Stirling Energy Systems, Inc.

Solar Power Now
The SES Stirling Solar Dish Technology
ABB Sharyland Dedication Seminar
October 11, 2007

Creating a
brighter future
for humanity through
SOLAR ENERGY

Solar Power Now – Its Coming

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- CSP or Concentrated Solar Power is gearing up and coming
- Deployment will be large-scale, central-station applications (250 to 1000 MW projects)
- 355 MW built in California in the late 80's and early 90's
- Recently a 65 MW project completed in Nevada
- Rooftop solar plays an important role, but is not the pathway to large-scale solar power generation
- Over 35 applications including large PV submitted to BLM for federal desert land in Southern California
- Stirling has two projects with Power Purchase Agreements for 900 MW with SDG&E and 850 MW with SCE
- Large Central Station CSP deployment is key to meaningful penetration of renewable solar production in the U.S.

Solar Power Now – Available Options

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- PV – Both Low Cost Panels and CSP, tracking and fixed
- Solar Parabolic Trough Technology
- Solar Power Tower or Central Receiver
- Stirling Solar Dish

Technological Comparison

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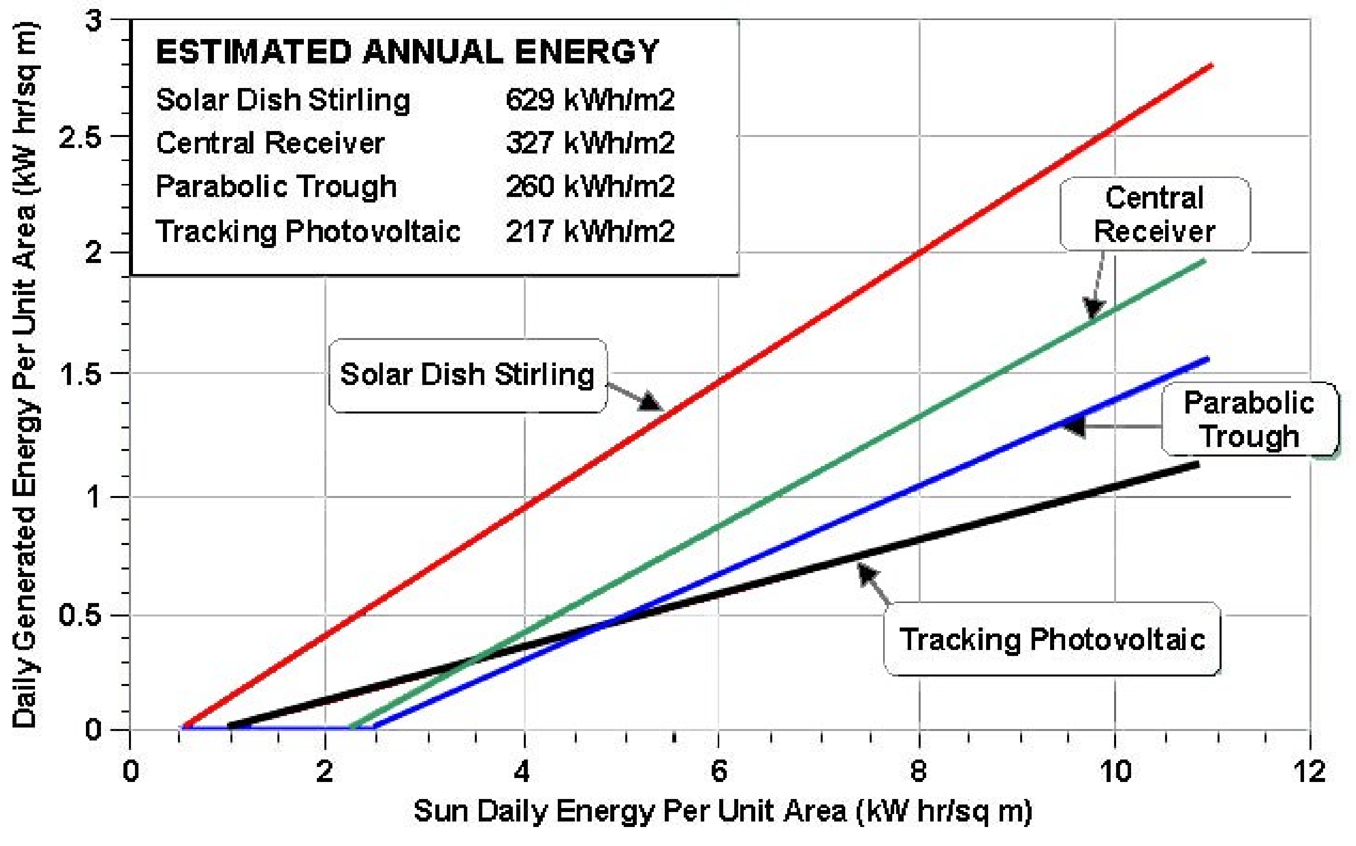
Stirling Solar Dish Efficiency vs. Other Solar



Source: Southern California Edison and Sandia National Laboratories

Efficiency is key to cost-competitiveness

The SES Stirling Solar Dish Technology

Details of the SES Solar Dish Assembly

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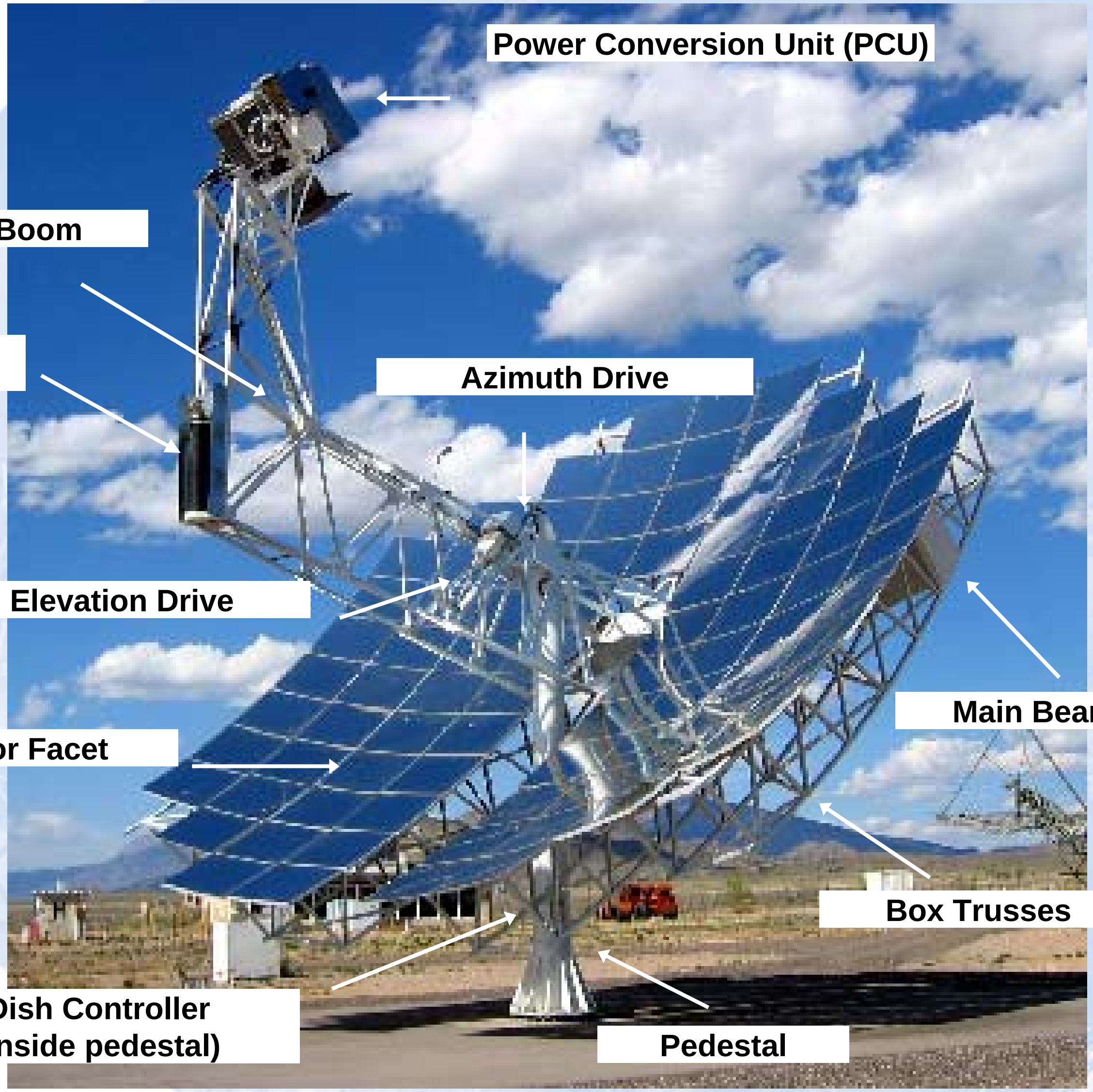
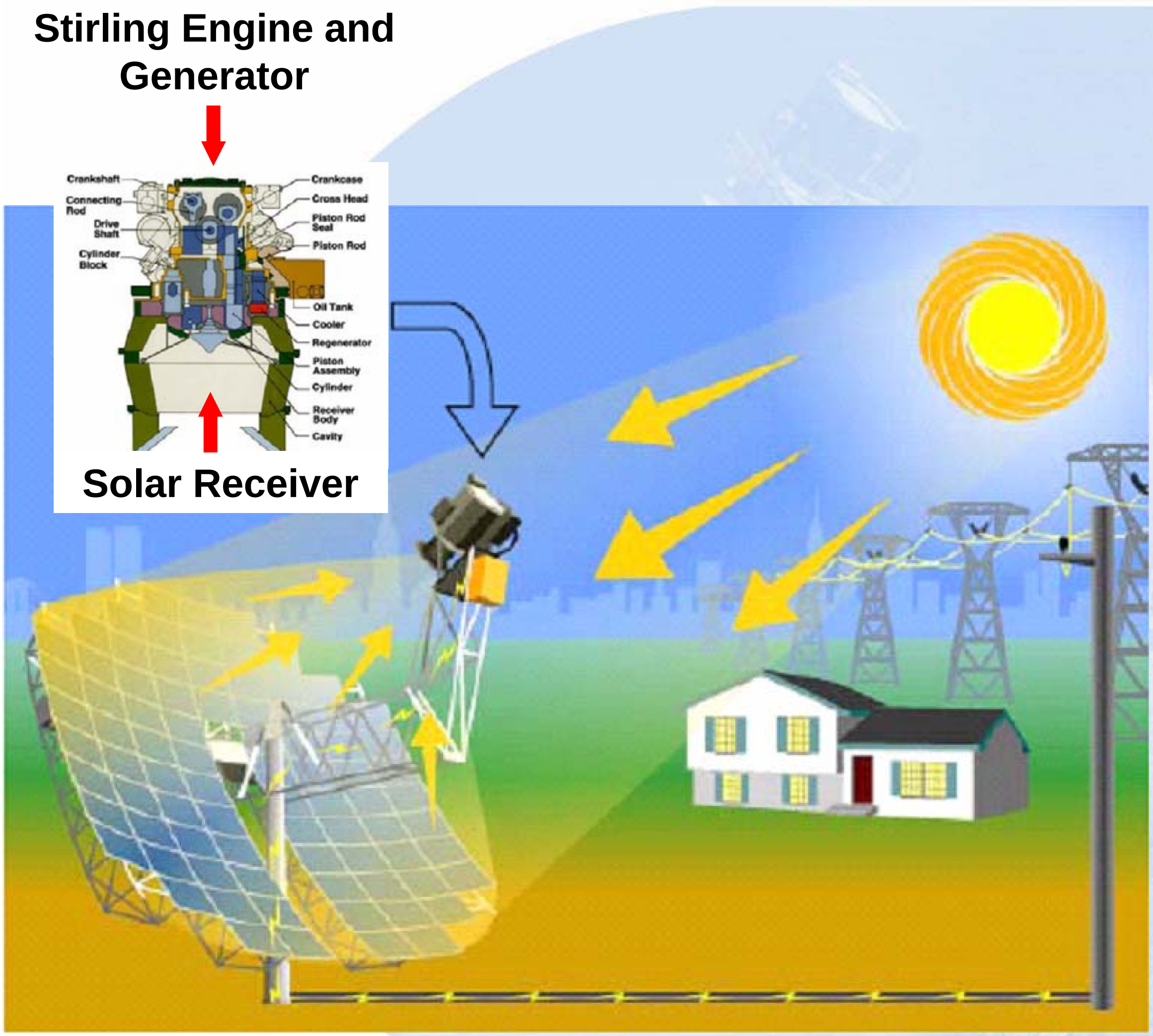


What is the Solar Powered Generating System?



- ✓ 25kW stand-alone solar-electric generating system
- ✓ Dish concentrator tracks and focuses the Sun's energy on to a Solar Receiver in the PCU heating hydrogen gas which in turn powers a Stirling engine
- ✓ Operation of the Stirling engine converts thermal energy to shaft power and drives an electric generator producing electricity
- ✓ The Stirling engine is a closed system that produces no combustion products
  and consumes no water and uses only solar energy to produce electricity

Holds the World's record as the most efficient technology for converting solar energy to grid quality electricity at 29.4%

SES Solar Dish Stirling Operation

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- ✓ Dish Concentrator Focuses Sun's Energy on Receiver
- ✓ Stirling Engine Converts Thermal Energy to Electrical Energy

Click image to advance animation

The SES Solar Dish Assembly On-Sun

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Time-Lapse of Actual Solar Dish Tracking

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Early Design Operating Solar Dishes

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SES Solar Technology Installed at the SES Model Power Plant in New Mexico

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The SES Power Generating System On-Sun at the Model Power Plant in New Mexico

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The SES Power Generating System On-Sun at the Model Power Plant in New Mexico

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The SES Power Generating System On-Sun at the Model Power Plant in New Mexico

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The SES Power Generating System at the Model Power Plant in New Mexico

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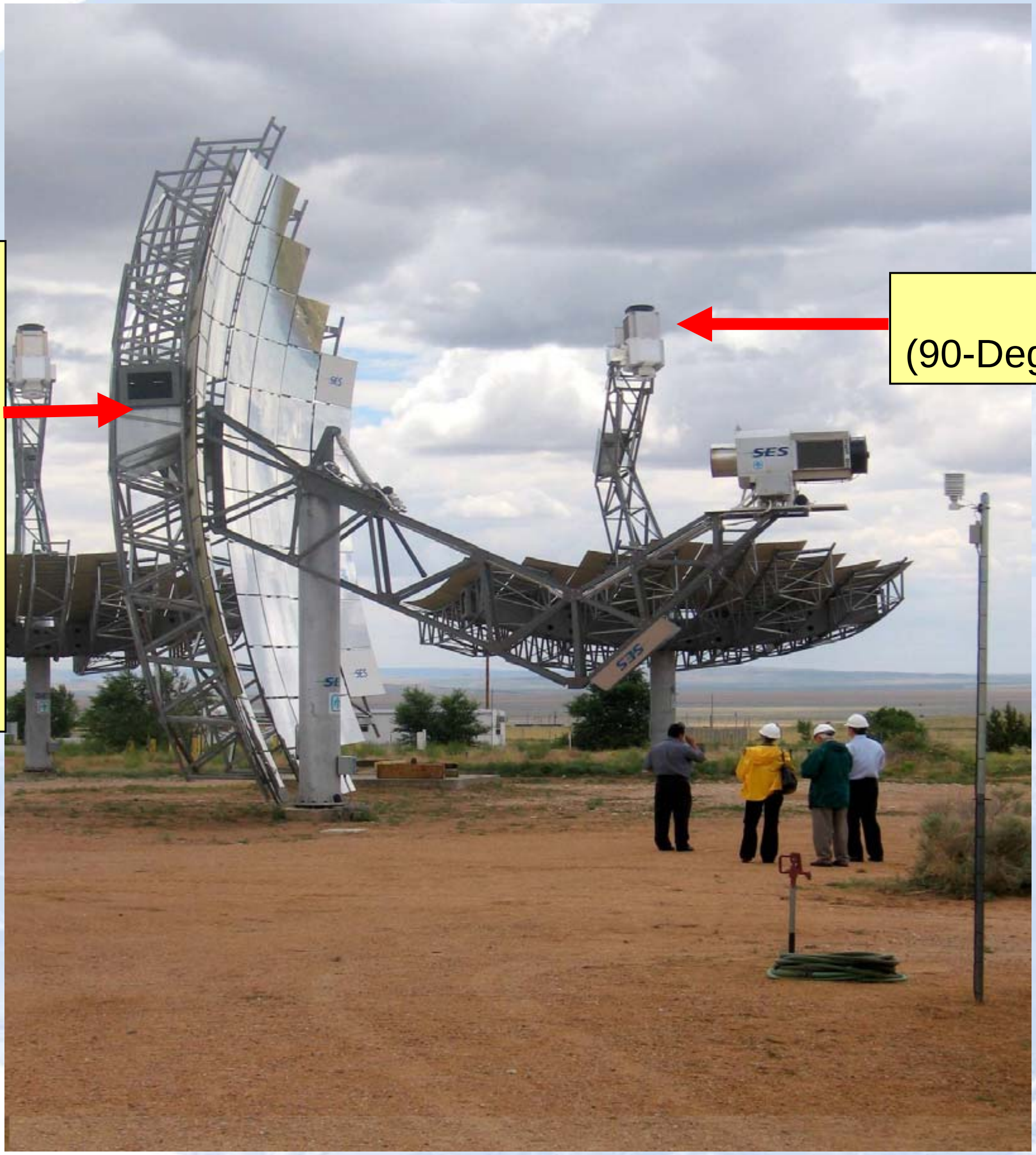
(0-Degree & Facing North)
Note that the Night Stow and Maintenance Position also faces north in a similar position with the PCU angled downward near the ground (see slide 93)



Wind Stow
(90-Degrees Facing Skyward)

Peak Power When It's Needed Most

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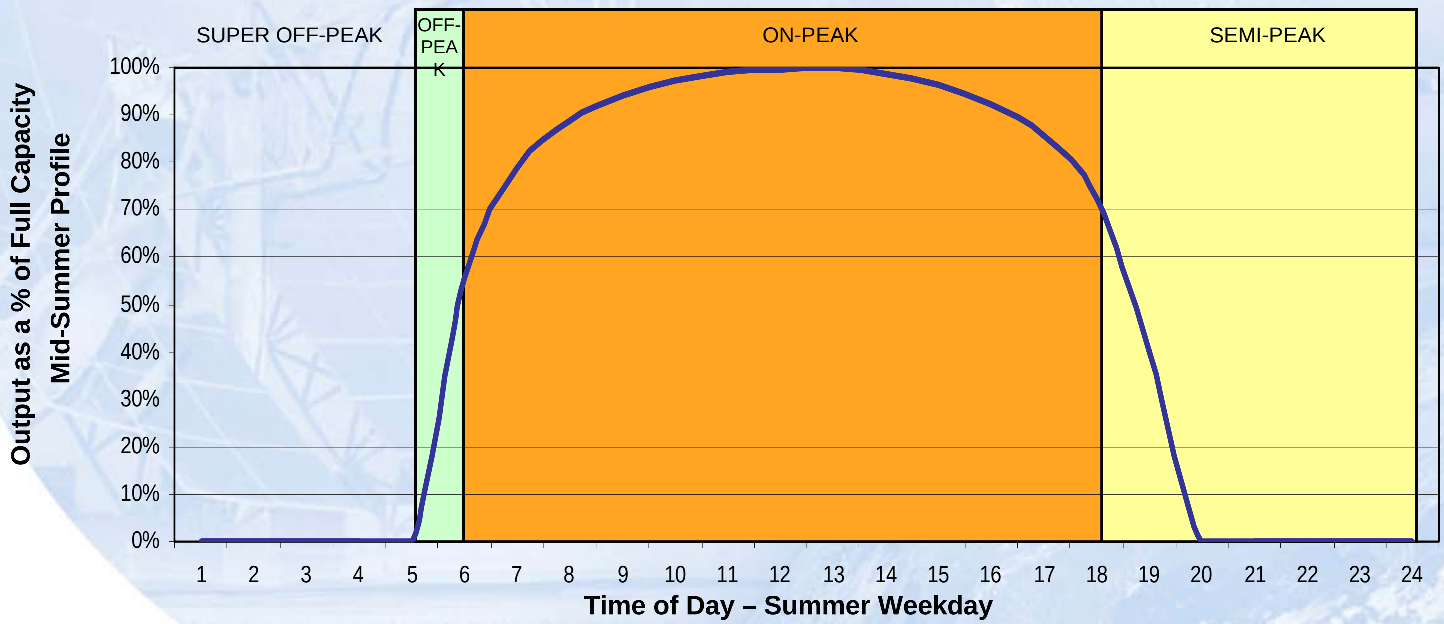
- ✓ Predictable "time-of-day" output
- ✓ SES Power Generating System provides reliable power when it is needed most
- ✓ Deliver periods shown are San Diego Gas & Electric summer weekday periods

Plant Summer Output without Cloud Cover – SES Solar Dish Technology



SES Solar Dish Stirling – Typical Power Curve

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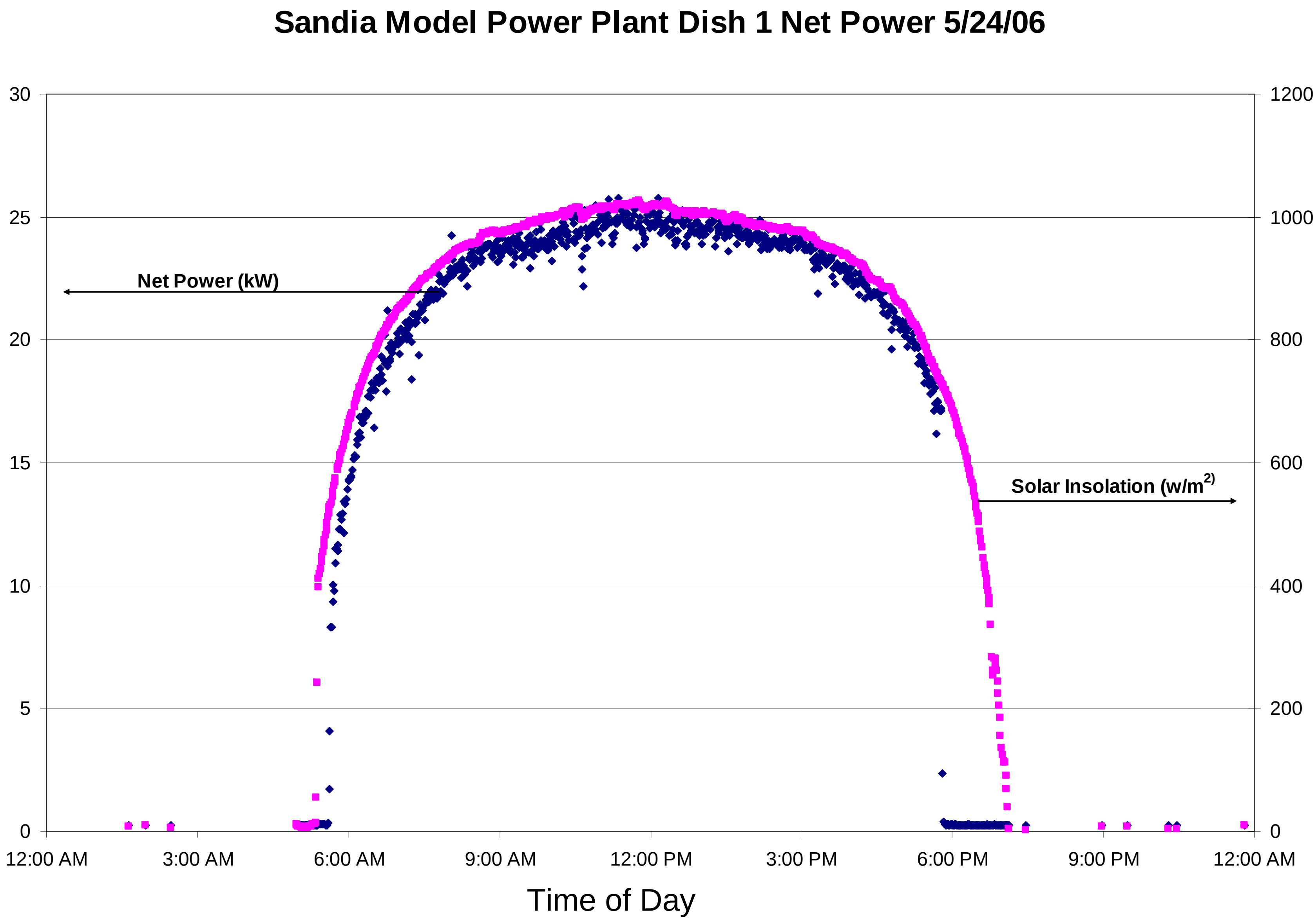

