# Integration of the Advanced Dish Development System

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**Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.**

# Dish/Stirling is the Original Solar Power Technology

- Dish-engine systems use heat engines to produce useful work
- Dish-engine systems were developed in the 1800s
- Dish/Stirling is inherently more efficient and lower cost than PV
- Dish/Stirling is inherently more complex than PV

Pasadena Ostrich Farm
Circa. 1903

# Dish/Stirling Characteristics

- Stirling engines use reciprocating pistons and heat exchangers to alternately compress, heat, expand, and cool a gaseous working fluid
  - Similar to automotive engines in manufacture and complexity
- Thermodynamic cycle similar to Carnot cycle
  - Engine brake efficiencies >40%
  - System net efficiency near 30%
- High pressure hydrogen or helium typically used in modern high-performance Stirling engines
  - High heat transfer rates tolerant to non-uniform flux distributions
  - High-pressure (20 MPa) hydrogen systems have many components in common with future solar hydrogen generation plants

# Advanced Dish Development System Background

- The U.S. Department of Energy has supported the development of dish/engine technology for decades
  - Advanco, SAIC, Cummins, Allied Signal, Boeing, SES
- Sandia and NREL have performed component R&D and provided technical support for contractor development activities
- Sandia's core competencies include concentrating solar power (CSP) and systems integration but Sandia had never integrated a CSP system
- The ADDS is the first CSP system ever integrated by Sandia

# Advanced Dish Development System Background (cont.)

- D.O.E. interest in helping Native American tribes in 1998 provided an opportunity
- Sandia proposed developing small dish/Stirling systems to address Native American remote power applications
  - Did not compete with commercial development focused on utility applications
  - Provided a systems level test bed for advanced components and remote power technology
- 9-kWe system proposed based on WGAssociates and Solo technology
  - WGA inherited outstanding Cummins controls and had developed innovative concentrator structure design
  - Sandia/Paneltec mirrors looked promising and ideal for WGA structure
  - Excellent experience with SOLO 161 Stirling engine at Ft. Huachuca

# Advanced Dish Development System Philosophy

- Work with American Indian tribes
  - Survey applications and visit sites
  - Water pumping identified as universal need
  - Better understand requirements by conducting training on our first prototype (Mod 1) grid-connected system
- Instill a "product" development mentality
  - Avoid expensive/complex solutions
  - Address all requirements in order of priority

# Advanced Dish Development System Philosophy (cont.)

- Utilize proven components
  - WGA concentrator and controls had benefit of decades of development
  - SOLO 161 well developed and previously integrated with WGA controls at Ft. Huachuca
  - Excellent cooperation with WGA and Solo
- Start with established grid-connected power management for Mod 1 to get into reliability improvement as soon as possible
- Initiate unattended operation as soon as possible
  - Cost of failure less than attended operation
  - Find problems sooner

# Advanced Dish Development System Requirements and Approaches

| System Requirement | Approaches |
|---|---|
| Reliability and durability | Initiate design and operation of grid-connected system.<br>Initiate automatic operation and internet access as soon as possible.<br>Establish reliability tracking and improvement processes.<br>Reduce stress on SOLO 161 PCU by switching to hydrogen working fluid.<br>Reduce stress on SOLO 161 PCU by reducing concentrator area.<br>Relentlessly pursue solutions to identified root causes. |
| Unattended automatic operation | Implementation of remote communications.<br>Development of robust closed-loop tracking sensors and algorithms<br>Development of low-cost sun sensor. |
| Stand-alone water-pump capability | Explore and rate power management options.<br>Test selected power management approach using gas-fired generator set.<br>Install and program engine crossover valve to facilitate PCU start up. |

