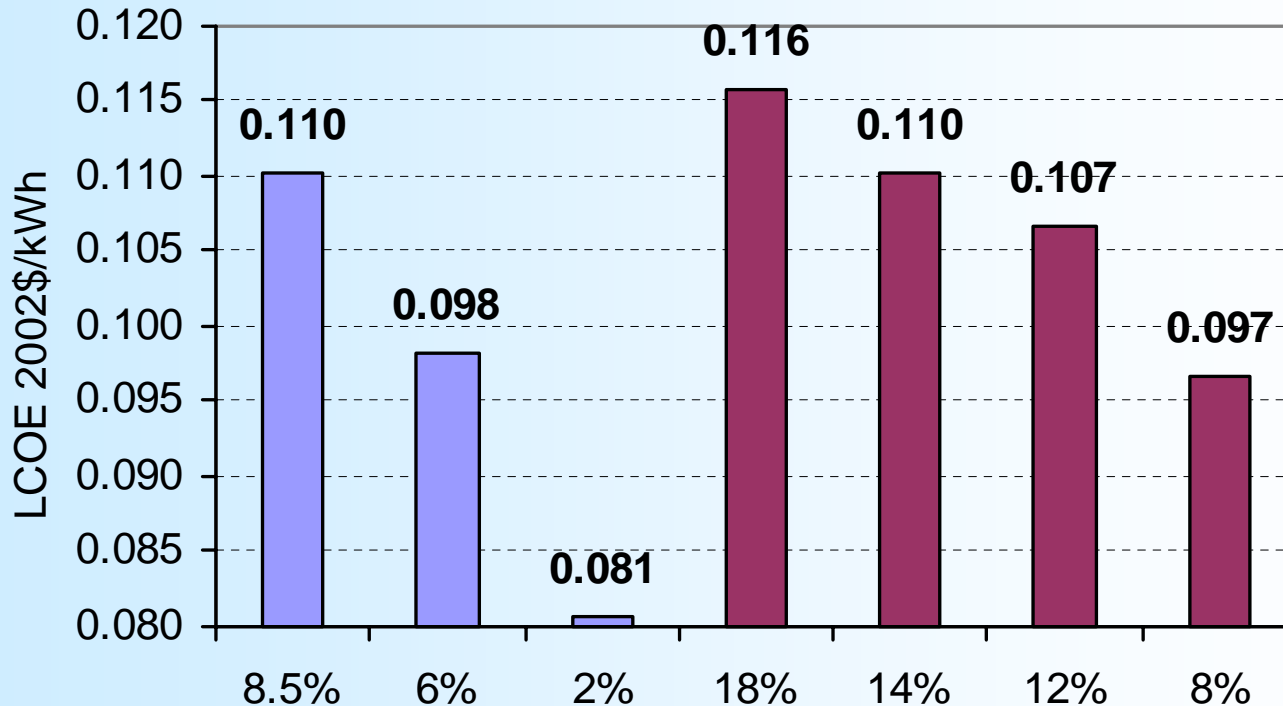
Integration with Combined Cycle Power Plant (ISCCS)

Site: Kramer Junction	Solar Rankine	ISCCS Solar Increment
Plant size, net electric (MWe)	50	40
Collector aperture area (km ²)	0.312	0.222
Thermal storage (hours)	0	0
Solar-to-electric efficiency (%)	13.9%	15.7%
Plant capacity factor (%)	29.2%	29.2%
Capital cost (\$/kWe)	2,745	1,988
O&M cost (\$/kWh)	0.024	0.008
Fuel cost (\$/kWh)	0.000	0.003 ¹
LCOE [(\$/kWh)]	0.110	0.073