Time-of-Year Generation Profile

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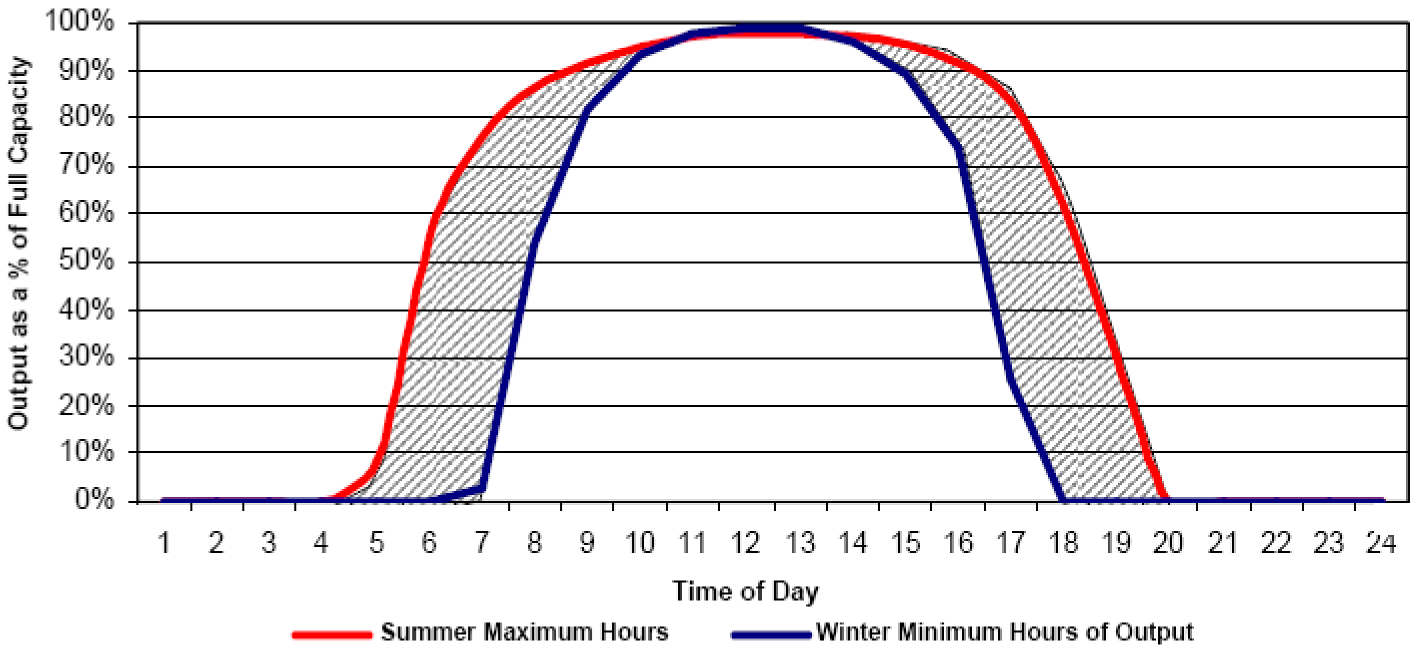
✓ SES Solar Dish technology provides power during sunlight hours year-around

Maximum Expected Energy Output (Summer – Longest Day) and Minimum Expected Energy Output (Winter – Shortest Day) Shown With Clear Sky Conditions



SES Solar Powered Generating Facility

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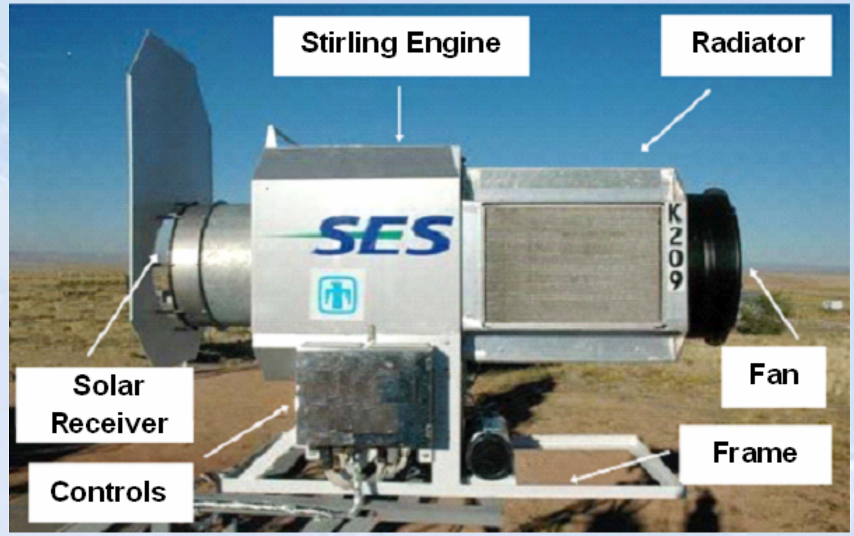
Modular & Scalable !

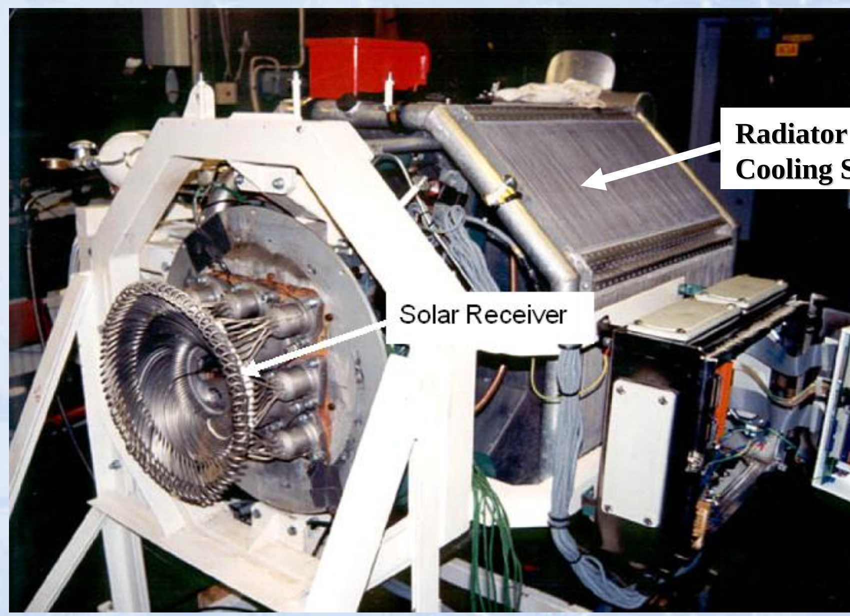
- Thousands of the SunCatcher Solar powered generating units can be constructed to comprise a single large-scale electric generating facility
- Installed dishes can be energized to produce power as they are completed during plant construction
- Maintenance can be done quickly on individual units with quick change out of power conversion units resulting in high overall availability

Power Conversion Unit
&
Stirling Engine System

SunCatcher Power Conversion Unit ("PCU")

- ✓ The PCU houses the Solar Receiver, Stirling Engine, Generator, Gas Radiator Cooling System and Auxiliaries
- ✓ The conversion process begins with the Solar Receiver absorbing the focused solar energy in a system of receiver tubes containing hydrogen gas
- ✓ The hydrogen gas within the solar receiver tubes absorbs the heat from the incoming solar energy raising the pressure in the receiver to approximately 200-bars or 2,900 pounds per square inch
- ✓ The high pressure hydrogen gas in turn drives the pistons of a high-efficiency, 380 cubic centimeter, 4-cylinder reciprocating Stirling Cycle Engine producing 35 Hp at 1800-rpm
- ✓ The rotating shaft power produced by the Stirling engine in turn powers an electrical generator producing 25kW at 575 Volt AC / 60Hz of grid-quality electricity
- ✓ The Stirling Engine is a closed-cycle, sealed system and the hydrogen gas is cooled, compressed and recycled back to the Solar Receiver
- ✓ The Stirling engine requires no combustion, produces no emissions and consumes no water





The SunCatcher PCU will use the Kockums' Stirling Engine Design

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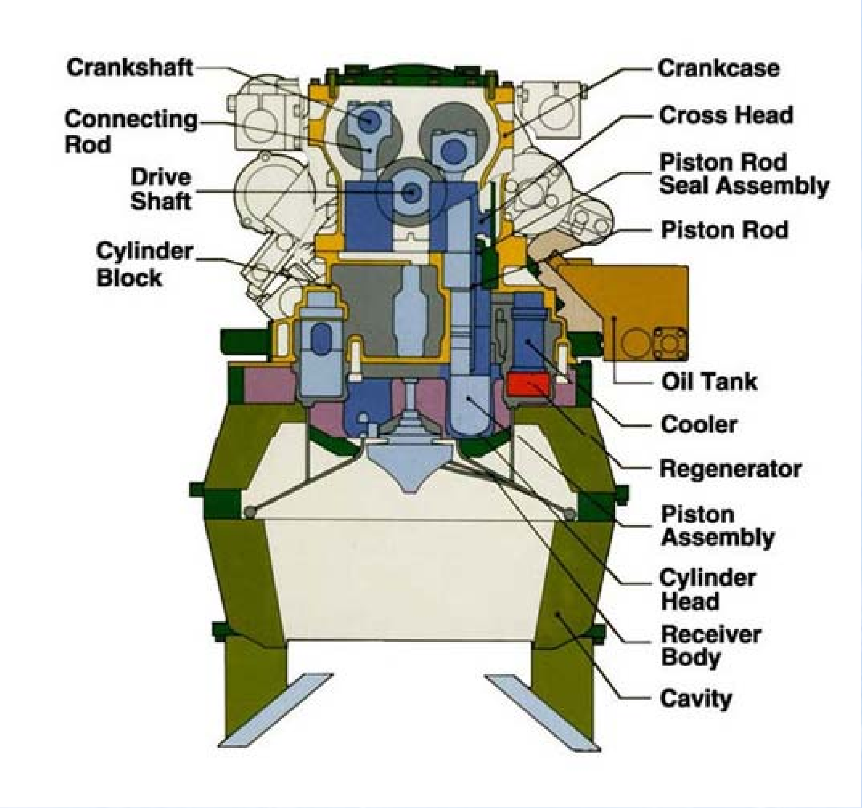
- ✓ SES will use the Kockums' Stirling Engine design for Solar Two which is the same design used by Kockums in its submarine propulsion system
- ✓ Kockums, a Swedish shipbuilder, is the world's leader in non-nuclear submarine technology and has over three decades of involvement in the research and development of high performance kinematics Stirling engines. Kockums has developed this engine technology for use as its submarine propulsion system. The Stirling Engine provides an alternative to surfacing and charging batteries with diesel power thereby adding submerged endurance and stealth to its submarines. Kockums has built over eight commercially successful submarines with the Stirling Engine propulsion system.
- ✓ The Kockums' Stirling engine design being used by SES is a proven, highly reliable, efficient, high tech engine with many hours of operating history and testing



SES Stirling Engine Test Unit

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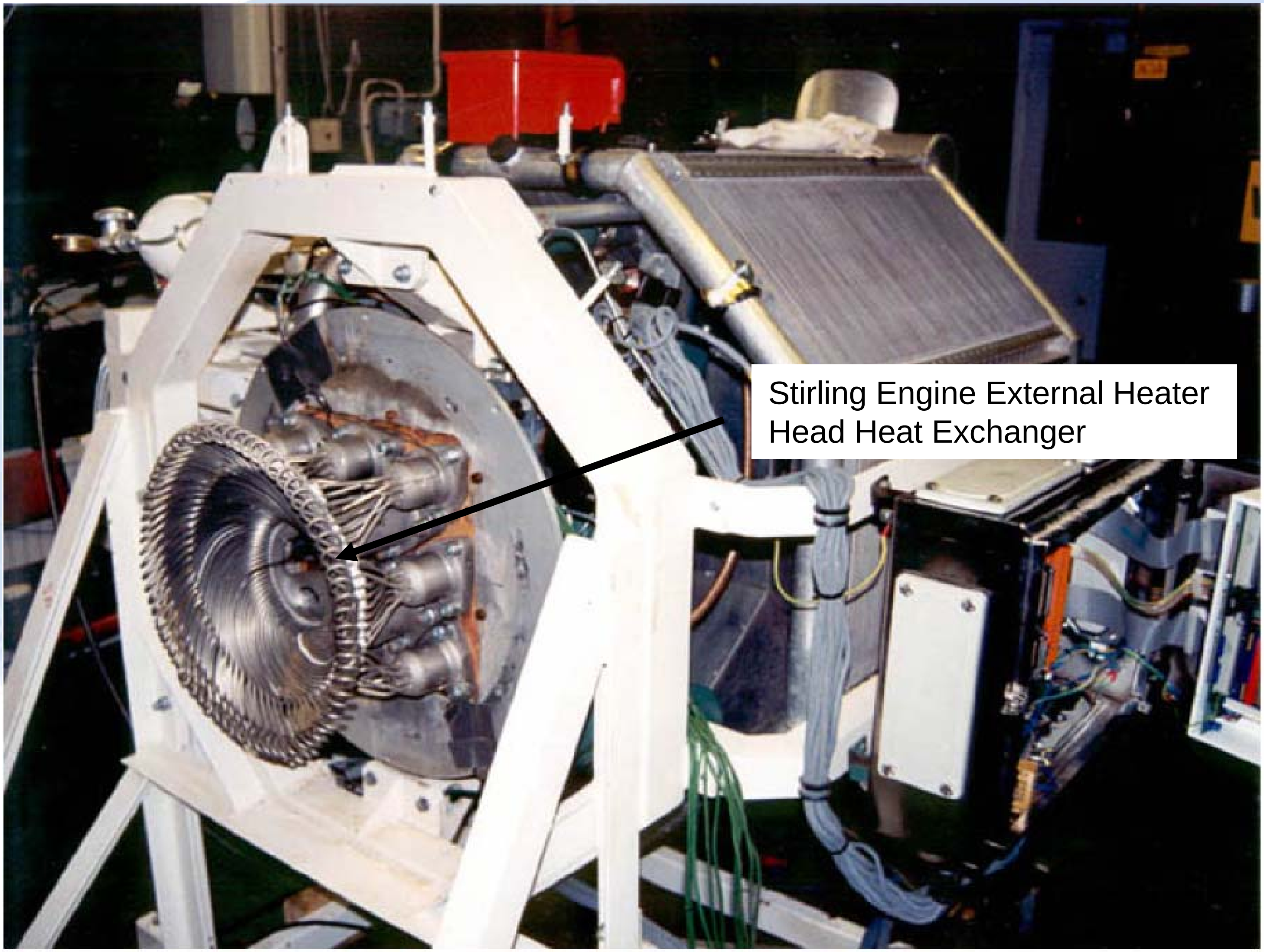
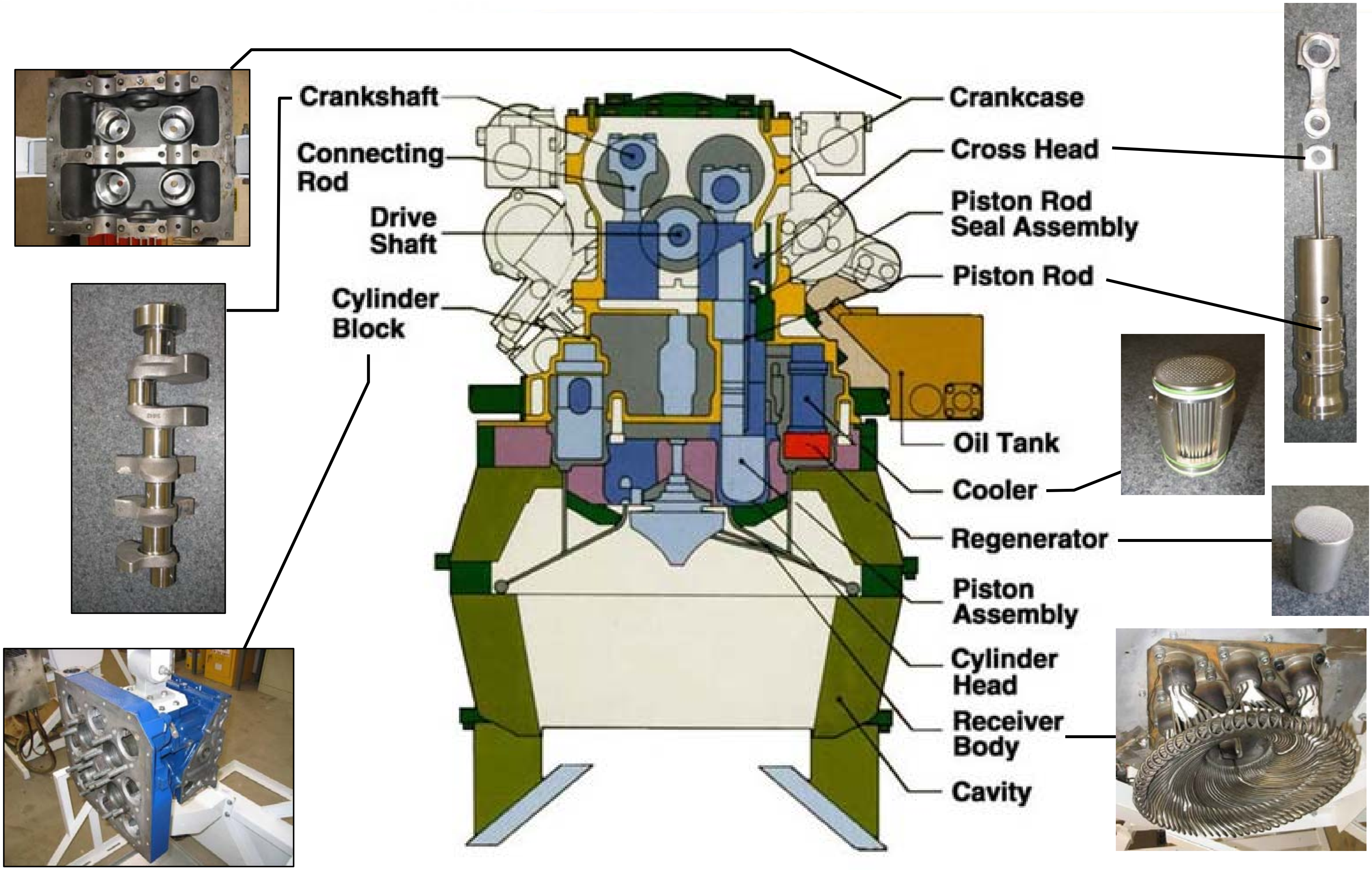


Stirling Engine External Heater Head Heat Exchanger

Cutaway View of Stirling Engine and Key Components



Power Conversion Unit with Generator

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PCU Design Model

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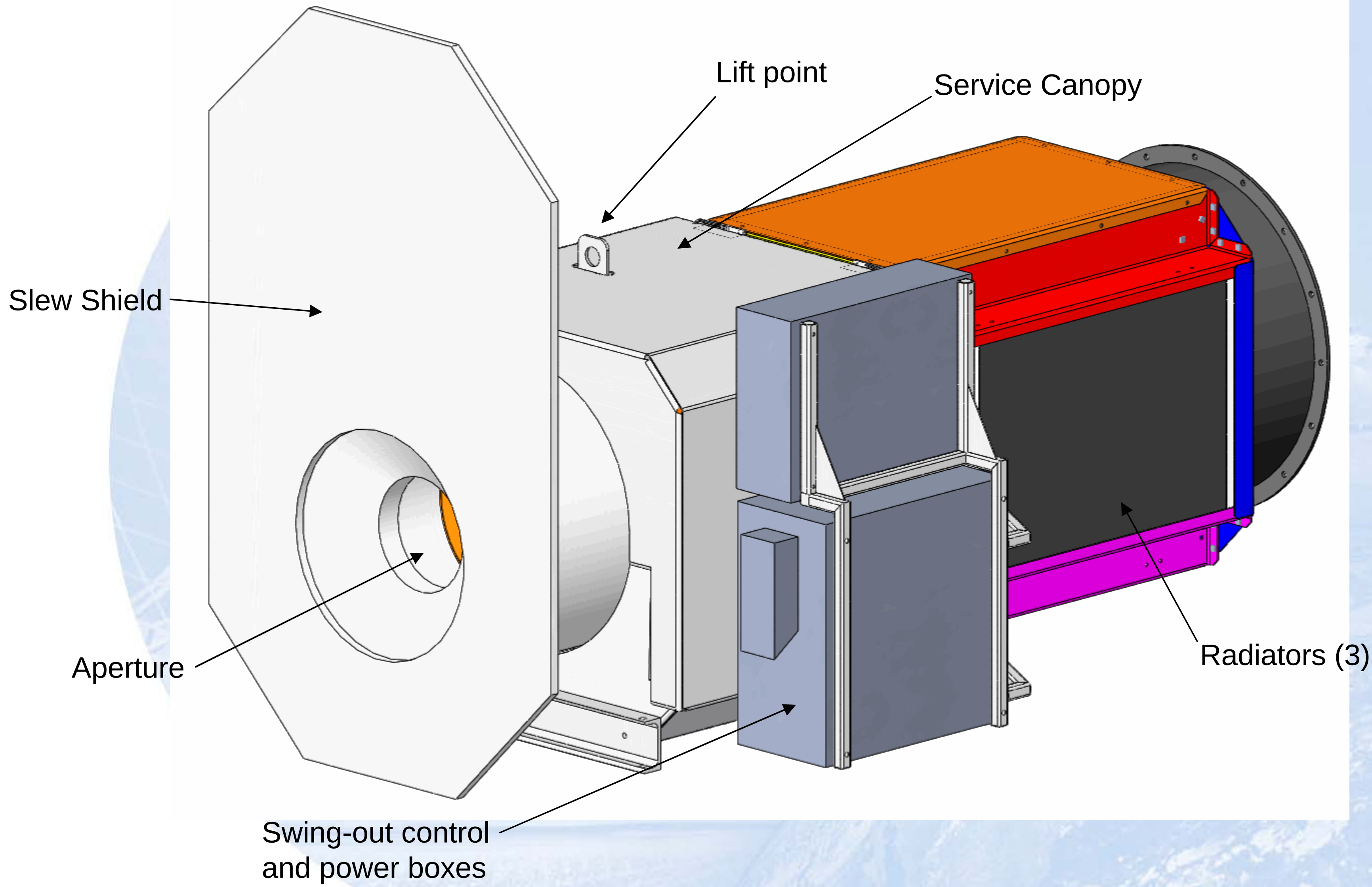