# Advanced Dish Development System Requirements and Approaches (cont.)

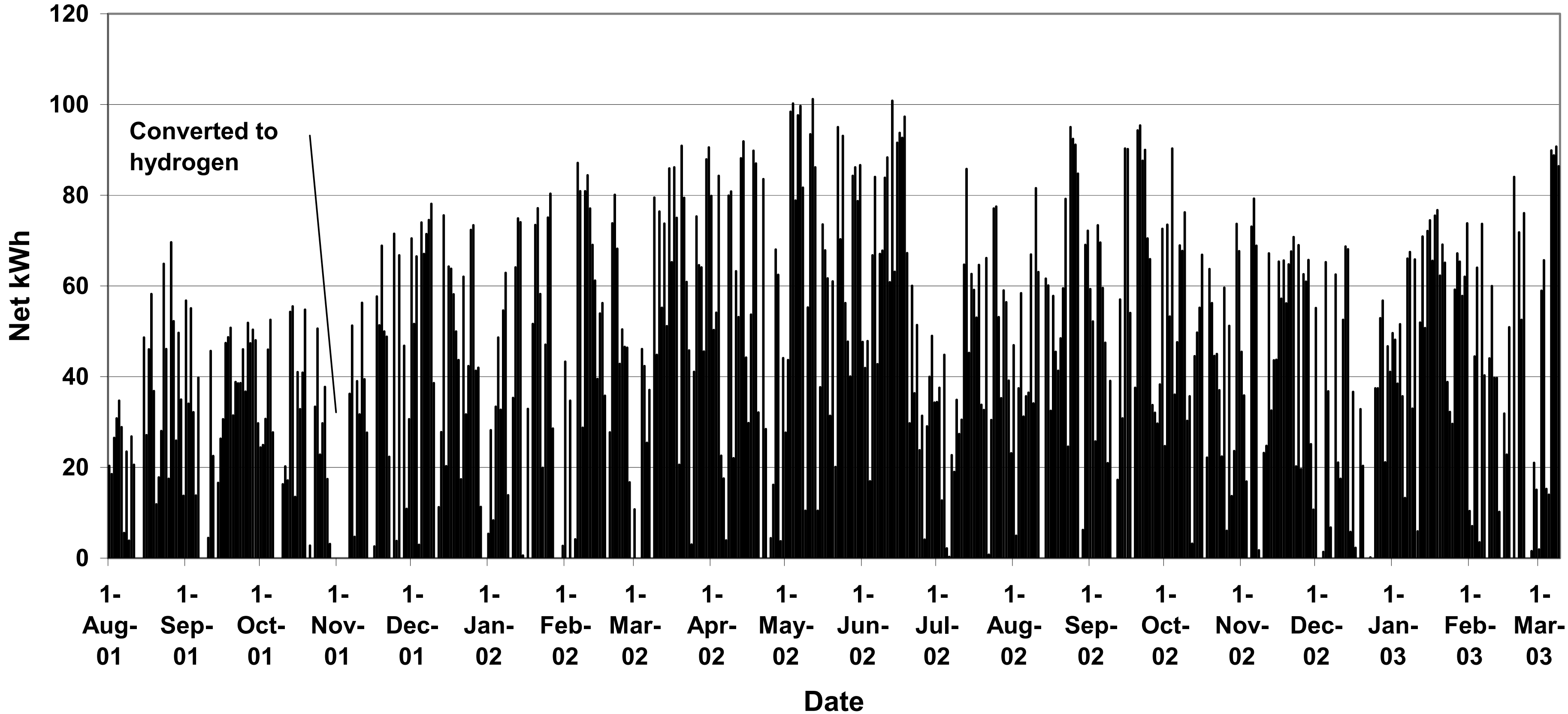
| System Requirement | Approaches |
|---|---|
| Safe and easy to use and maintain | Engineering staff required to participate in all aspects of O&M.<br>Slew rate increased to 38 degrees per minute to reduce wait time.<br>Dish kneels down for near ground level PCU access.<br>Push button operation and automated safe slewing implemented.<br>Mirror cleaning techniques for the field developed.<br>Development of field maintenance repair tools and techniques.<br>O&M Documentation. |
| Capable of being installed in remote locations | Design universal foundations suitable for remote locations.<br>Develop self-erection hardware and approaches.<br>Factory pre-assembly and pre-wiring where possible.<br>Mirror alignment procedures developed for night and day alignment. |
| Low cost | Utilize most developed components available.<br>Simplify component designs when possible.<br>Increase system performance by switching to hydrogen working fluid. |