Cost of Capital

Impact on Cost of Energy

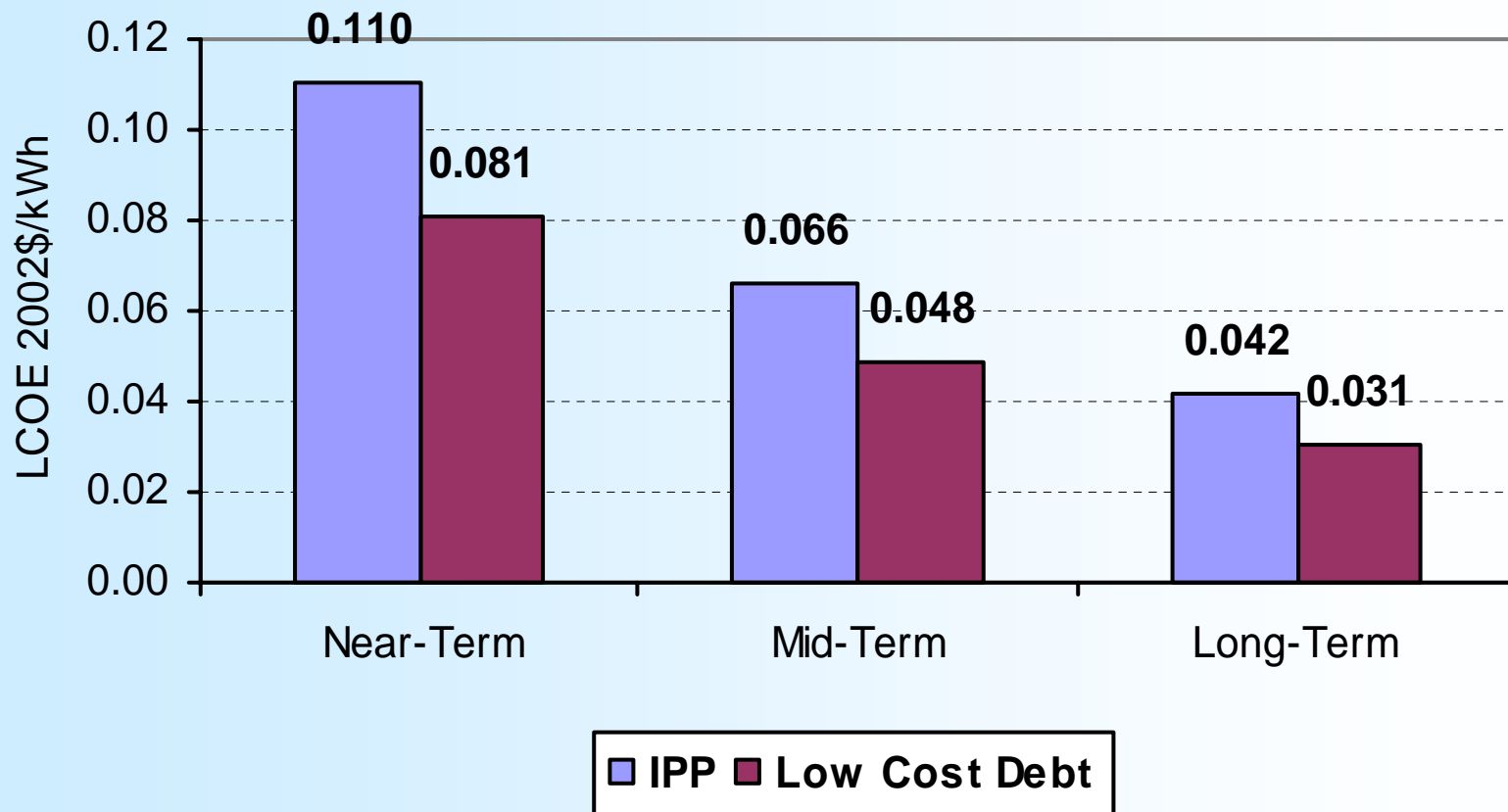
Near-Term 50 MWe Trough Plant



■ Debt rate, IRR=14% ■ IRR, debt 8.5%

Future Cost Reduction

Parabolic Trough Technology



Future Development Scenario

Parabolic Trough Technology

	SEGS VI 1989	Near- Term	Mid- Term	Long- Term
Plant Size: MWe	30	50	100	400
Solar Multiple	1.2	1.5	2.5	2.5
Collector	LS-2	LS-2	LS-3+	Adv
Receiver	Luz	UVAC2	Adv	Adv
HTF	VP-1 390 C	VP-1 390 C	Salt 450 C	Salt 500 C
TES	NA	NA	12 hrs TC Dir	12 hrs TC Dir
Capacity Factor	22%	30%	56%	56%
Solar to Electric η	10.6%	13.4%	16.2%	17.2%
Cost Reduction			5%	20%
Capital Cost \$/kWe	2954	2865	3416	2225
O&M Cost \$/kWh	0.0462	0.0233	0.0103	0.0057

Relevance to Algeria

Parabolic Trough Technology

- Technology
 - Extensive operating track record
 - Recent improvements in the technology
 - Thermal storage technologies under development
 - Future cost reduction potential
- Market
 - Growing interest in parabolic trough technology
 - Increased industrial supply
 - Industry gearing up for projects