Exploded View of Power Conversion Unit Components

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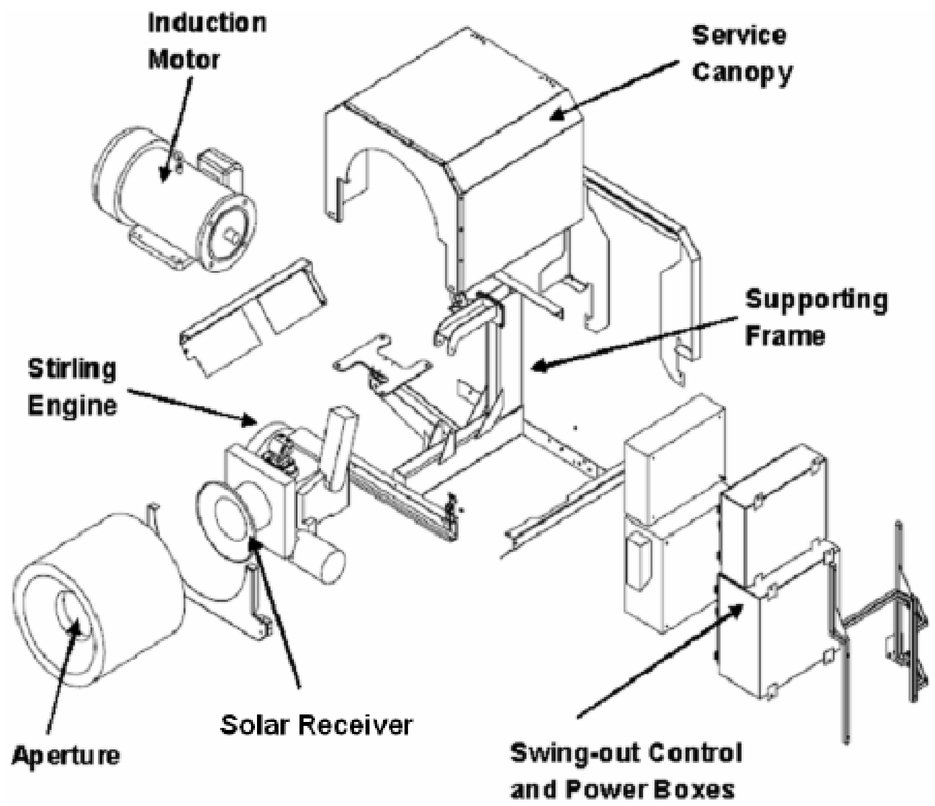
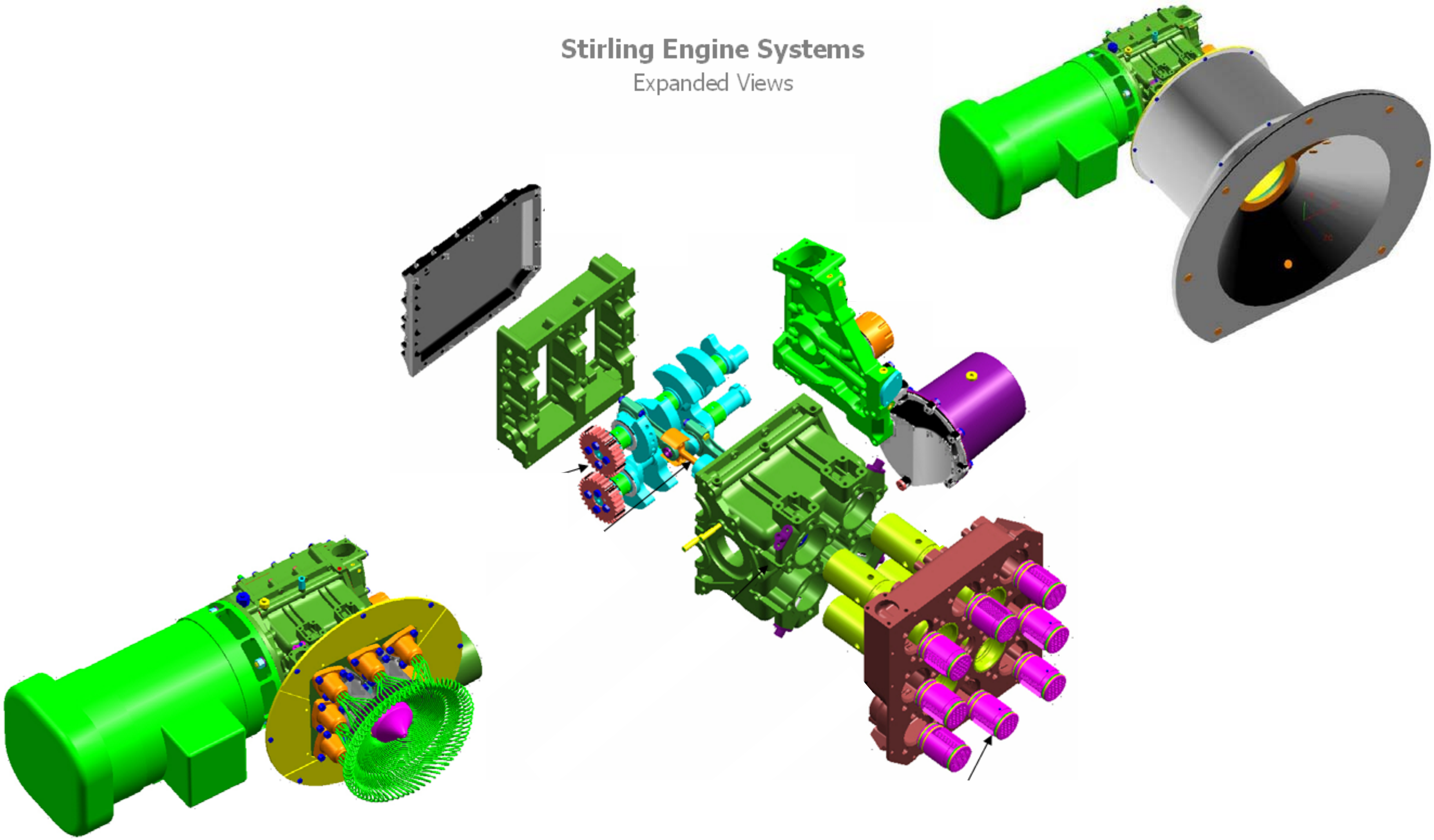


Expanded View of Power Conversion Unit Components



Stirling Engine with Solar Receiver

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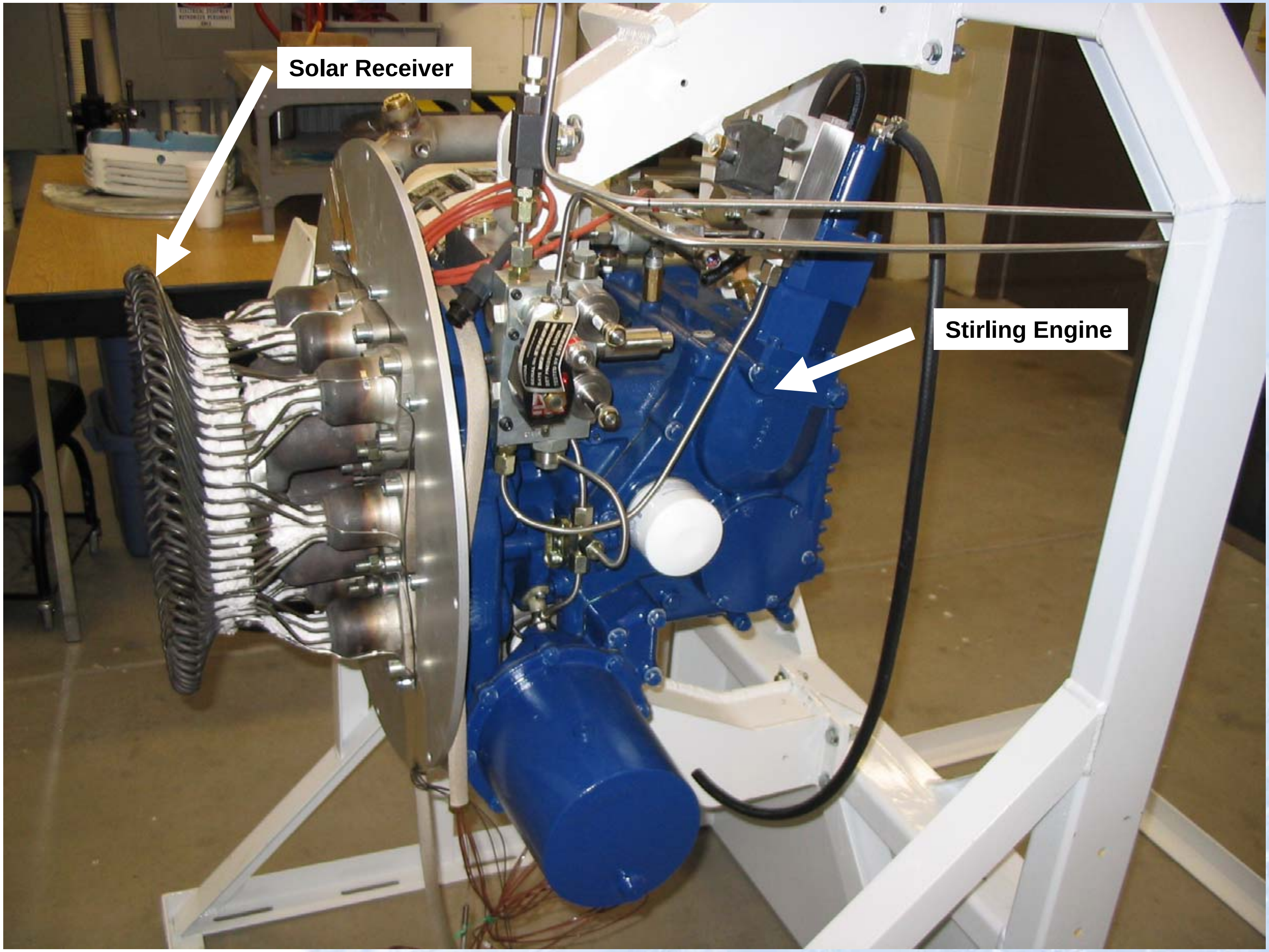
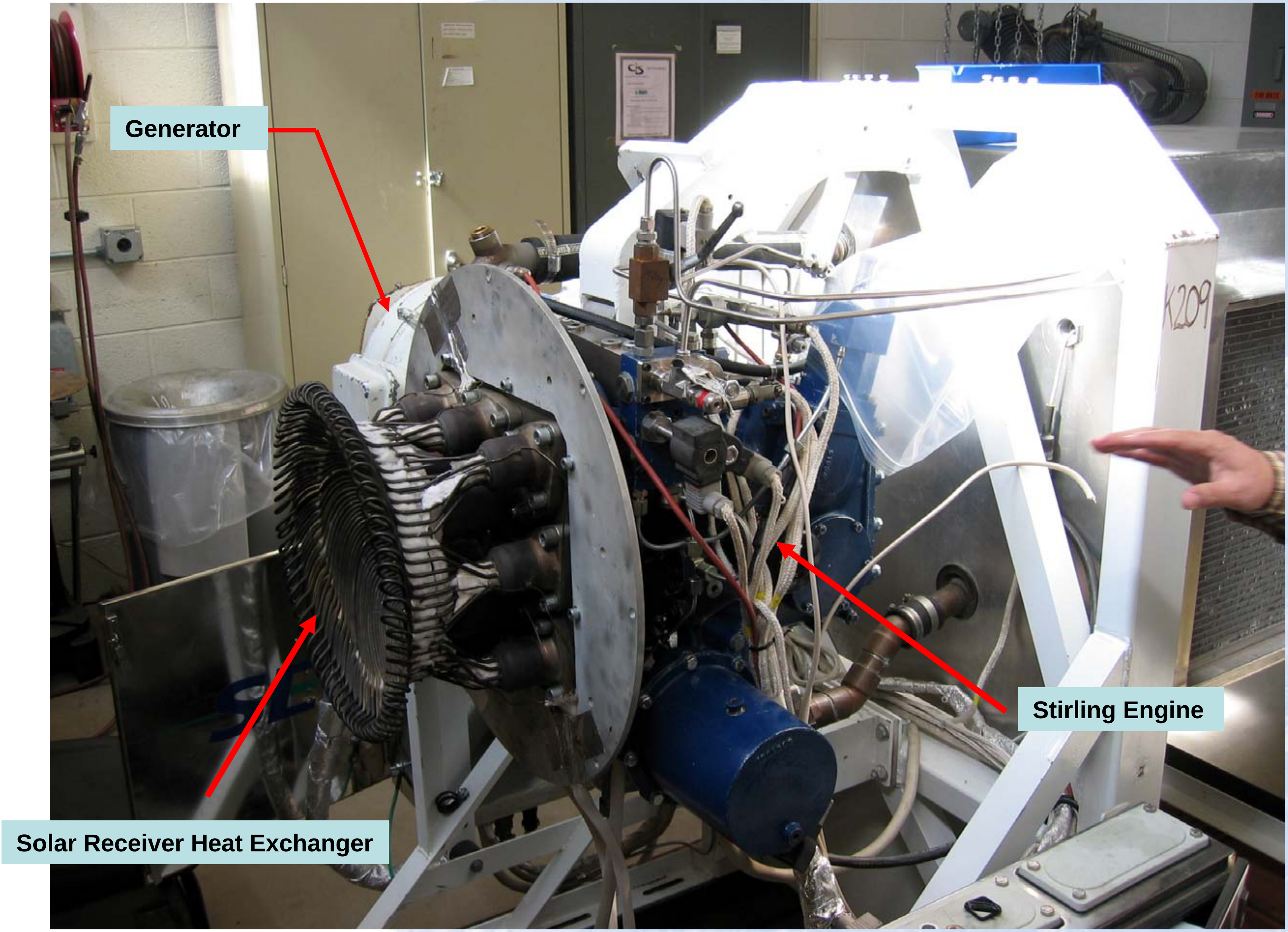


Assembled Power Conversion Unit



PCU Radiator Gas Cooling System

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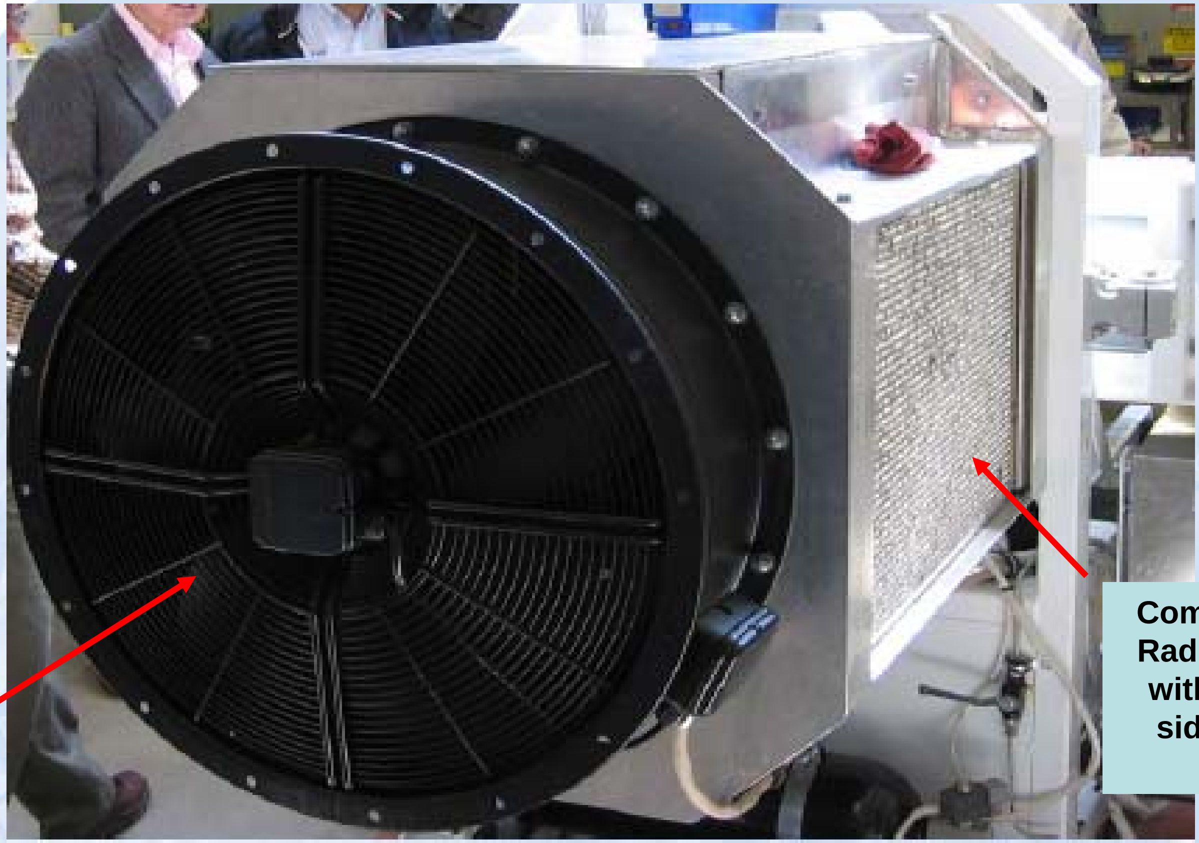

Two Speed High Volume Fan

Commercial Grade Radiator (total of 3 with one on each side and one on bottom)

Basics of the Stirling Engine Thermodynamic Cycle

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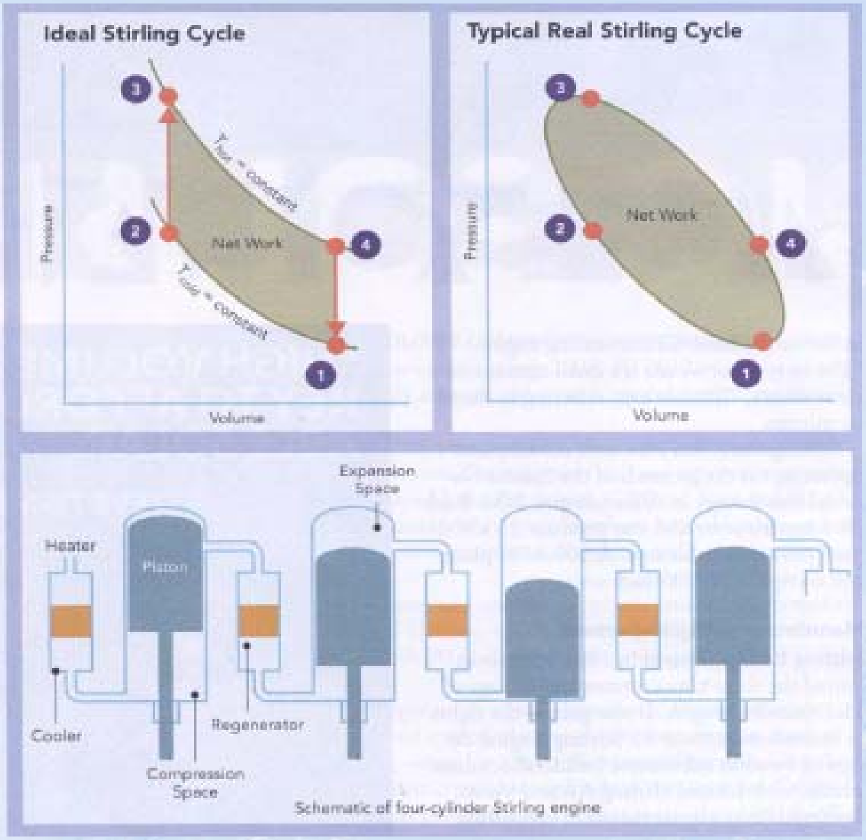
- ✓ The hydrogen gas is heated in the Solar Receiver at constant volume to a higher pressure (points 2 to 3).
- ✓ During the rotating cycle of the Stirling engine, the heated hydrogen is admitted into a cylinder and powers the cylinder piston assembly toward the crankshaft in the power stroke losing pressure (points 3 to 4).
- ✓ The hydrogen gas is next cooled to a lower pressure at constant volume in the cold end of the engine by the radiator cooling system (points 4 to 1)
- ✓ At the same time as the power stroke, gas in an adjacent cylinder that has been cooled is compressed and transferred back to the Solar Receiver (points 1 to 2).
- ✓ The hydrogen gas is next heated in the Solar Receiver repeating the cycle
- ✓ The difference between work supplied (expansion) and work performed (compression) provides for a net output that is converted to mechanical motion driving an electrical generator.