# Advanced Dish Development System Remotification

- Water pumping selected for remote application
  - Universally of interest by Native American tribes
  - Large potential market
  - Avoids complex energy storage and power management issues (store water)
- Use of synchronous generator driving standard 10 hp three-phase 480-volt submersible water pump motors at variable speeds was selected for power management
  - Automotive starter used for starting engine
  - Simple, low cost, and no inverters needed
- Second-generation (Mod 2), off-grid, stand-alone water-pumping system developed and testing initiated July 5, 2001

# Advanced Dish Development System

## Mod 1 Net Daily Output Aug 1, 2001 – Mar 9, 2003

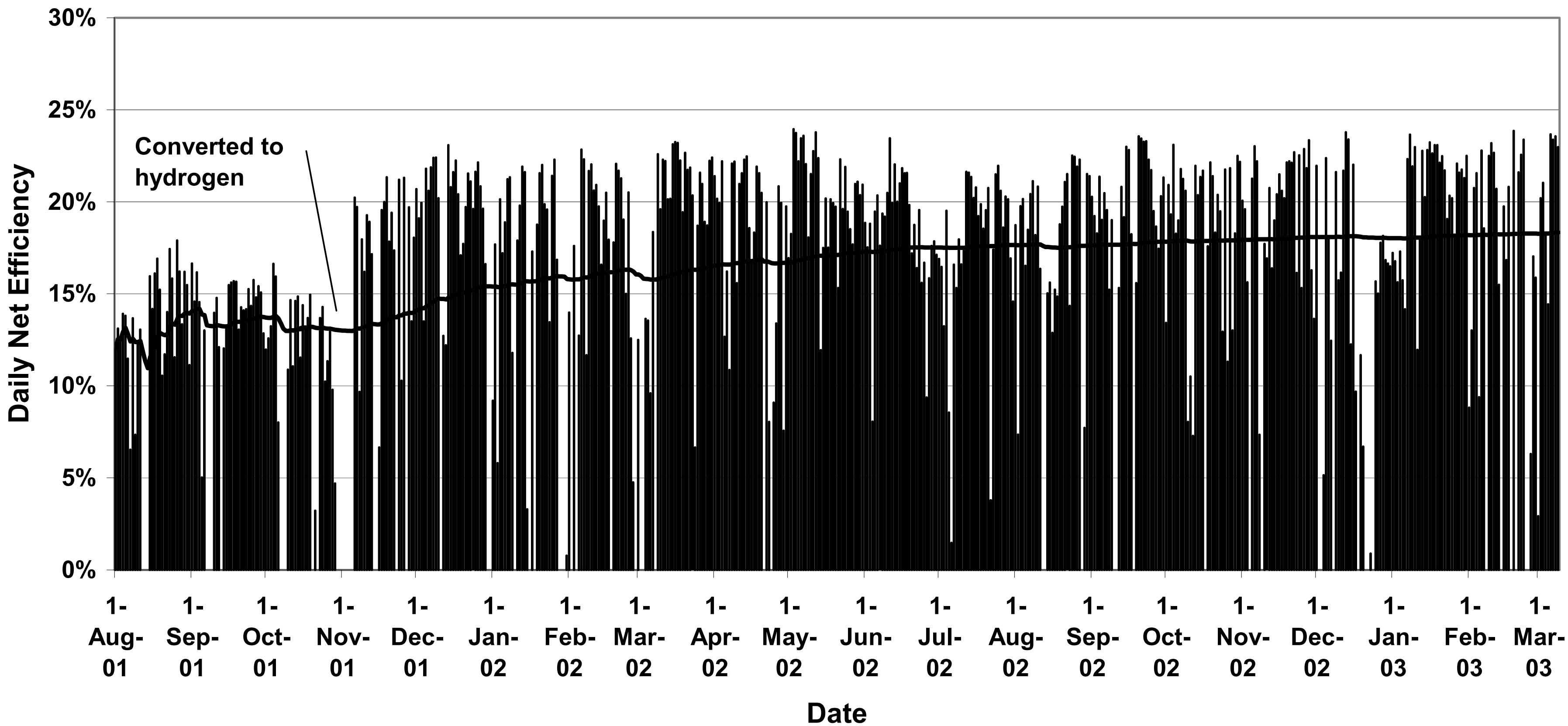



Net output includes all parasitics midnight to midnight.