Stirling Engine Block With Cylinder Head Removed

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Stirling Engine Cylinder Head and One Quadrant of Solar Receiver

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Stirling Engine Piston and Internals

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Stirling Engine – Side View

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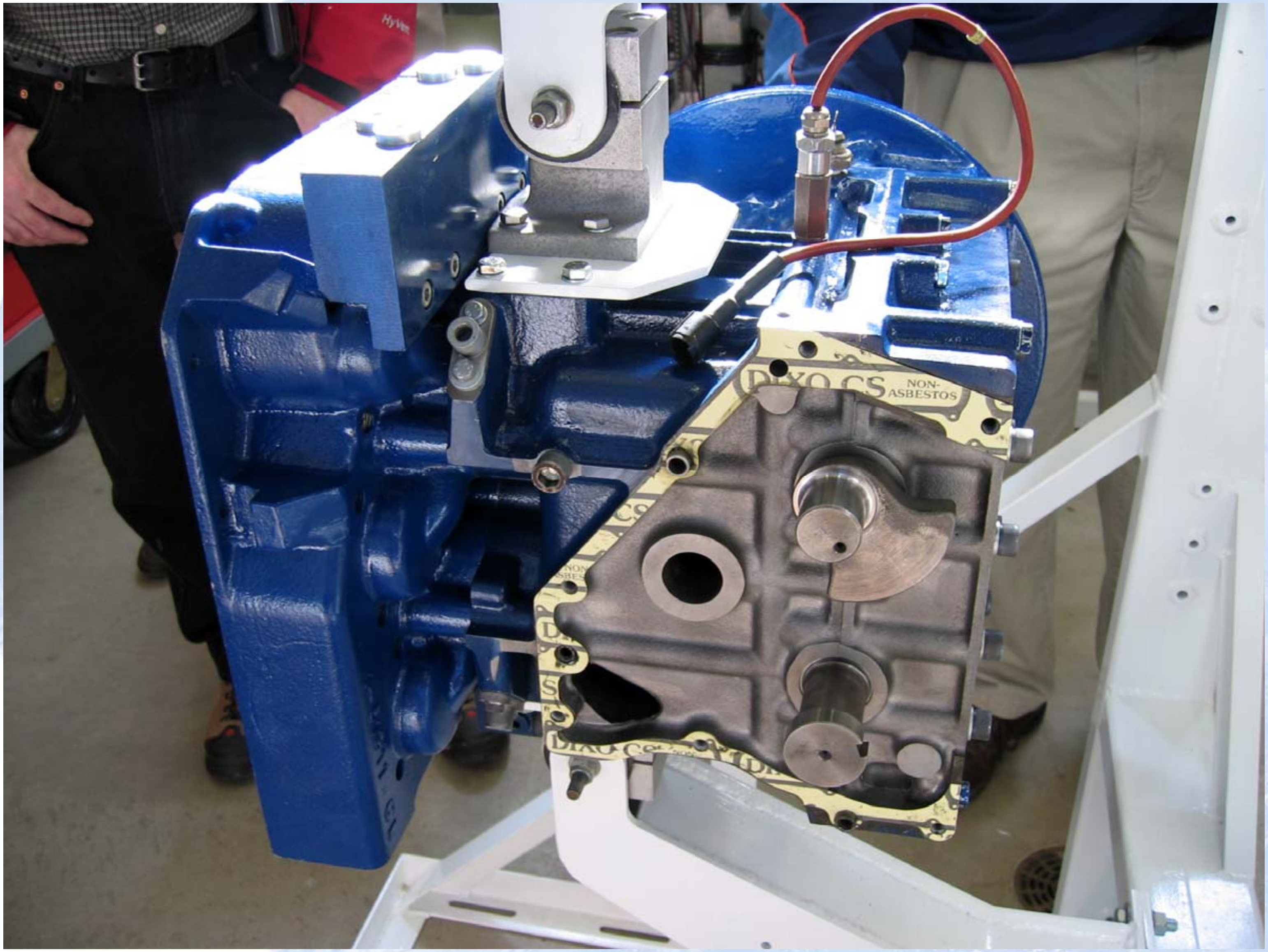

Stirling Engine – Bottom View

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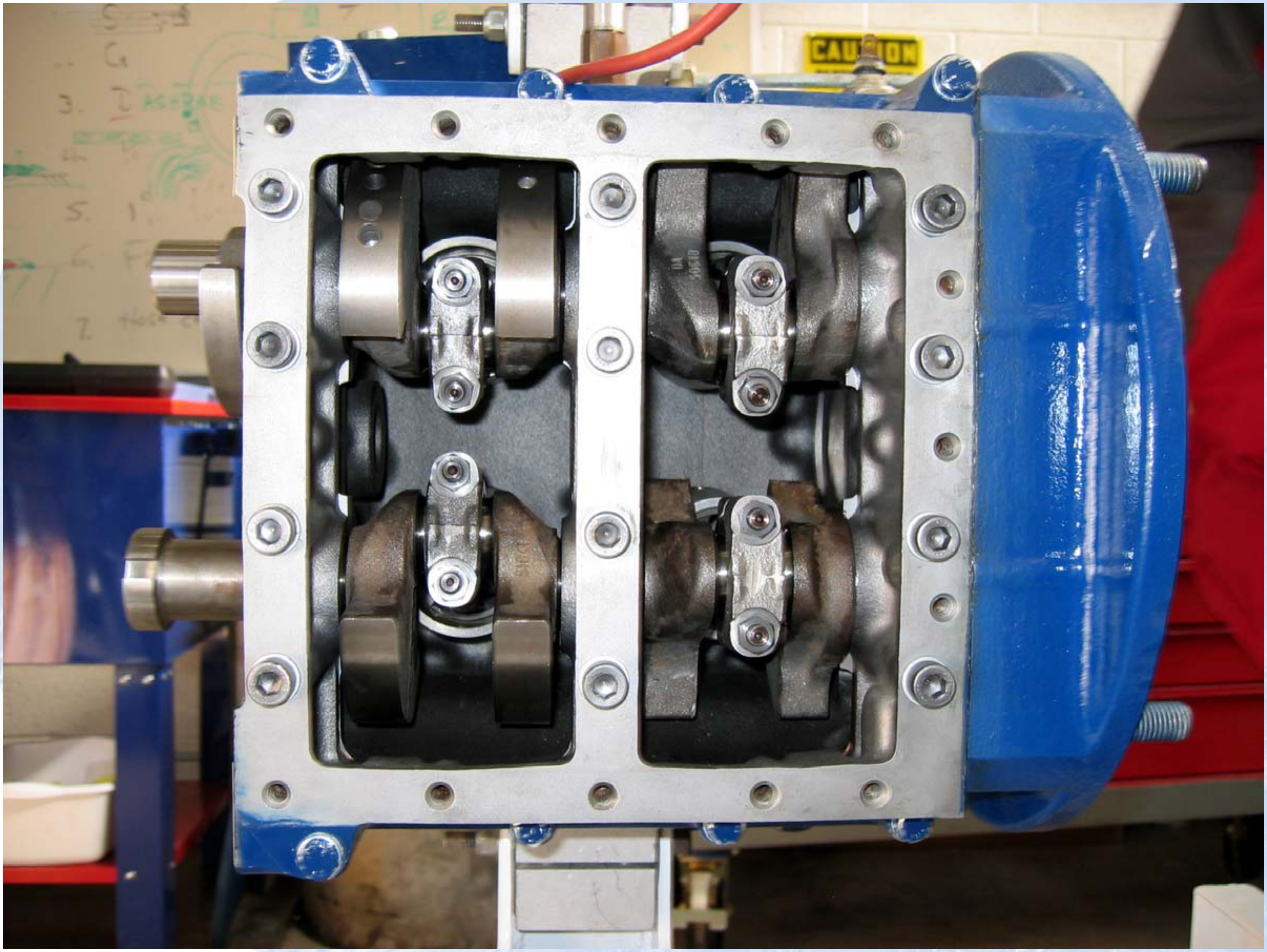
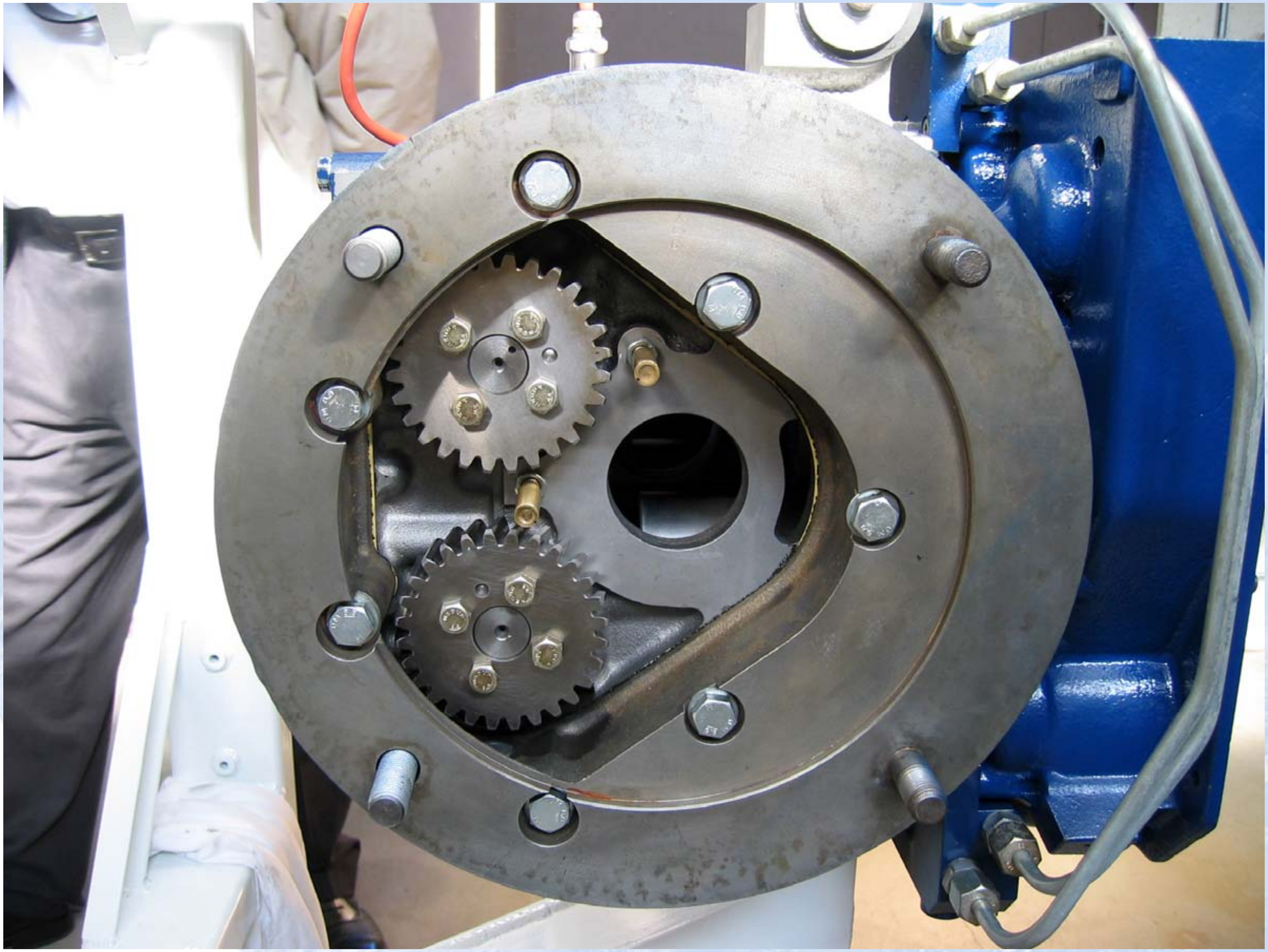


Stirling Engine – Side View

Stirling Energy Systems, Inc. SES



Stirling Engine – Top View

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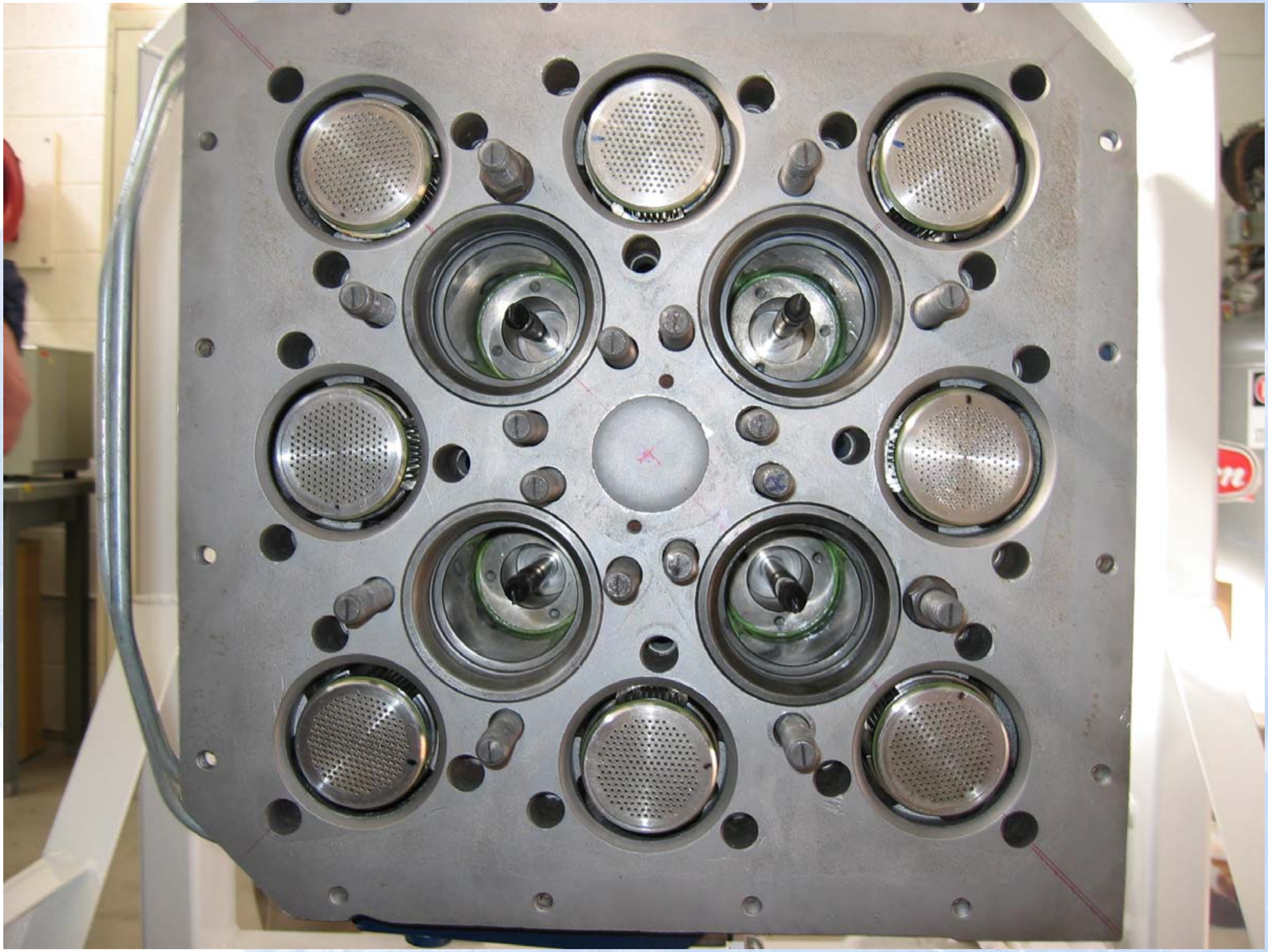

Gas Management System

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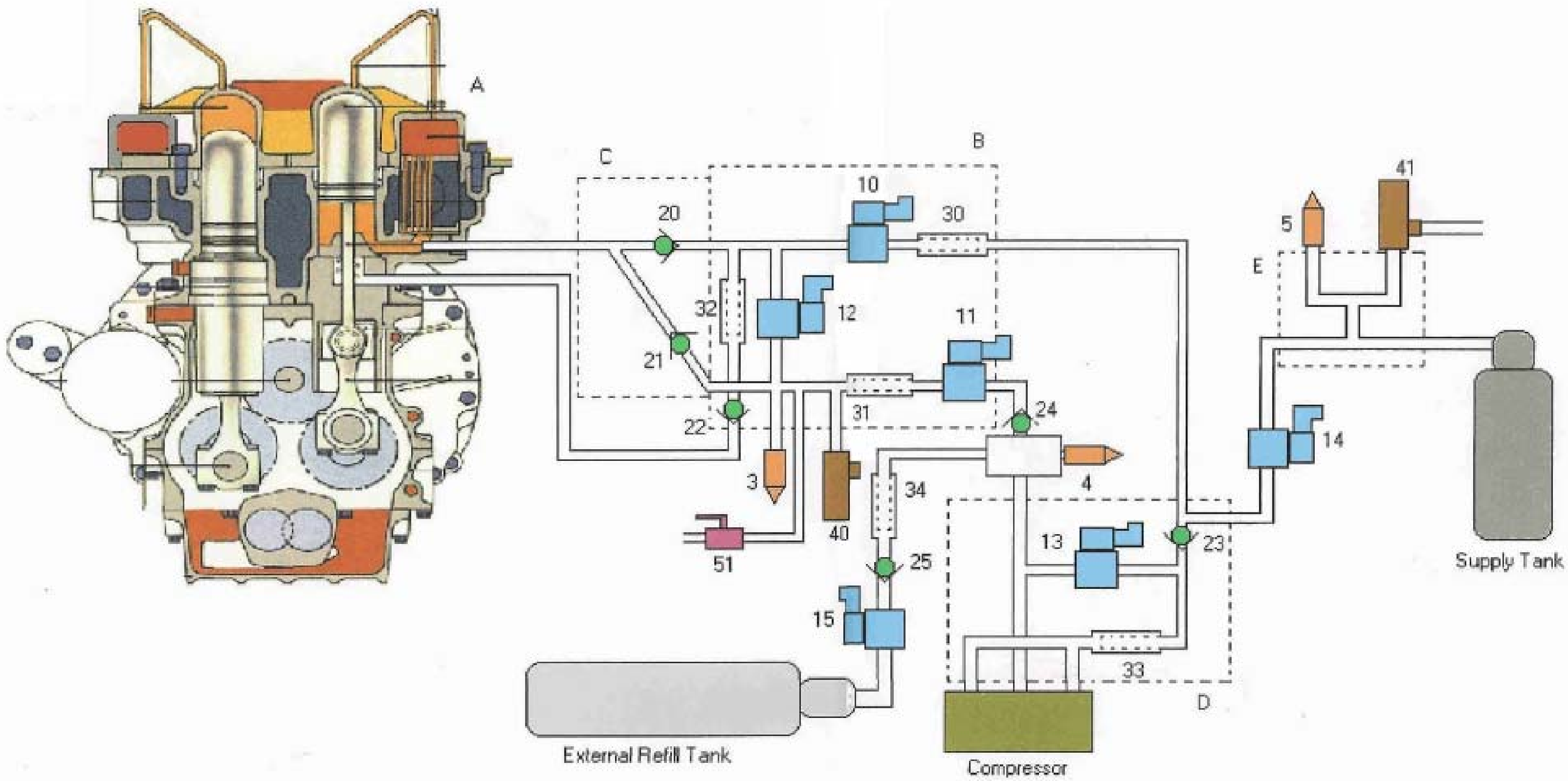
Gas Management System Schematic



3	Pressure Transducer (Pmax)	23	Compressor Out Check Valve	A	4-95 Mk II Stirling Engine
4	Pressure Transducer (Pcompressor)	24	Compressor In Check Valve	B	Control Block
5	Pressure Transducer (Ptank)	25	External Refill Check Valve	C	Check Valve Block (2 per engine)
10	Supply Valve	30	Supply Filter	D	Compressor Idle Block
11	Dump Valve	31	Dump Filter	E	Distribution Block
12	Engine Short Circuit Valve	32	Seal Housing Drainage Filter		
13	Compressor Short Circuit Valve	33	Compressor Filter		
14	Tank Valve	34	External Refill Filter		
15	External Refill Valve	40	Cycle Safety Valve		
20	Min Pressure Check Valve (Supply)	41	Compressor/Supply Tank Safety Valve		
21	Max Pressure Check Valve (Dump)	51	Manual Engine Dump Valve		
22	Seal Housing Drainage Check Valve		**Note**: Dotted lines represent manifold blocks		

		VALVES					
		10	11	12	13	14	15
G	Add	OPEN	CLOSE	CLOSE	OPEN	OPEN	CLOSE
A	Remove	CLOSE	OPEN	CLOSE	CLOSE	OPEN	CLOSE
S	Refill	CLOSE	CLOSE	CLOSE	CLOSE	OPEN	OPEN
	Bypass	N/A	N/A	OPEN	N/A	N/A	N/A

Note: Engine Short Circuit Valve (12) : No Voltage = OPEN
All other valves: No Voltage = CLOSE

SES Model Power Plant Operating at Sandia

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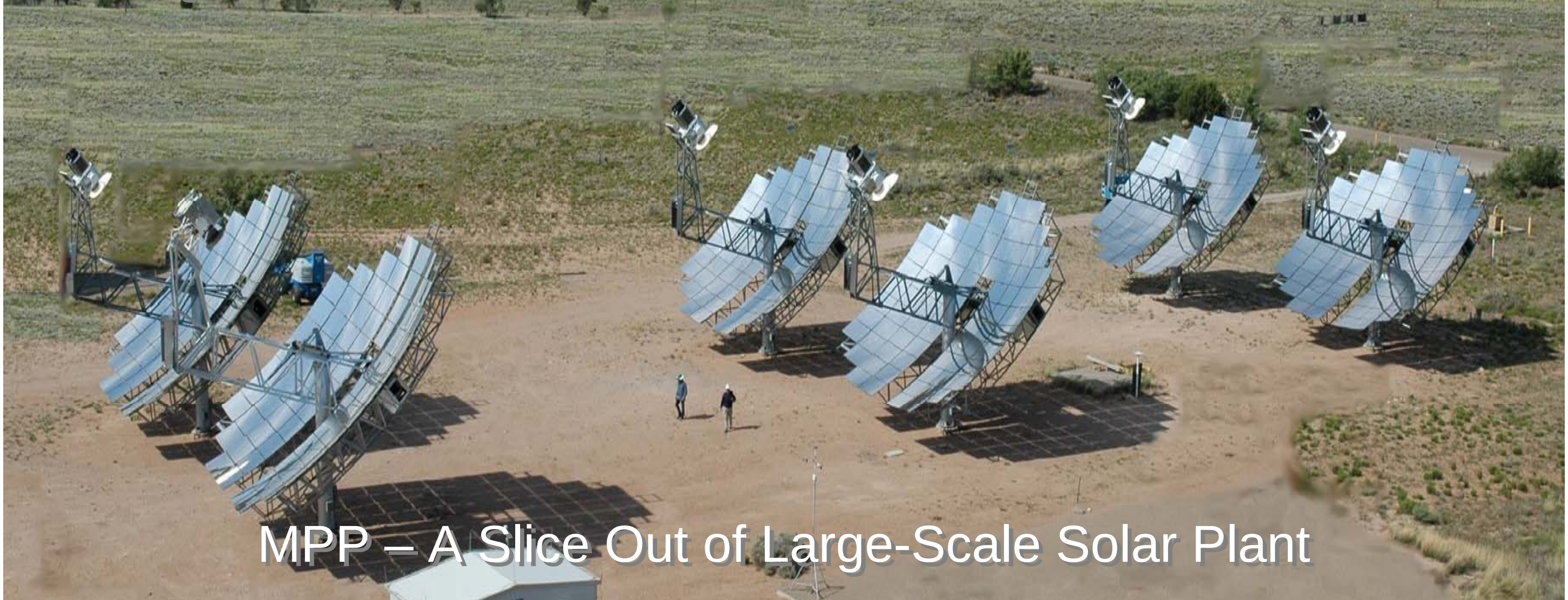
- ✓ Located at the NSTTF
- ✓ Proving Ground & Showcase
- ✓ On-Going System Testing
  - Performance
  - Reliability
  - Systems Integration
- ✓ Augmented with Sandia Scientists & Engineers



MPP – A Slice Out of Large-Scale Solar Plant

SES Solar Technology Installed at Sandia

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SES Model Power Plant Video

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Stirling Engine

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SES Solar Dish in Stow for Maintenance

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Stirling Engine

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SES Key Advantages

SES Solar Technology - Key Advantages

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- ✓ Cost Competitive in utility-scale Central Station Deployment
- ✓ Fuel is Free and Hedges Price Volatility of Fossil Fuel Sources
- ✓ Very High Solar-to-Electric Efficiency
  - ➢ Over twice that of other Conventional Solar (other technologies require roughly twice the equipment and thus higher cost). Stirling holds the world record for conversion efficiency at 29.4%.
- ✓ Provides Peak Power When Needed Most
- ✓ Zero Pollution
  - ➢ No Combustion Products or Air Emissions
  - ➢ No Water Discharge
  - ➢ No Hazardous Heat Transfer Fluids
- ✓ No Natural Gas Infrastructure Needed or additional Power Generation Facilities
- ✓ High Contour Terrain Tolerance = Minimal Land Grading and Flexible Siting
- ✓ Very Low Water Use Compared To Other Thermal CSP (< 1%)
- ✓ Water is only required for Mirror Washing and No Water is consumed in the Power Cycle
- ✓ Uses the Kockums' Stirling Engine design which is a Highly Reliable, Low Maintenance and Thermodynamically Efficient
- ✓ Modular System with High Availability
- ✓ Electrical Collection System utilizes Wind Farm Technology and Equipment

SES Technological Advantages

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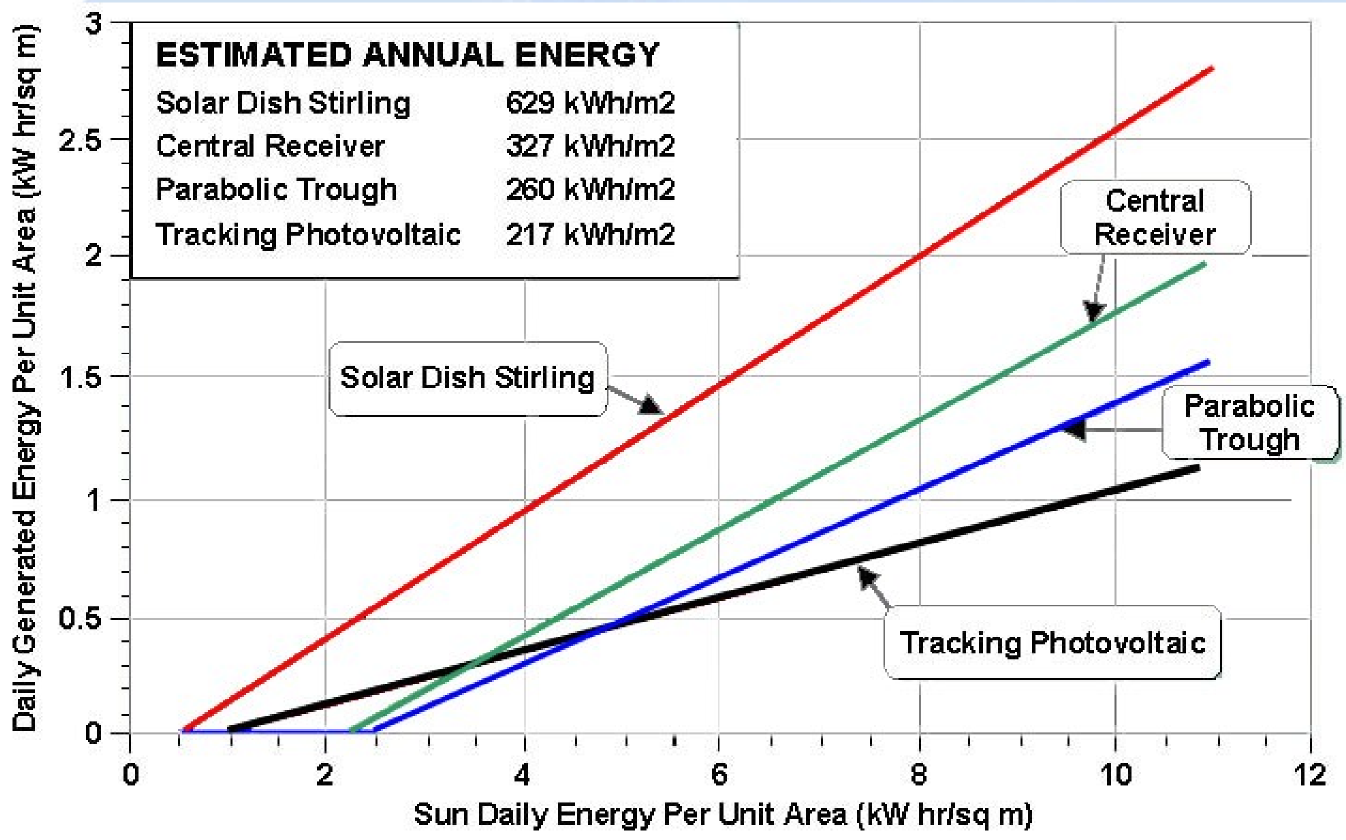
Stirling Solar Dish Efficiency vs. Other Solar



Source: Southern California Edison and Sandia National Laboratories

Efficiency is key to SES cost-competitiveness

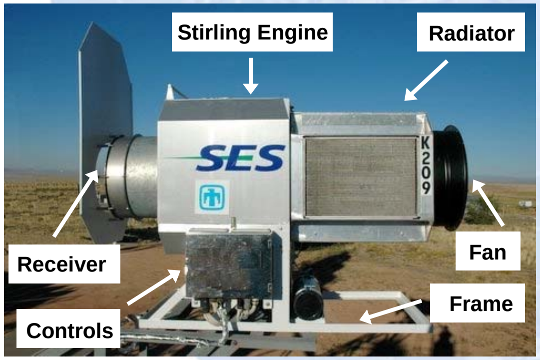
Proven, World-Leading Solar Technology

Stirling Energy Systems, Inc. SES

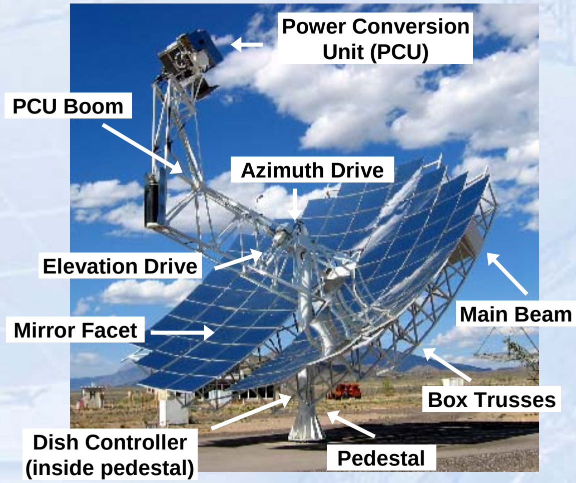
- ✓ Developed by leading solar industry pioneers: Kockums, McDonnell Douglas, Southern California Edison, the Department of Energy, and Sandia National Laboratories
- ✓ Proven track record of 20+ years of R&D and testing at a total cost of over $400 million
- ✓ World's most efficient solar generation technology: converting sunlight into grid-quality electricity

Operating History

Power Conversion Unit:
158,000 hrs On-Sun & Test Cell



Dish Concentrator:
100,000 hrs On-Sun

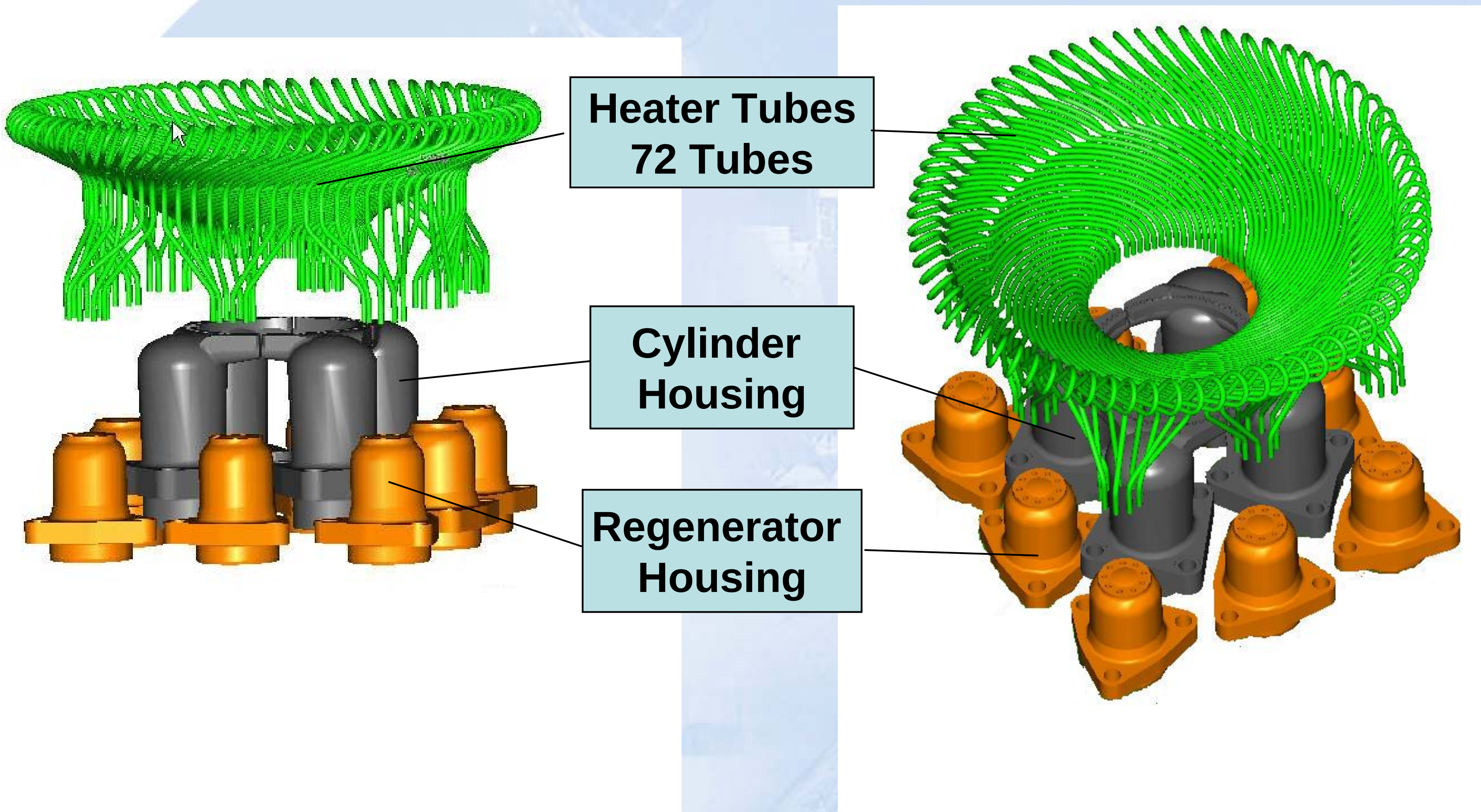


Complete System:
33,000 hrs On-Sun

Equivalent Daily Solar Operation: ***48 years*** ***30 years*** ***10 years***

Power Conversion Unit (PCU)

Heater Head


Heater Tubes
72 Tubes
Cylinder
Housing
Regenerator
Housing

PCU Design Model

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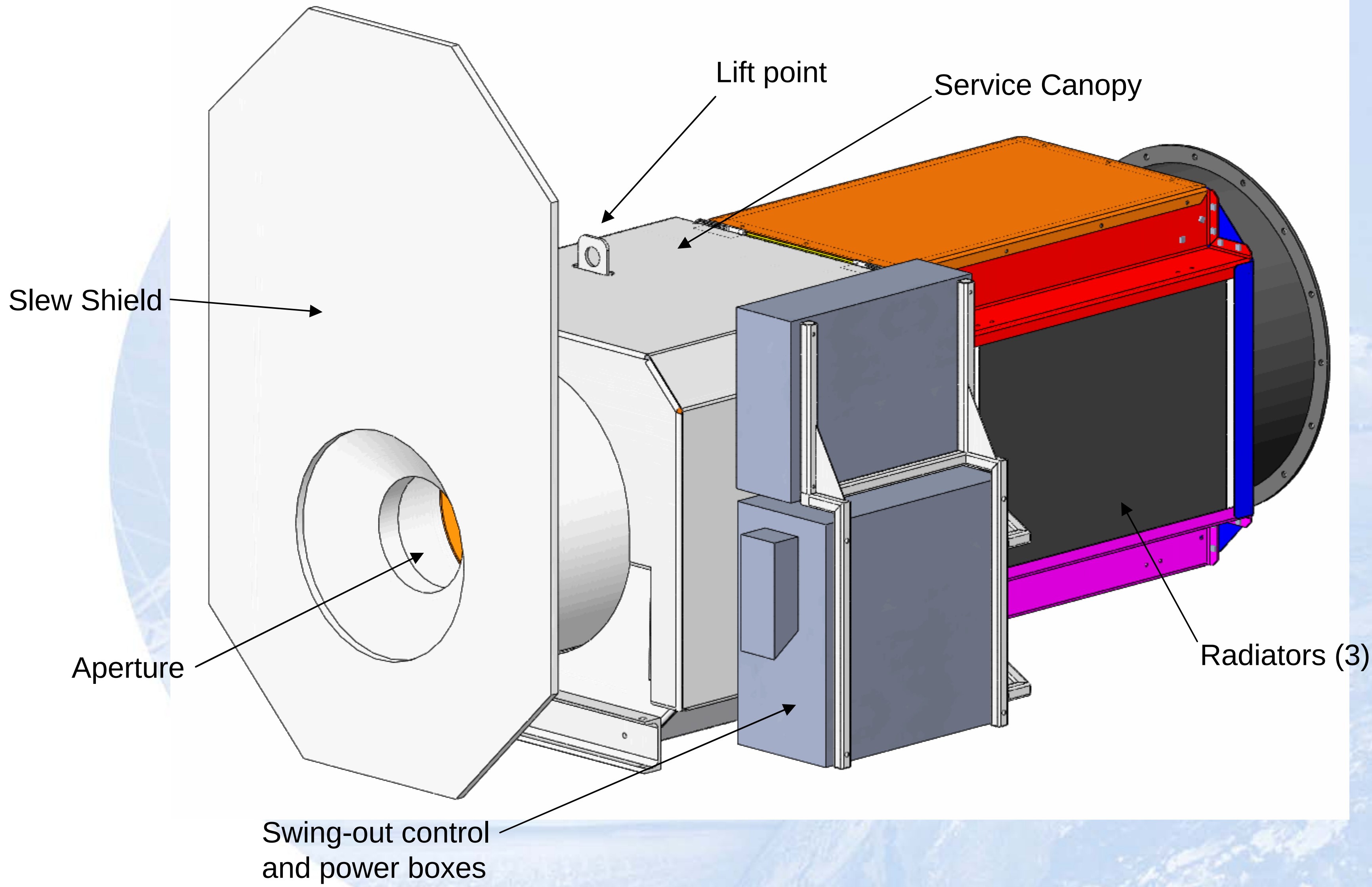

PCU Design Model

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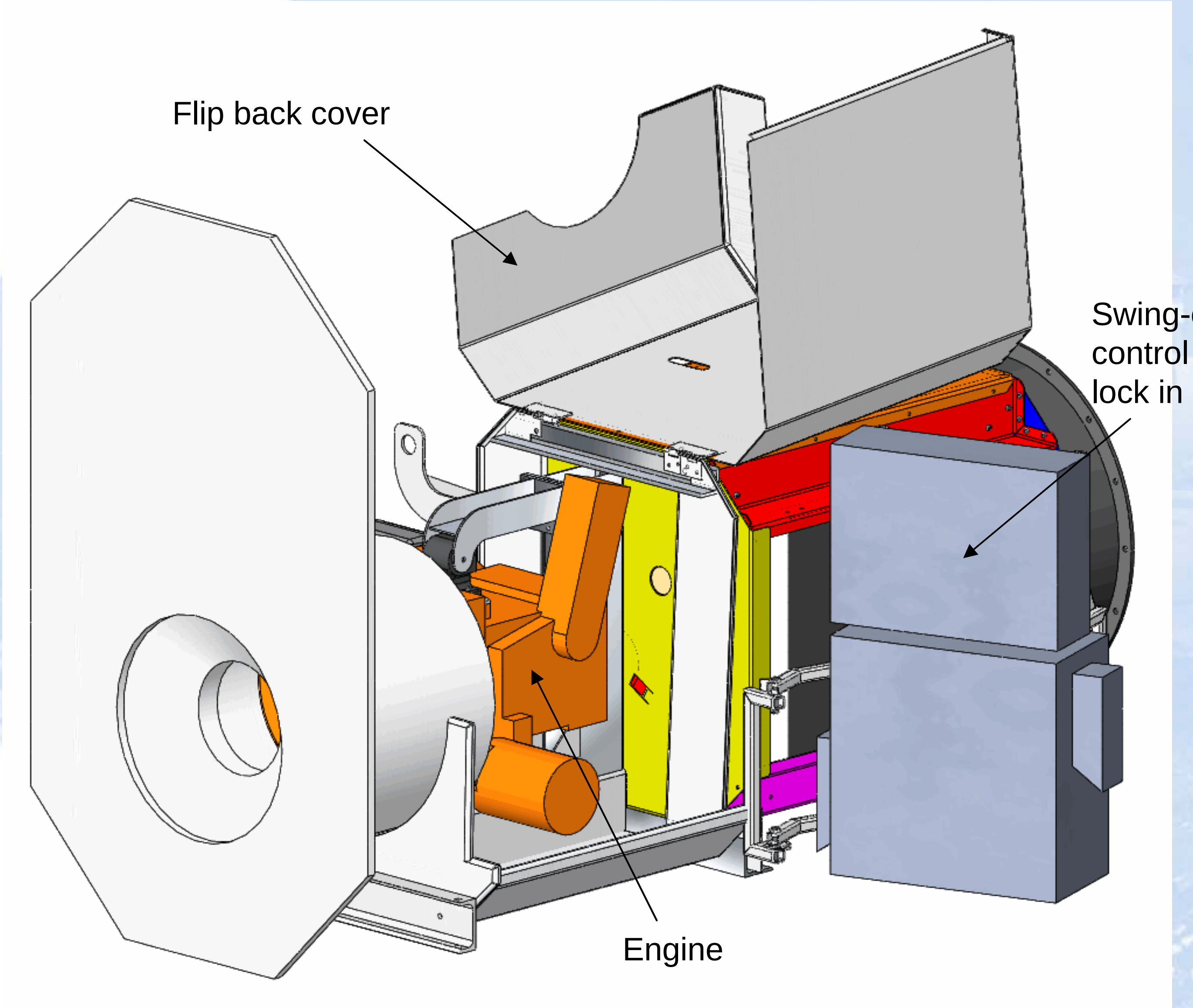
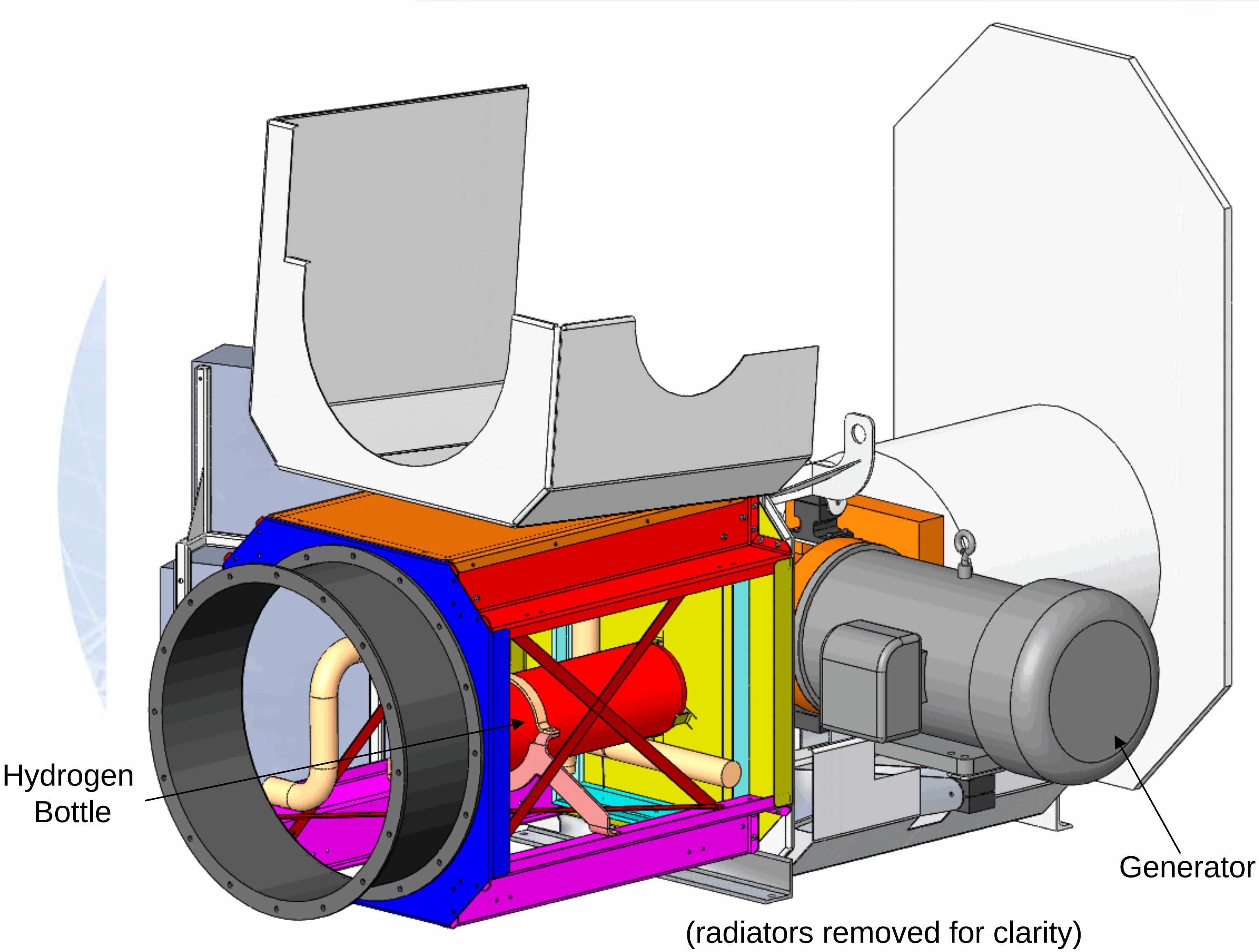


PCU Design Model

Stirling Energy Systems, Inc. SES

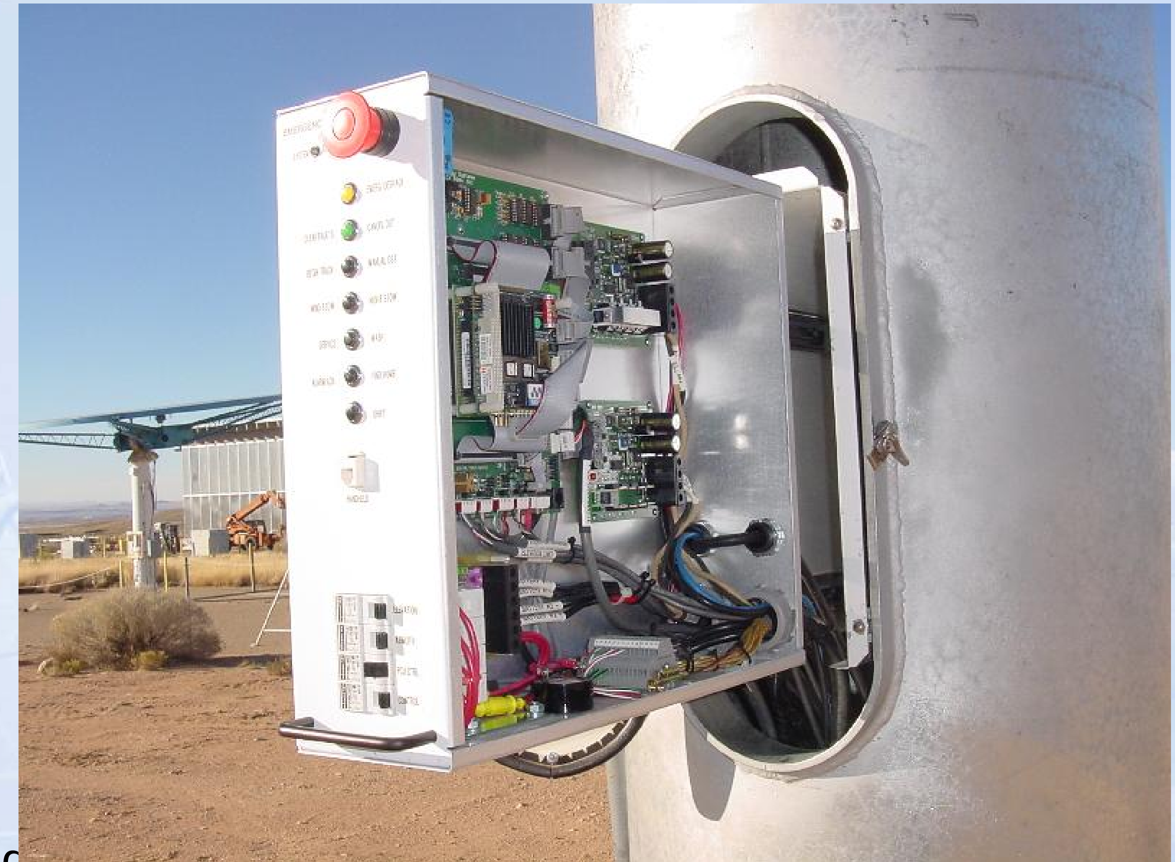


Controls Overview

- ✓ **Dish Controls**
  - Sun tracking
  - Azimuth and elevation drives
  - 24VDC drive motors
  - Battery system

- ✓ **PCU Controls**
  - System starting
  - Engine controls
  - Grid intertie
  - Alarms and Trips

- ✓ **SCADA System**
  - Supervisory Control and Data Acquisition
  - Fault logging, P/M indicators
  - Overall system performance
  - Individual dish performance



SCADA Screen Sample – 25kW Dish Stirling Operation Summary

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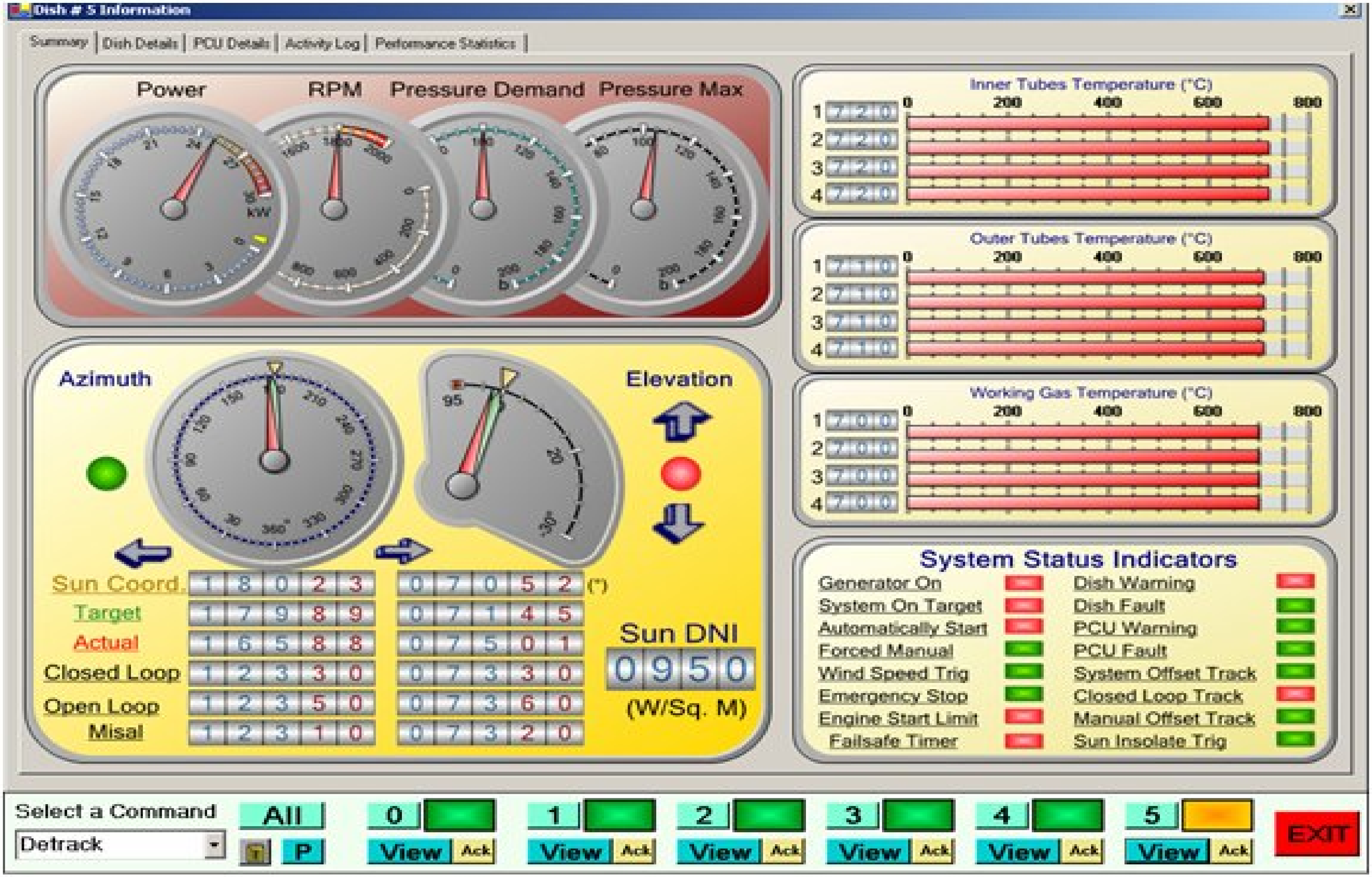

Site Configuration
&
Solar Field Deployment

1.5MW Solar Group Configuration

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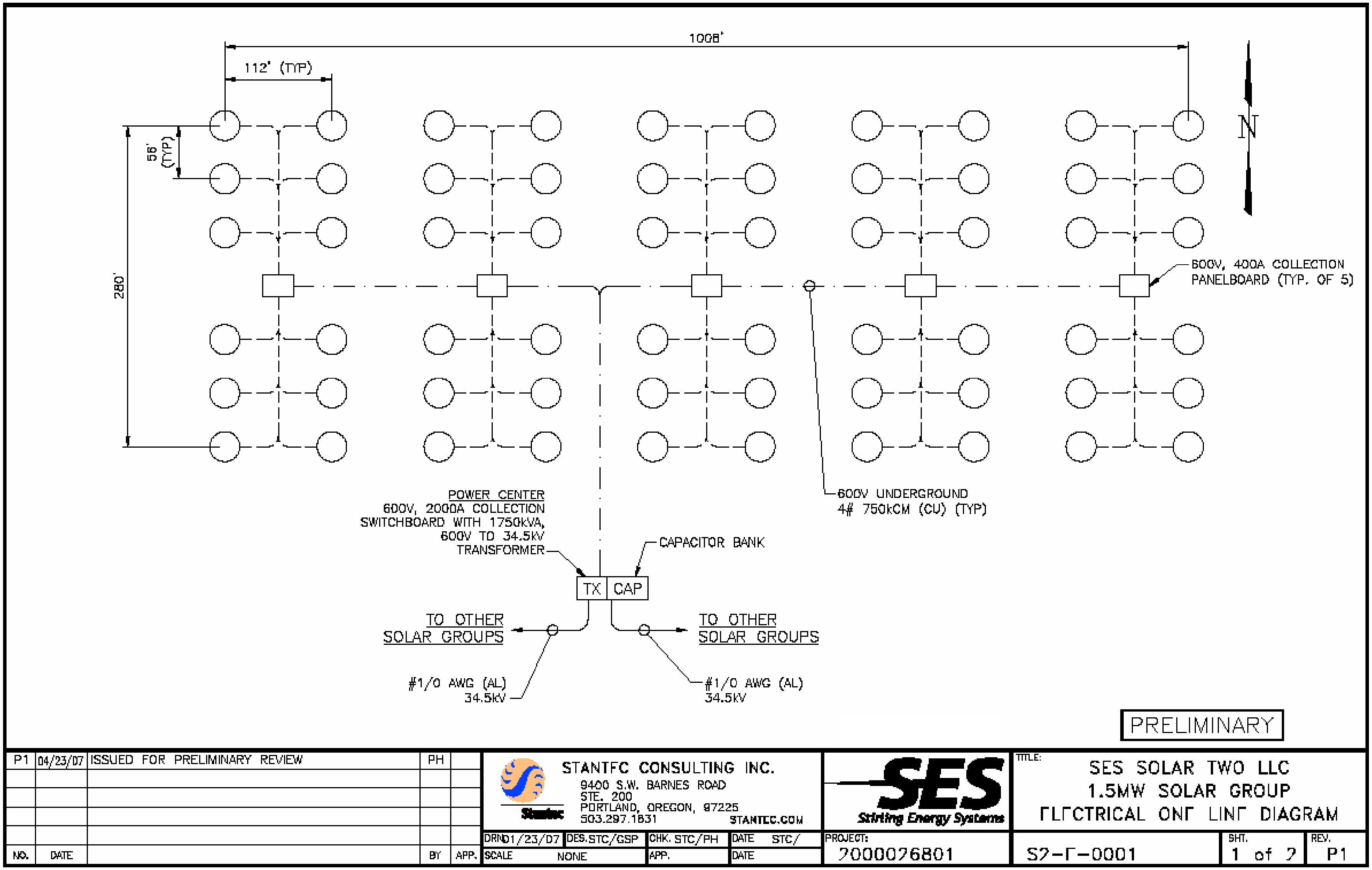

1.5MW Solar Group Electrical One Line

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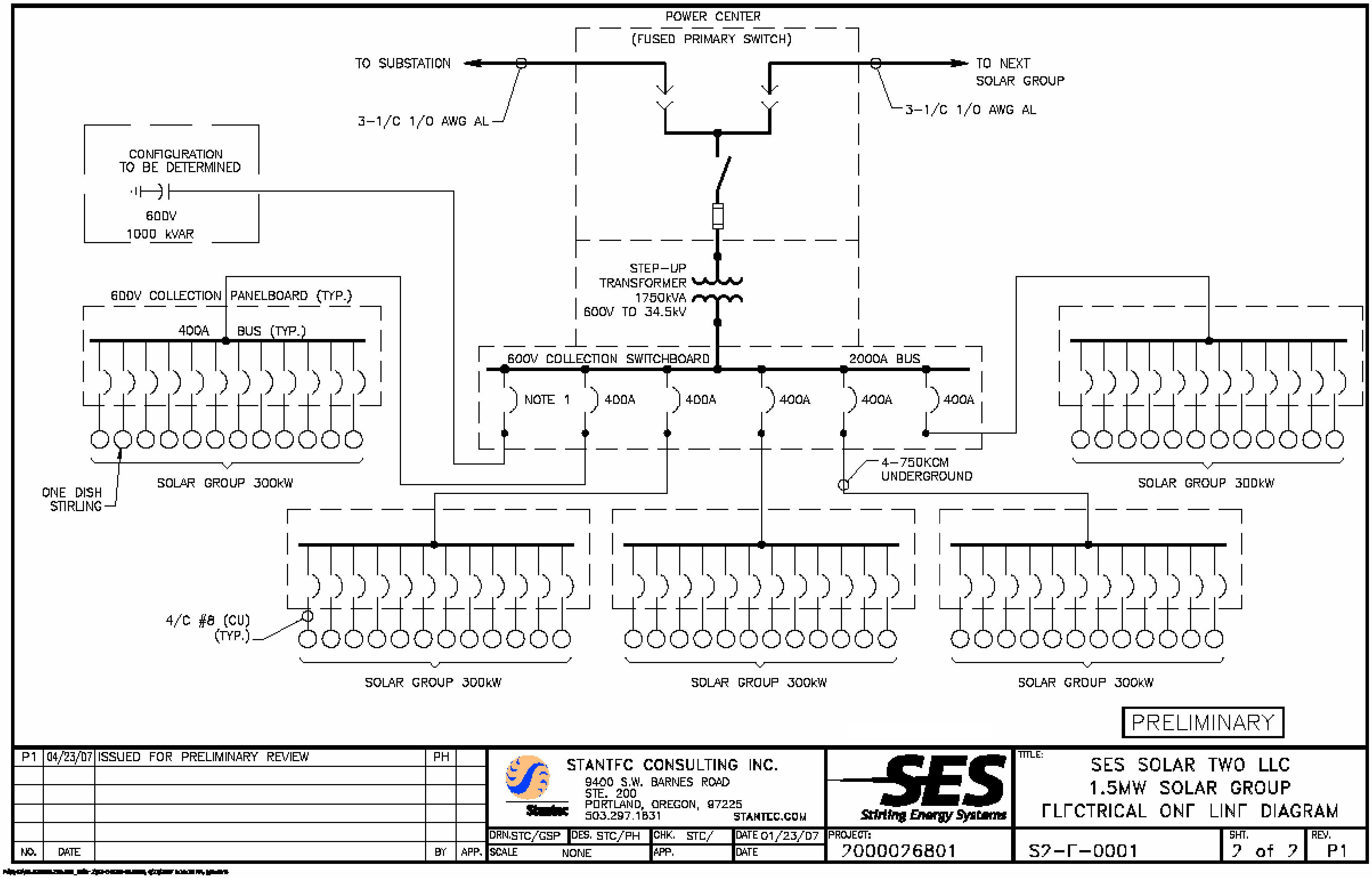

Solar Field Consists of 18MW & 24MW Blocks Made up of Three or Four 6MW Groups Each Consisting of 1.5MW Groups

(Collection Voltage after 1.5MW Group is 34.5kV)

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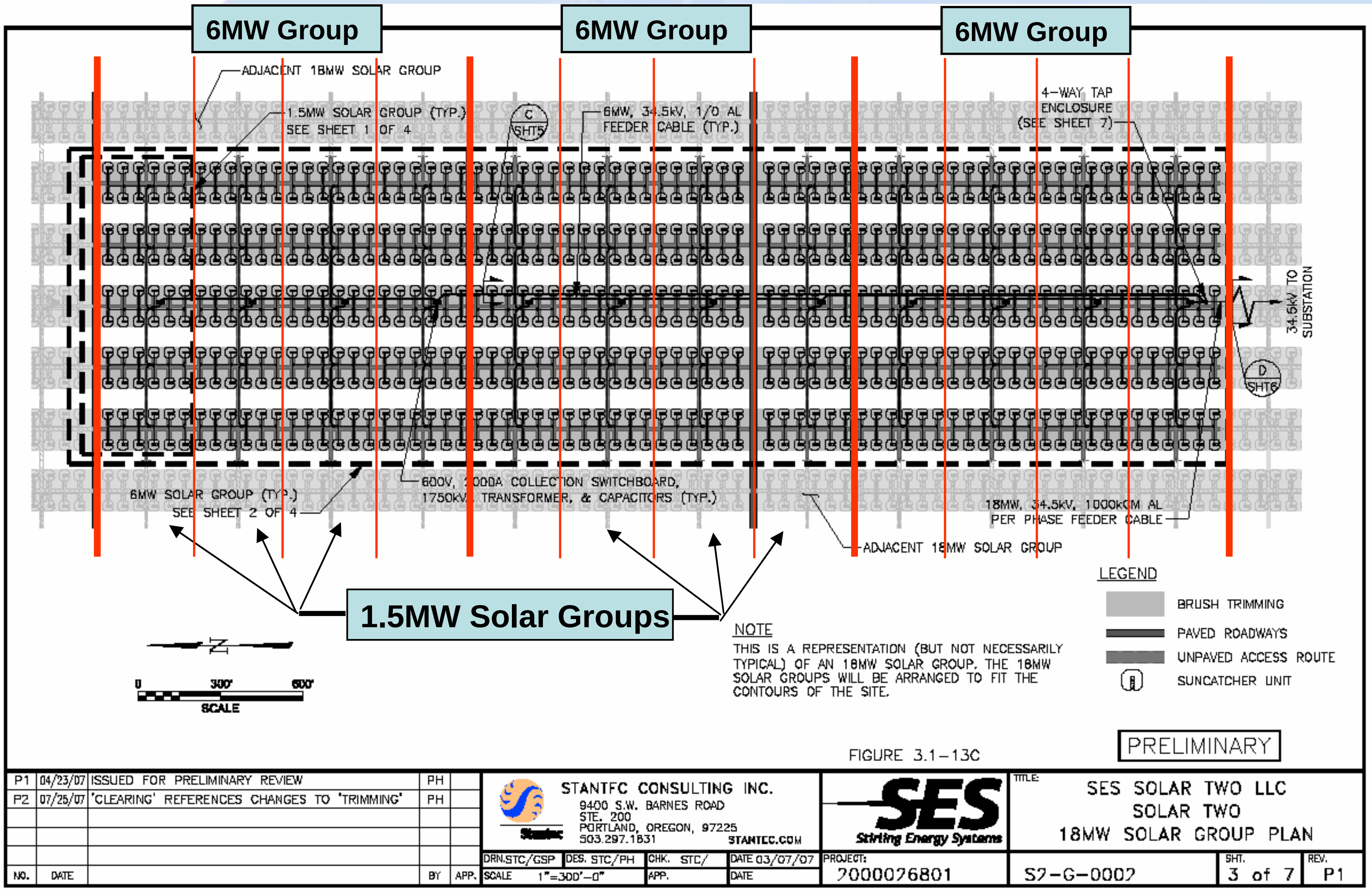
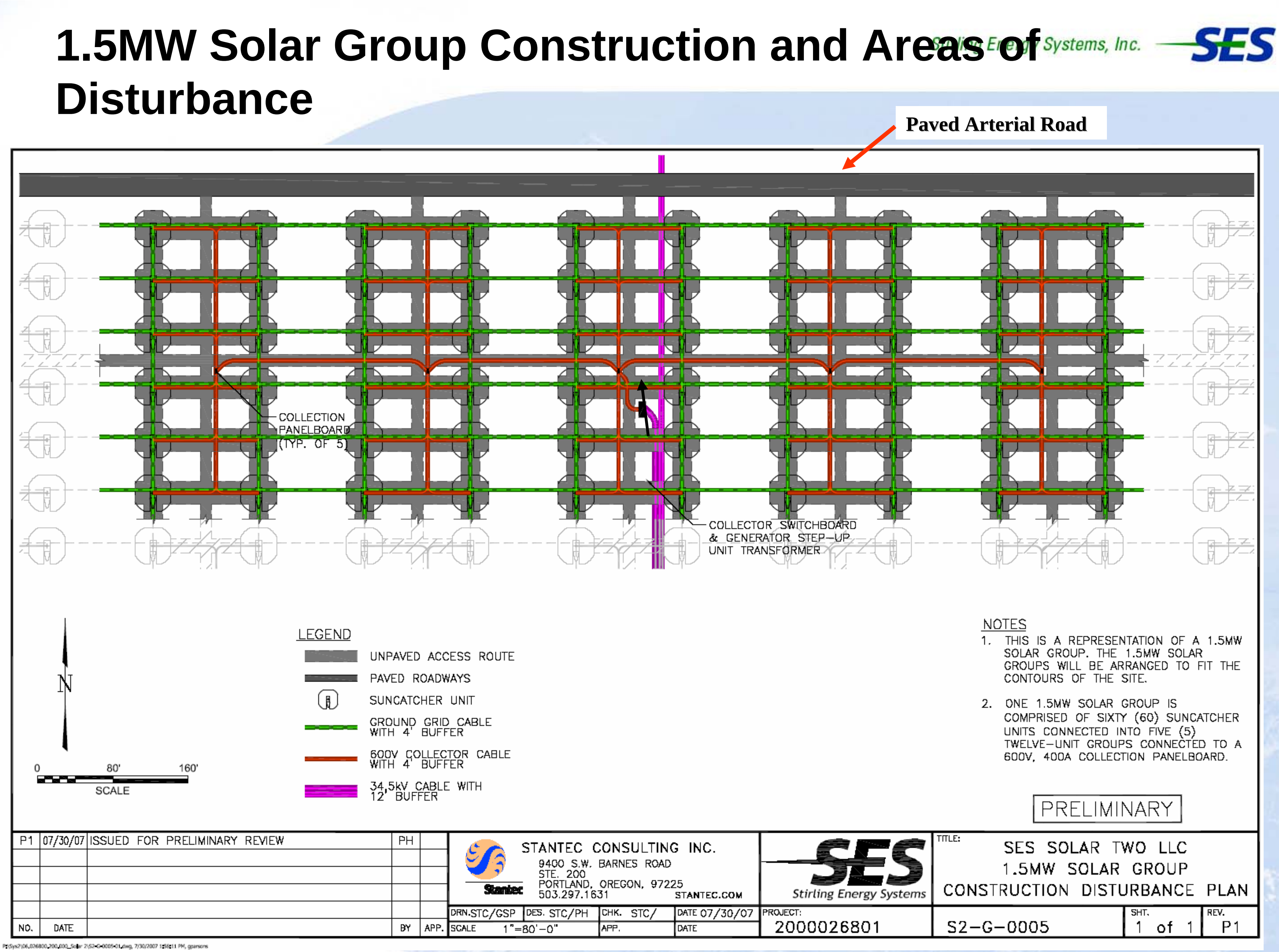


1.5MW Solar Group Construction and Areas of Disturbance



Aerial Rendering of a Typical Portion of the Solar Field (SunCatchers Facing Southwest On-Sun)

Proposed Sprung Structures For Assembly

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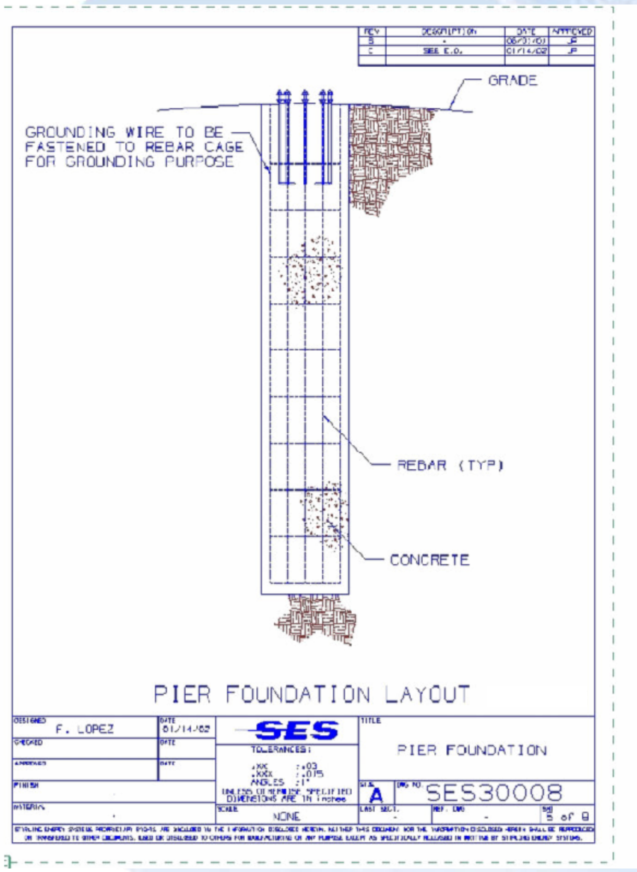
Engineered Structures:

- Re-locatable
- Designed to meet all seismic, wind and weather conditions
- Reduced construction cost and timelines

Concrete Caisson SunCatcher Foundation (Conventional)



Metal Fin-Pipe SunCatcher Foundation (Under Evaluation)

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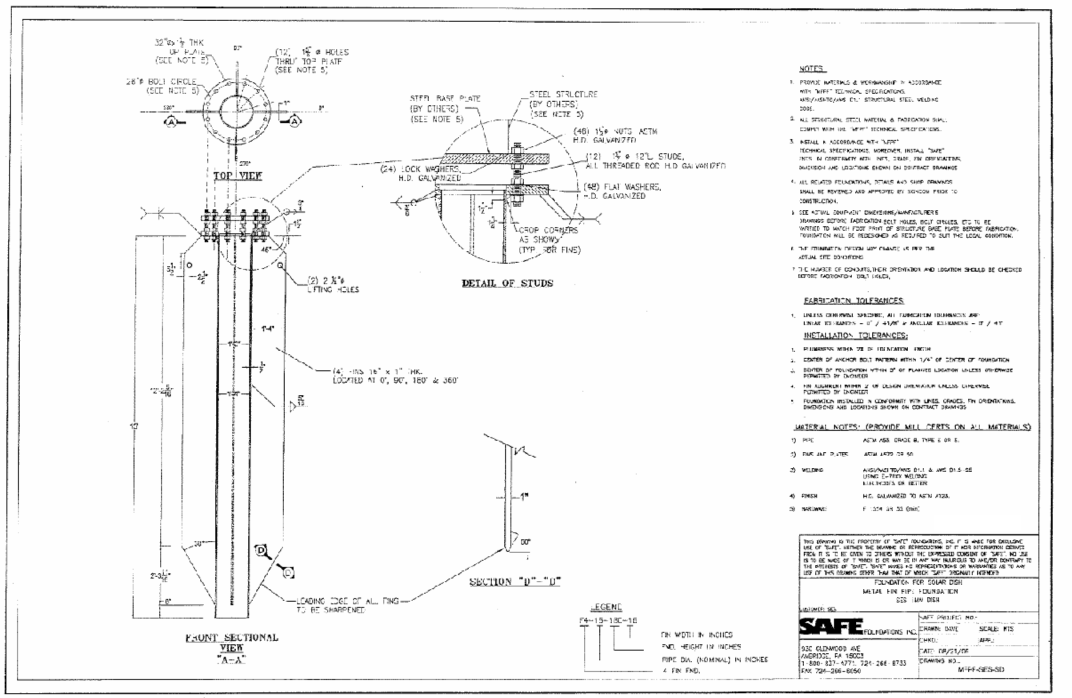
- ✓ One of Several Options being studies that do not require Concrete
- ✓ Engineered to all Seismic, Wind and Soils Conditions
- ✓ Speed of installation, estimated at less than 30 minutes per foundation
- ✓ Able to accept SunCatcher load immediately after installation, no concrete curing time required



Computational Fluid Dynamic Modeling of Multi-Dish Array for Wind Effects Analysis

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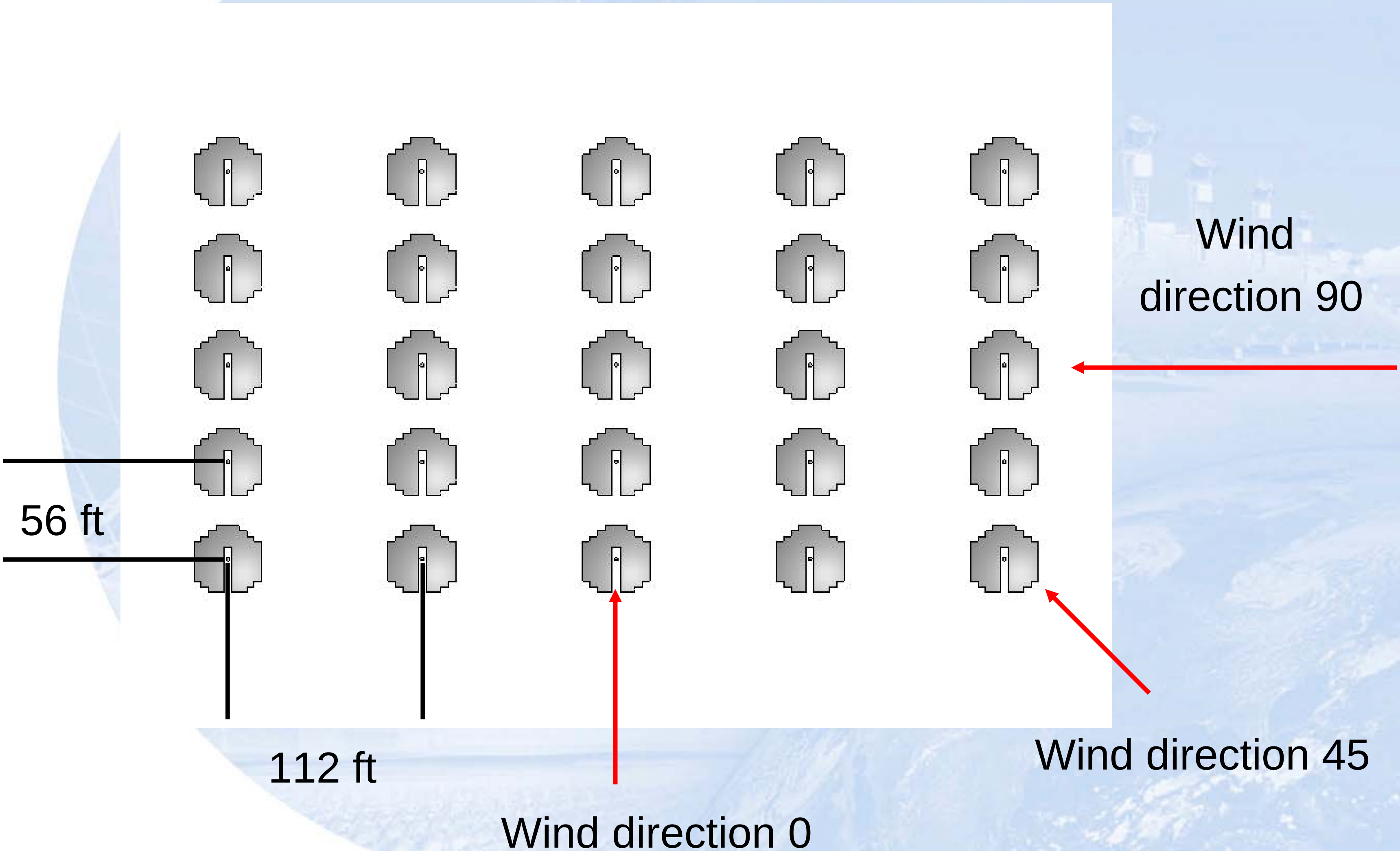
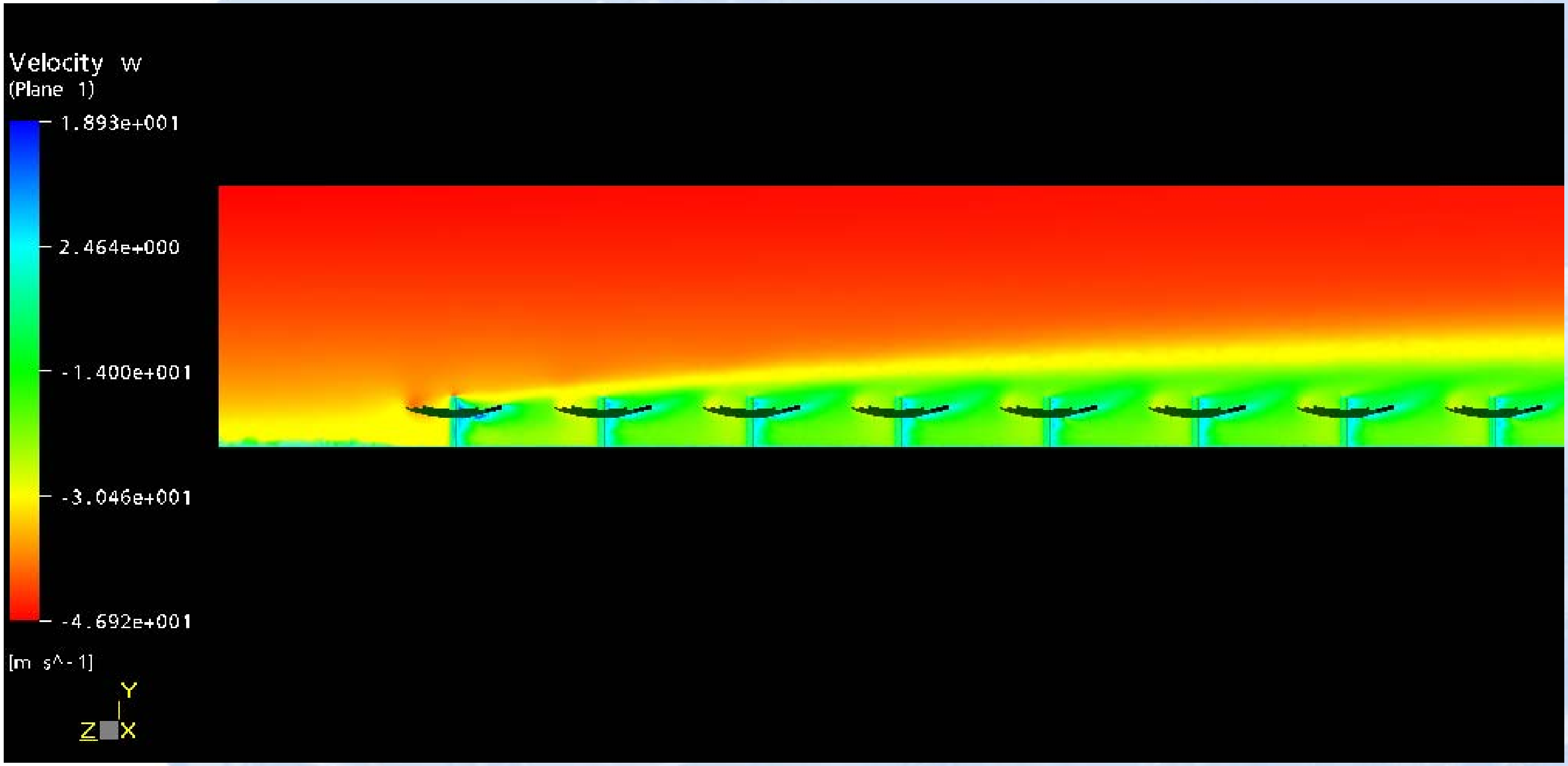
Top View of the 5-by-5 Field



Flowfield Development, 0 Degrees

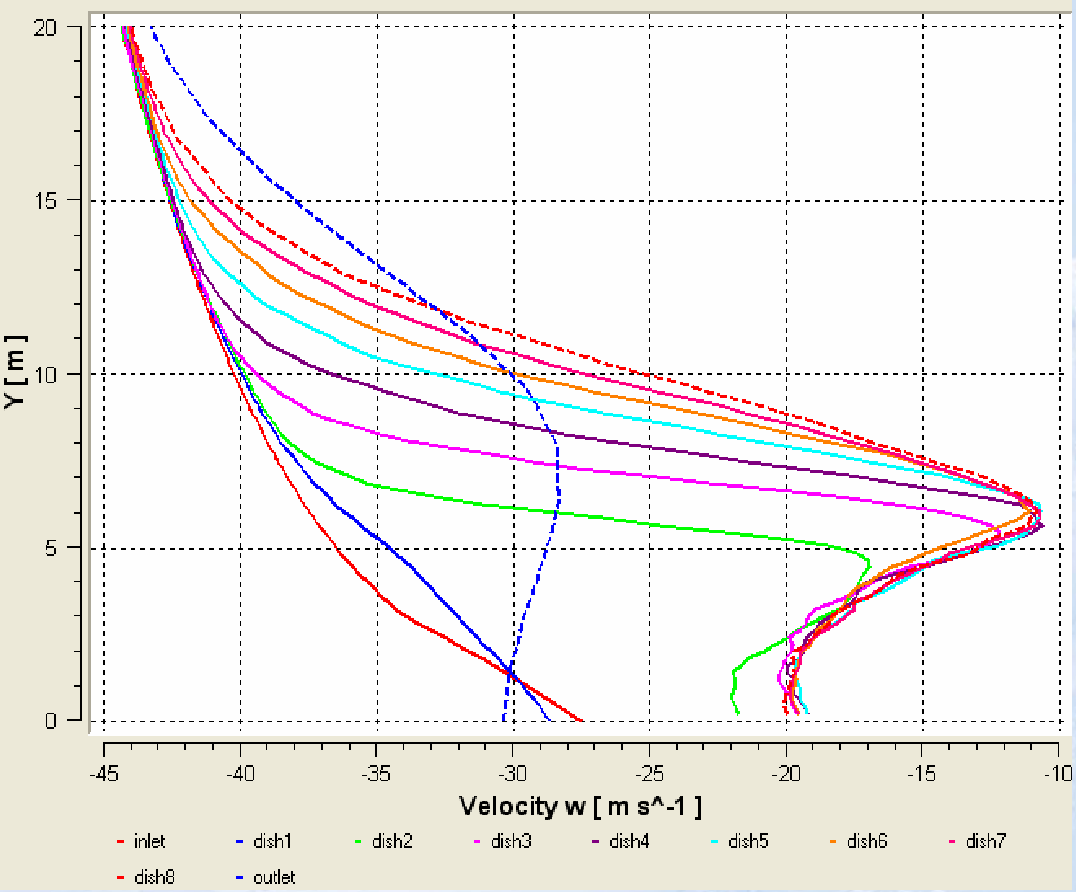
Stirling Energy Systems, Inc. SES



Notice that only the first dish is affected by the full wind load and the remaining dishes only encounter the wake flow of the first dish.

Velocity Profiles, 0 Degree Wind Direction

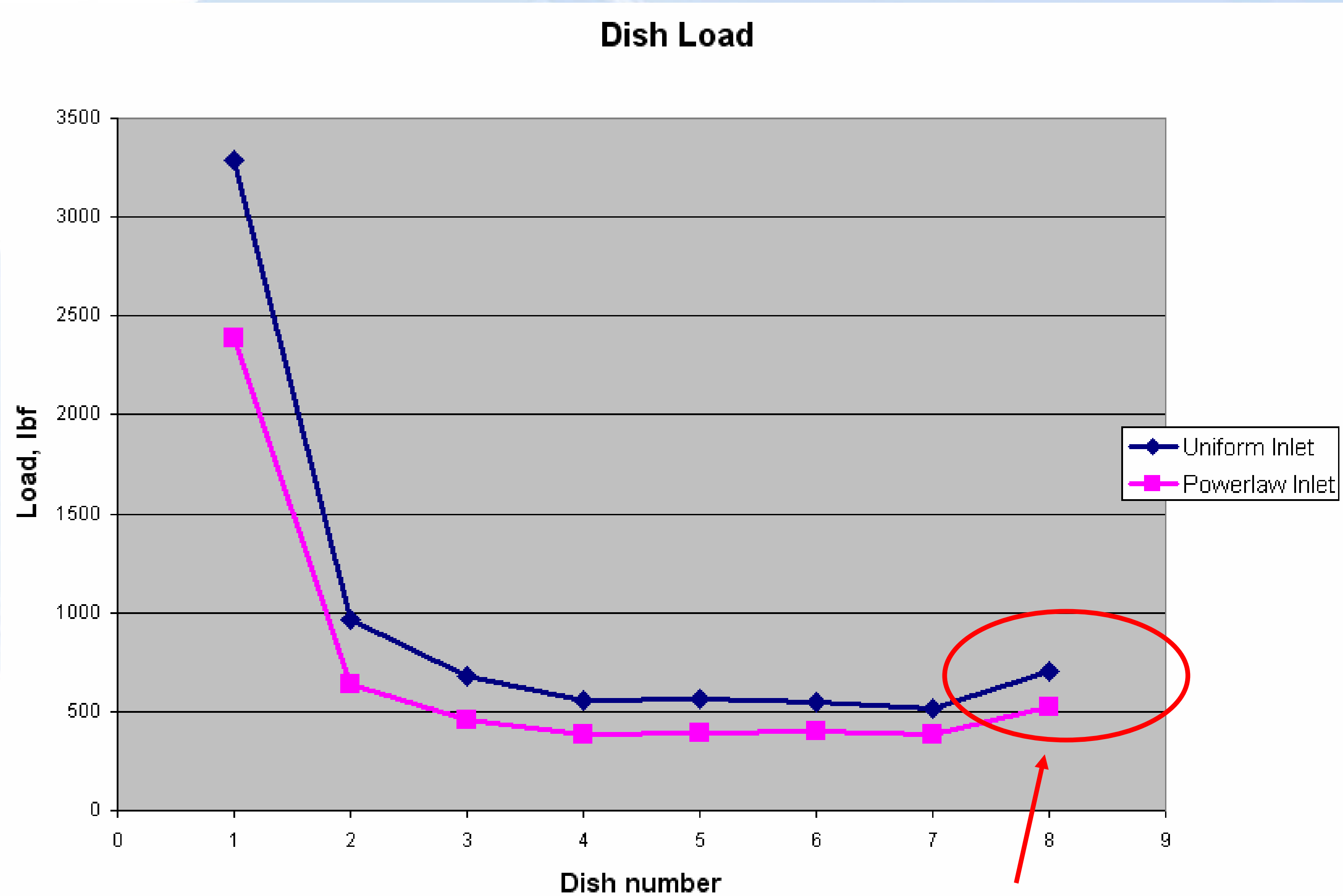
Stirling Energy Systems, Inc. SES



Note that the velocity profiles for dishes 3-8 are very similar, i.e. the boundary effect is limited to the first two rows

Mirror Loading, 0 Degree Wind Direction

Stirling Energy Systems, Inc.

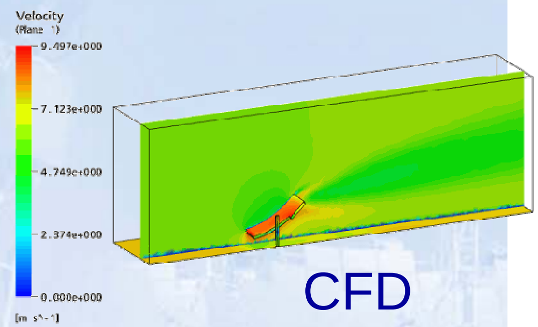


Increase in load due to unobstructed wake

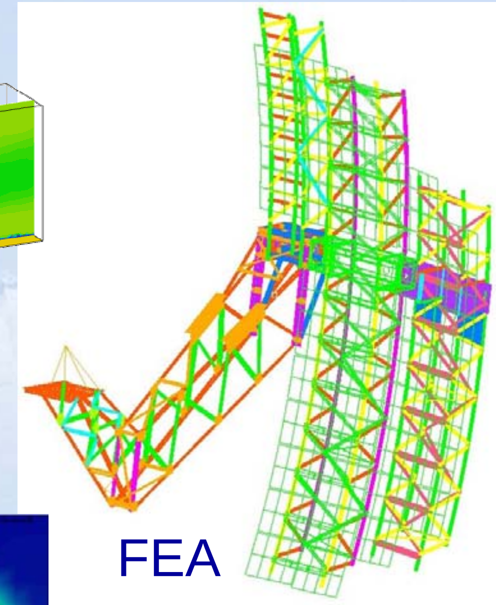
Structural Design Tools

Stirling Energy Systems, Inc. SES

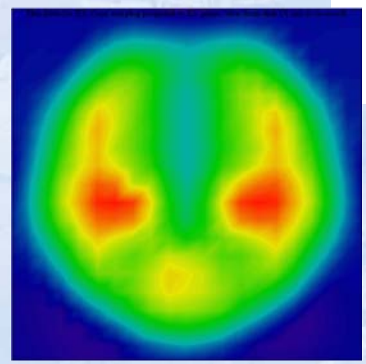
- ✓ **Systems Design Tool**
  - CFD Wind load model
  - FEA structural model
  - CIRCE2 optical model
  - MathCad user interface
- ✓ **Provides Structural Designer with True Metric**
  - Deflection impact on flux distribution
- ✓ **Empirical Validation of Tools**
  - Fluxmapper
  - Deflection measurements



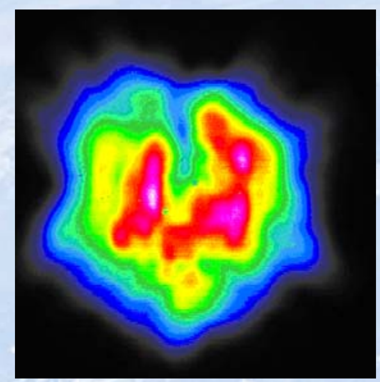
CFD



FEA



CIRCE



Flux Mapper

Systems Design Tools

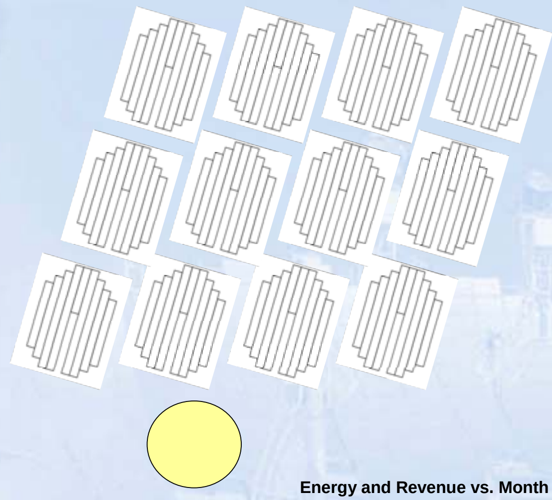
Stirling Energy Systems, Inc. SES

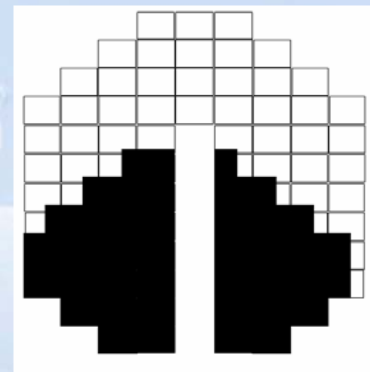
✓ **Field Layout Optimization**

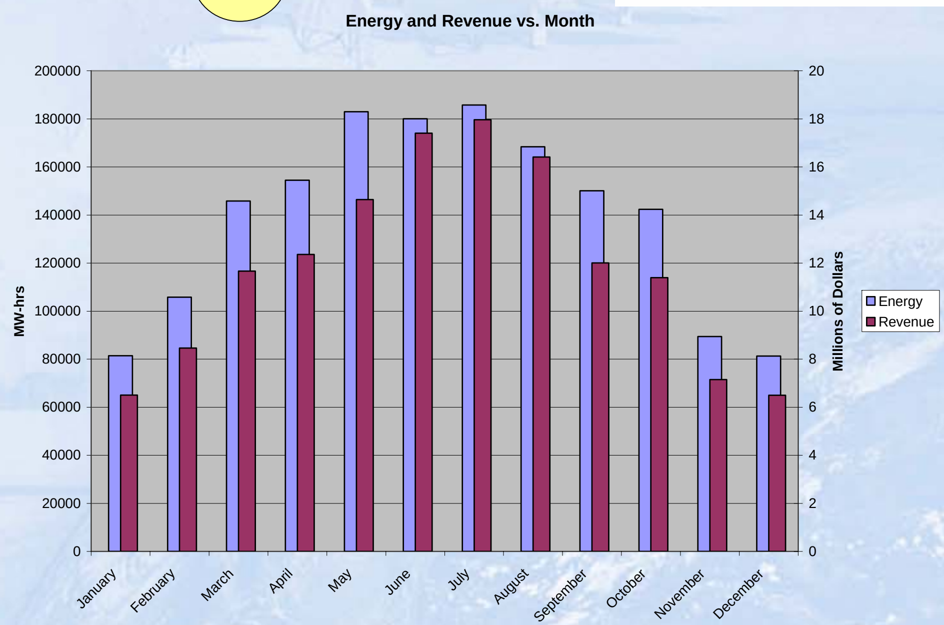
✓ **Features**
- Row stagger
- TOD and TOY electricity value
- Edge effects

✓ **Shading Model**
- True dish shape
- Incorporates real shading performance degradation
- Input TMY2 or 15-minute Solar 2 data

✓ **Results**
- Shade shape validated with hardware



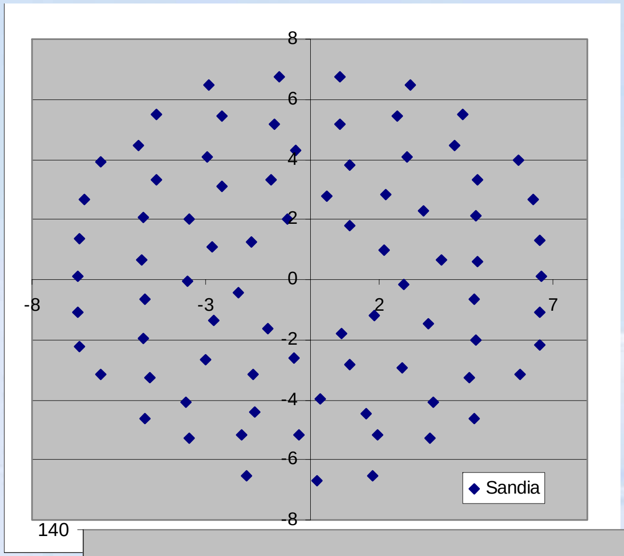


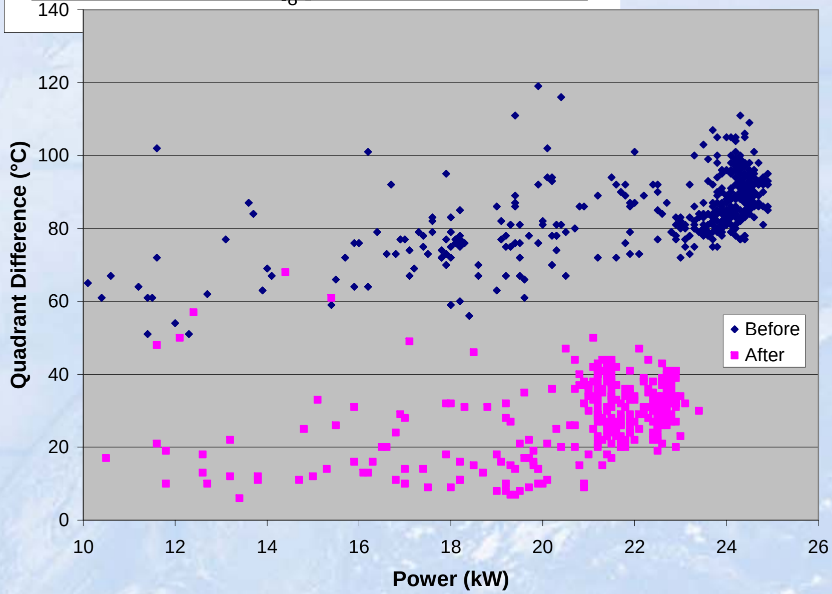


Dish Alignment Tools

Stirling Energy Systems, Inc. SES

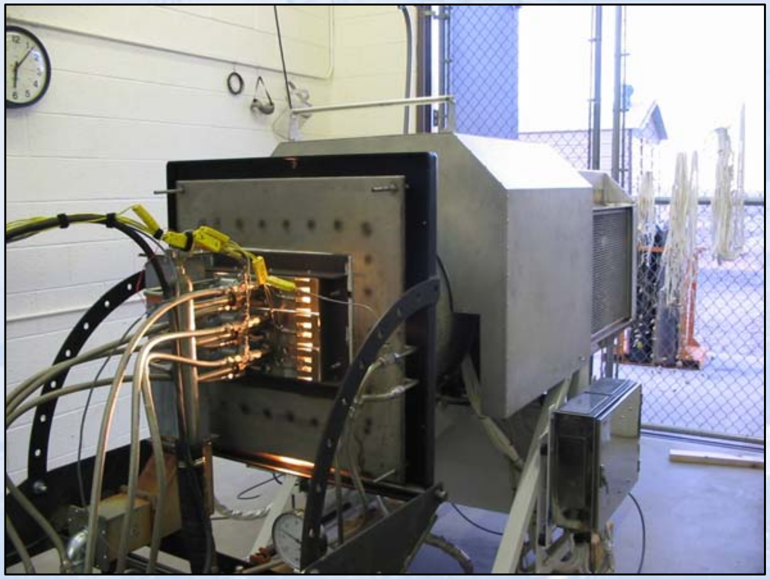
- ✓ Optimize aim point using molecular dynamics-like code
- ✓ Increase output with existing aperture design
  - – 1 to 1.5 percentage points performance improvement
- ✓ Uniformity
  - – Reduced quadrant difference from near 100C to 20C
  - – Increases operating “headroom”
- ✓ Aperture effects
  - – Aperture 7.5” diameter, compared to MDAC at 9.5”
  - – Expect 0.5kW$_e$ additional output





Development Facilities

- ✓ Model Power Plant – Sandia Site
- ✓ Engine Test Facility
  - Assembly and documentation development
  - Lamp bank testing (short term)
  - Gas fired testing (long term cyclic)
- ✓ Electronics Lab: SES Controls Simulator
  - Critical to next-generation software development
- ✓ Sandia National Laboratories
  - Materials
  - Manufacturing
  - Failure analysis
  - Lightening protection
  - Facilities



FRACAS Implementation Underway

Failure Reporting Analysis and Corrective Action System

XFRACAS Also Includes..

- ✓ Tracking of part repair/replacement and serialized system configuration management.
- ✓ Integration with reliability analysis engines including part life calculations, system reliability and reliability growth analyses
- ✓ Interactive graphical interface.
- ✓ Web-based- easy access, collaboration and deployment to multiple sites.
- ✓ Reliability data/history repository
- ✓ Framework for FMEA and failure analysis.
- ✓ Flexible and scalable enterprise system.

- **Tests are conducted at various product levels:**
  - Component
  - Subsystem
  - System
  - Power Plant
- **Types of Testing**
  - Proof-of-concept
  - Development/Commercialization
  - Integration
  - Requirements Validation
  - Endurance
- **Test Locations**
  - Suppliers
  - Sandia National Labs
    - Fossil-fuel fired engine test cell
    - Model Power Plant Dish Stirling units
    - Bench test facilities
  - Stirling Engine Test Cells

Test Planning – Example

Stirling Energy Systems, Inc. SES

Component	Phase 3 Product Definition: Bench	Phase 3 Product Definition: Integration	Phase 3 Product Definition: Validation	Phase 3 Product Definition: Endurance	Phase 4 Tech Data Package: Bench	Phase 4 Tech Data Package: Integration	Phase 4 Tech Data Package: Validation	Phase 4 Tech Data Package: Endurance	Phase 5 Test and Readiness: Bench	Phase 5 Test and Readiness: Integration	Phase 5 Test and Readiness: Validation	Phase 5 Test and Readiness: Endurance	Phase 6 Low Rate Initial Production: Bench	Phase 6 Low Rate Initial Production: Integration	Phase 6 Low Rate Initial Production: Validation	Phase 6 Low Rate Initial Production: Endurance
Dish Structure	X				X						X					
Mirrors	X				X						X	X			X	X
Drives	X				X						X	X			X	X
Dish Controls	X				X						X	X			X	X
Radiators	X				X						X	X			X	X
Seals	X			X	X			X			X	X			X	X
Sensors	X		X	X	X		X	X			X	X			X	X
Heater Heads	X		X	X	X		X	X			X	X			X	X
Regenerators	X		X	X	X		X	X			X	X			X	X
Coolers	X		X	X	X		X	X			X	X			X	X
Cold Engine Parts	X				X		X	X			X	X			X	X
PCU Controls	X				X						X	X			X	X
SCADA	X				X						X	X			X	X

Operations and Maintenance (O&M)

Stirling Energy Systems, Inc. SES

- ✓ Solar Dish Stirling system and overall power plant are designed to minimize O&M costs
  - Modular design for ***Ease of Maintenance***
  - 25kW units in 1.0 – 1.5 MW groups provides ***High Availability***
  - Quick R&R with "rotatable" spares **Minimizes *"Down-time"***
  - Self-contained vehicles enable ***Efficient Maintenance Actions***
  - Power Conversion Unit (PCU) design allows ***Low Cost Overhauls***
- ✓ Overhaul philosophy uses two maintenance levels…
  - Line (field)
  - Depot (on-site repair facility)
- ✓ Automated monitoring and decision-making systems via SCADA (Supervisory Control and Data Acquisition) provide O&M efficiencies

Pathway to Commercialization

Stirling Energy Systems, Inc. SES

Past… Today
"Technology"

"PATHWAY"

"Bridging the Gap"

"Commercialization"

Starting Point

- ✓ 20 Year History
- ✓ Development units
  - HB, NV, SA, SNL
- ✓ Model Power Plant
  - 6 Systems
  - SES Supply Chain

Commercialization Program

- ✓ Product Commercialization
- ✓ Supply Chain Development
- ✓ Expand Company Infrastructure
- ✓ Model Power Plant
- ✓ 1 MW Pilot Project
- ✓ SCE and SDG&E Projects

Goals

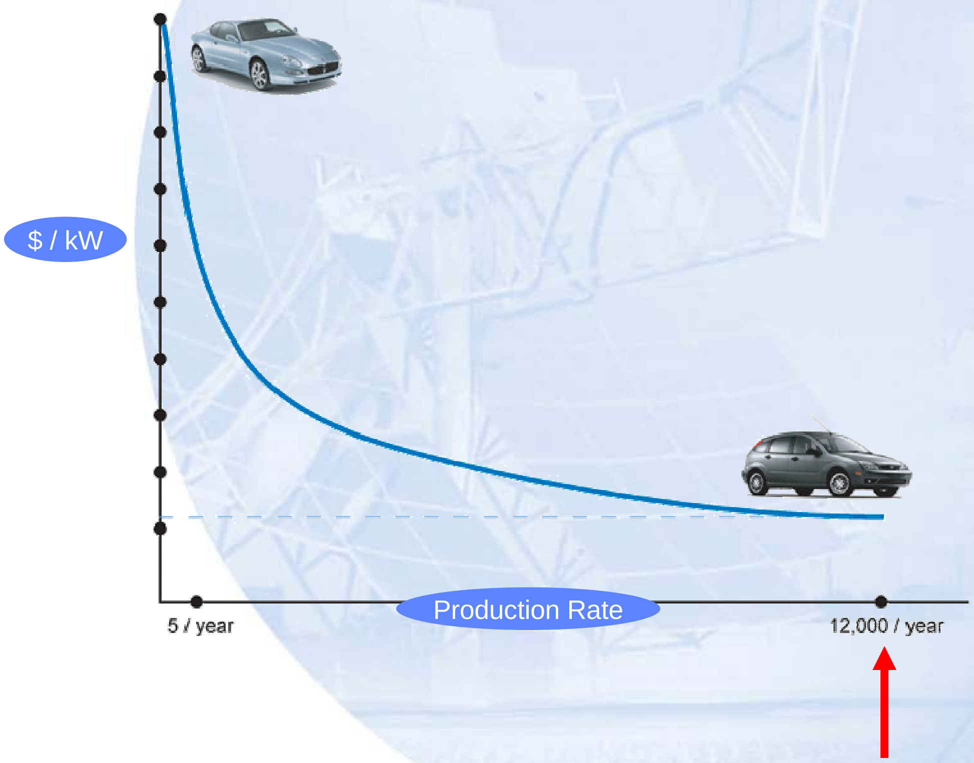
- ✓ US & International Markets
- ✓ US Based Supply Chain with Global Reach
- ✓ Ultra-Low Cost Systems
- ✓ High Volume Manufacturing
- ✓ 5,000 MW by 2018

The Commercialization Program is the pathway to fulfilling production contracts

High Volume, Low Cost Manufacturing Model

Stirling Energy Systems, Inc. SES

- ✓ SES is <u>leveraging potential strategic partners and key suppliers</u> to transform hand-built units into a high performance, low-cost product
- ✓ <u>Significant cost reductions</u> are possible based on a learning curve approach widely used in industry

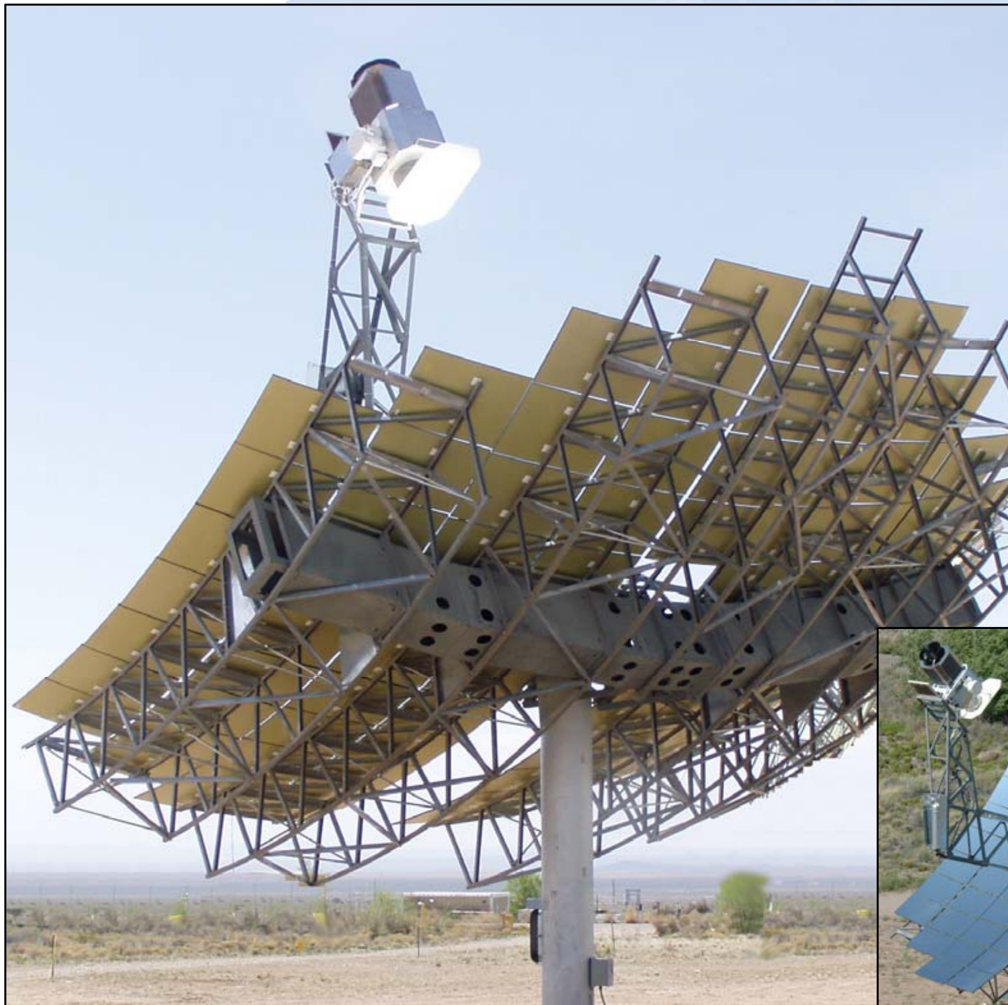


Cost Reduction Drivers:

- ✓ Economies of Scale
- ✓ Automation
- ✓ Simplify product / reduce number of parts
- ✓ Off-the-Shelf Components
- ✓ Simplify assembly

Keys to Cost Reductions

Stirling Energy Systems, Inc. SES



Keys to Cost Reductions

- **Design Optimization**
- **Maximum Automation** - Invest in Proper Equipment
- Use of **Off-the-Shelf Commercial Hardware** Whenever Possible
- Dedicated **High Volume Manufacturing**
- **Large Central Station Generation Application**

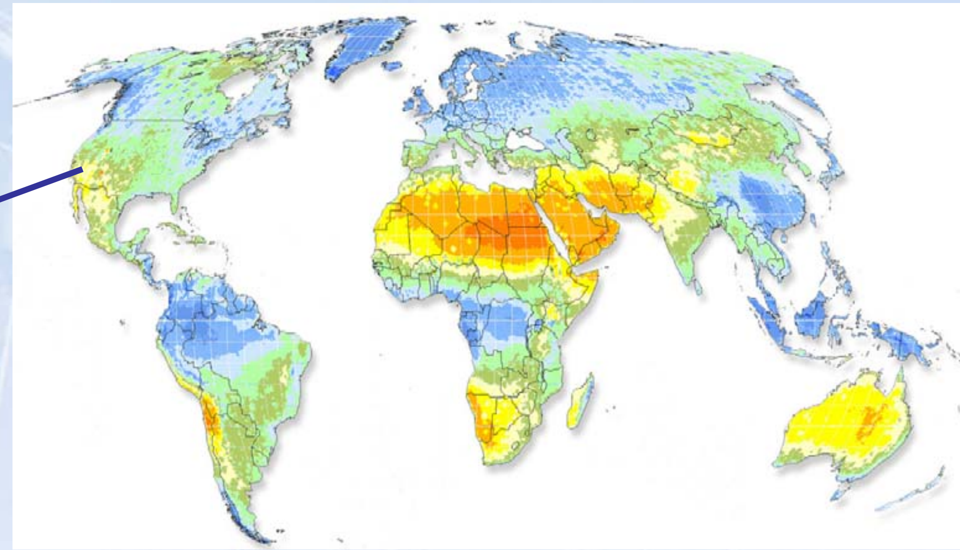
A New Generation of Solar Power

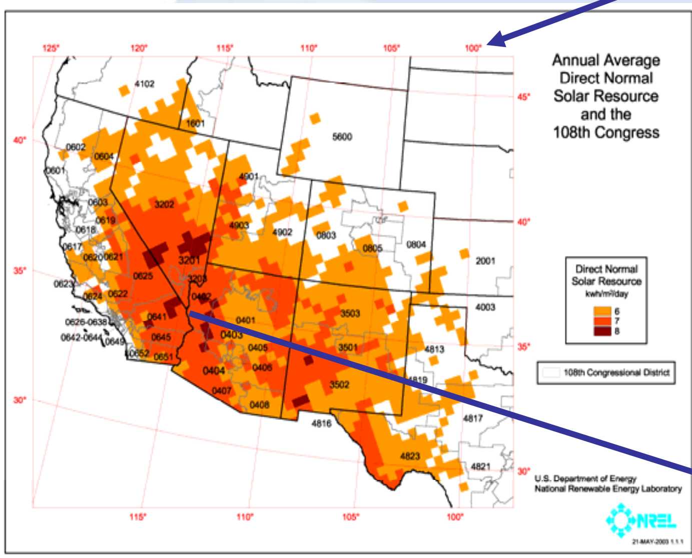
Stirling Energy Systems, Inc. SES

- ✓ The SES Solar Technology is the ***world's most efficient solar technology*** (conversion of sunshine to grid-quality electricity)
- ✓ Proven and backed by ***20+ years of testing*** of the Solar Dish Stirling Engine
- ✓ ***Launching commercialization phase for high volume production***
- ✓ Leveraging strategic partners and suppliers for ***low cost manufacturing***
- ✓ Pursuing ***future siting opportunities*** for continued growth

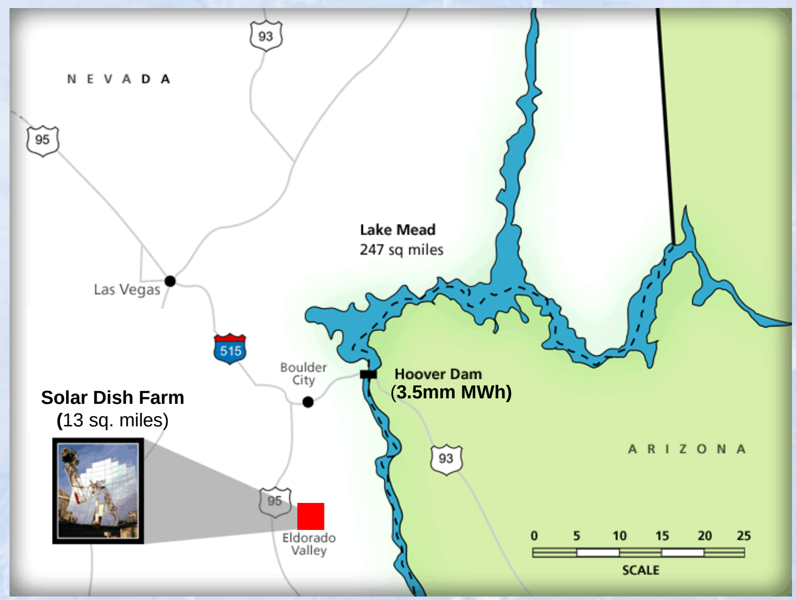
Solar Energy is an Abundant, Clean, and Free Resource

***FACT:* 1,750 MW of SES Solar Systems can displace 1.8 million tons of coal consumption per year – reducing CO_2 emissions by 4 million tons**





***FACT:* 13 square miles of SES Solar Systems can produce power equivalent to the Hoover Dam - in an area less than 5% of the size of Lake Mead**

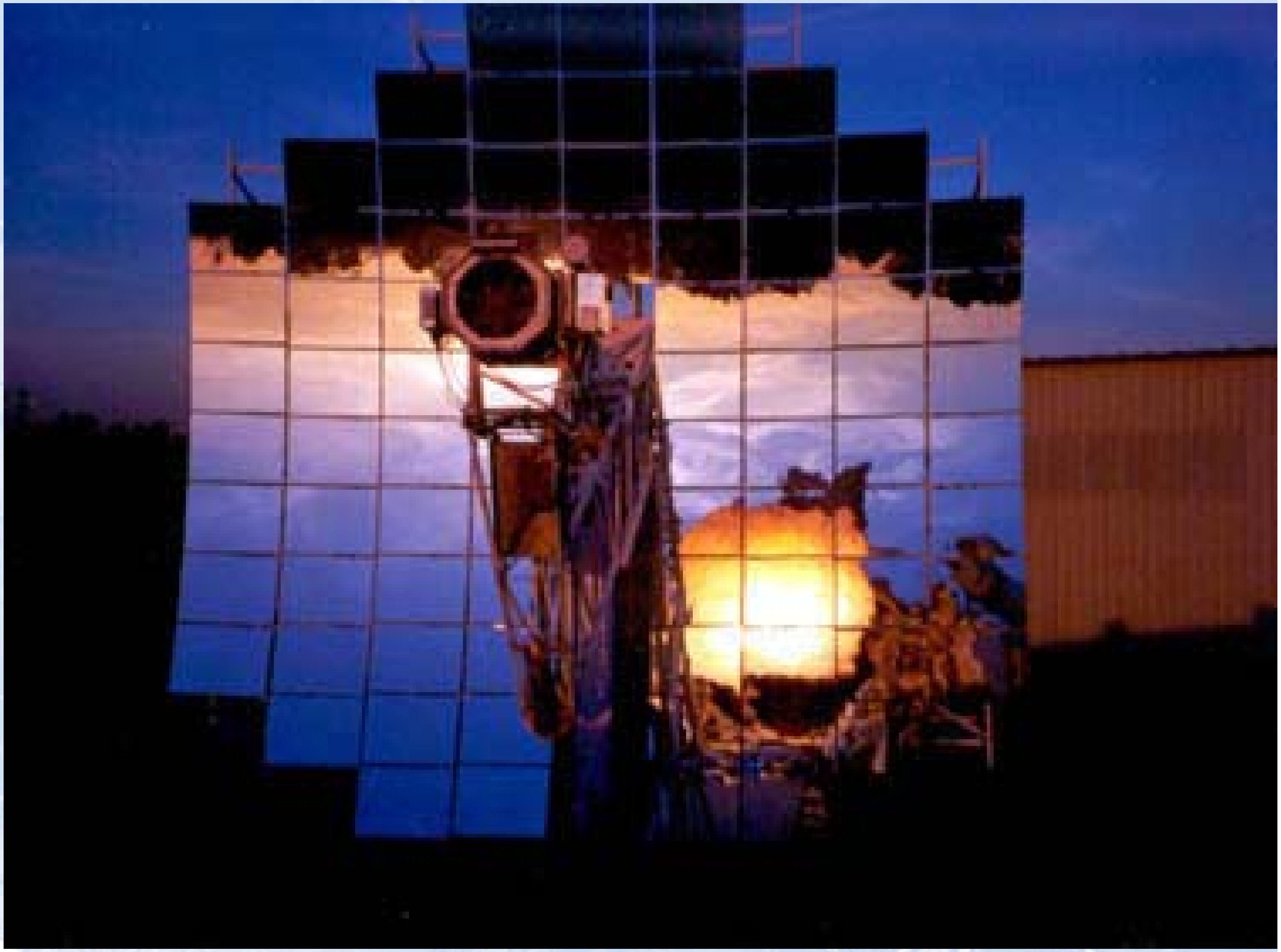


Tour of the SES Model Power Plant at Sandia By President Bush

Stirling Energy Systems, Inc. SES

The Dawn of Efficient Large-Scale Solar Power
"The SES Stirling Technology"

Stirling Energy Systems, Inc. SES



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