Mod 1 operated 2628.9 hours and net system output was 17,133 kWh for 2002

# Advanced Dish Development System

## Mod 1 Net Daily Efficiency Aug 1, 2001 – Mar 9, 2003




Efficiency= Net output/DNI incident on mirrors while weather is within specifications

For 2002 Mod 1 was 18.93% efficient

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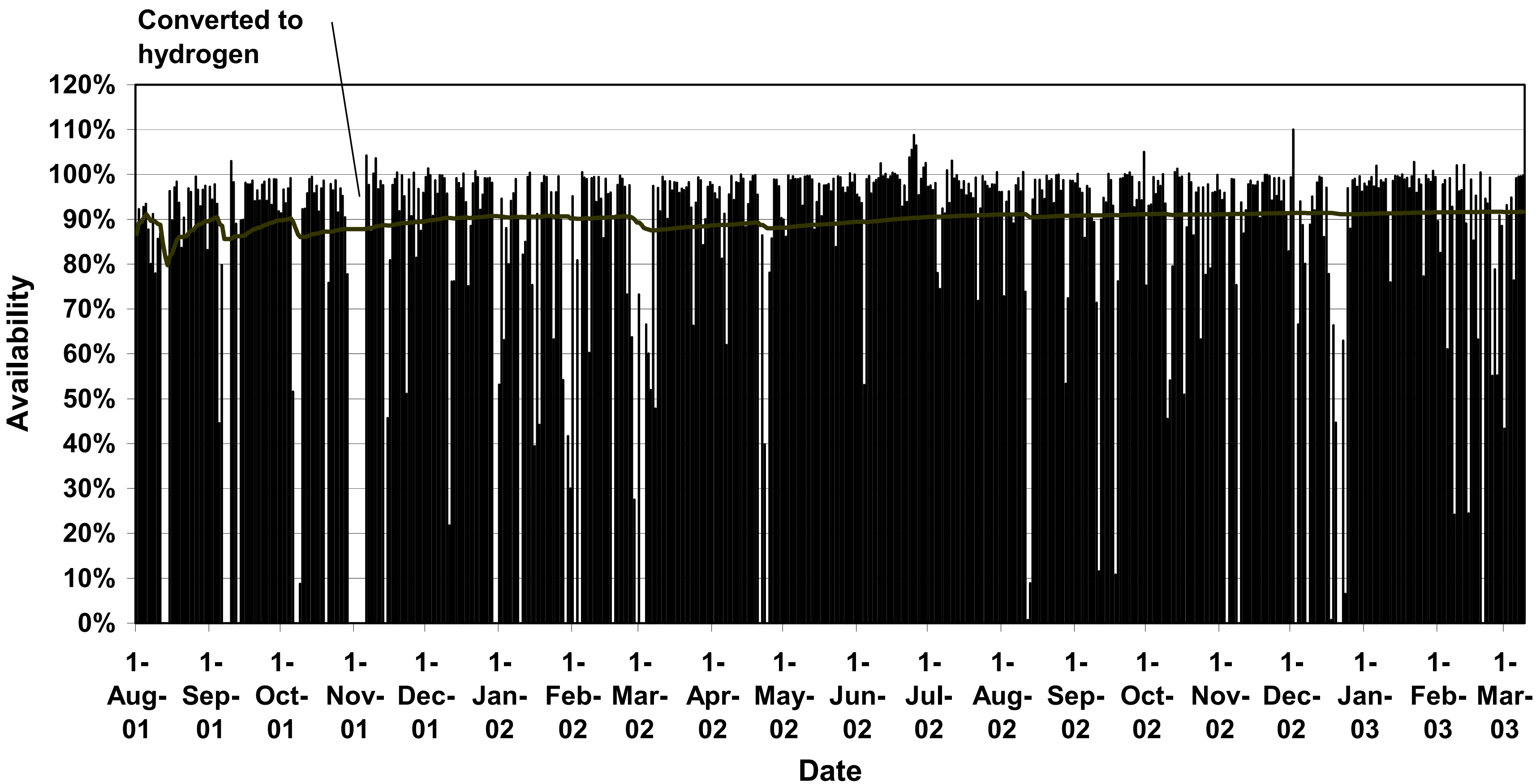
Sun♦Lab

Sandia National Laboratories, Albuquerque, NM
National Renewable Energy Laboratory, Golden CO

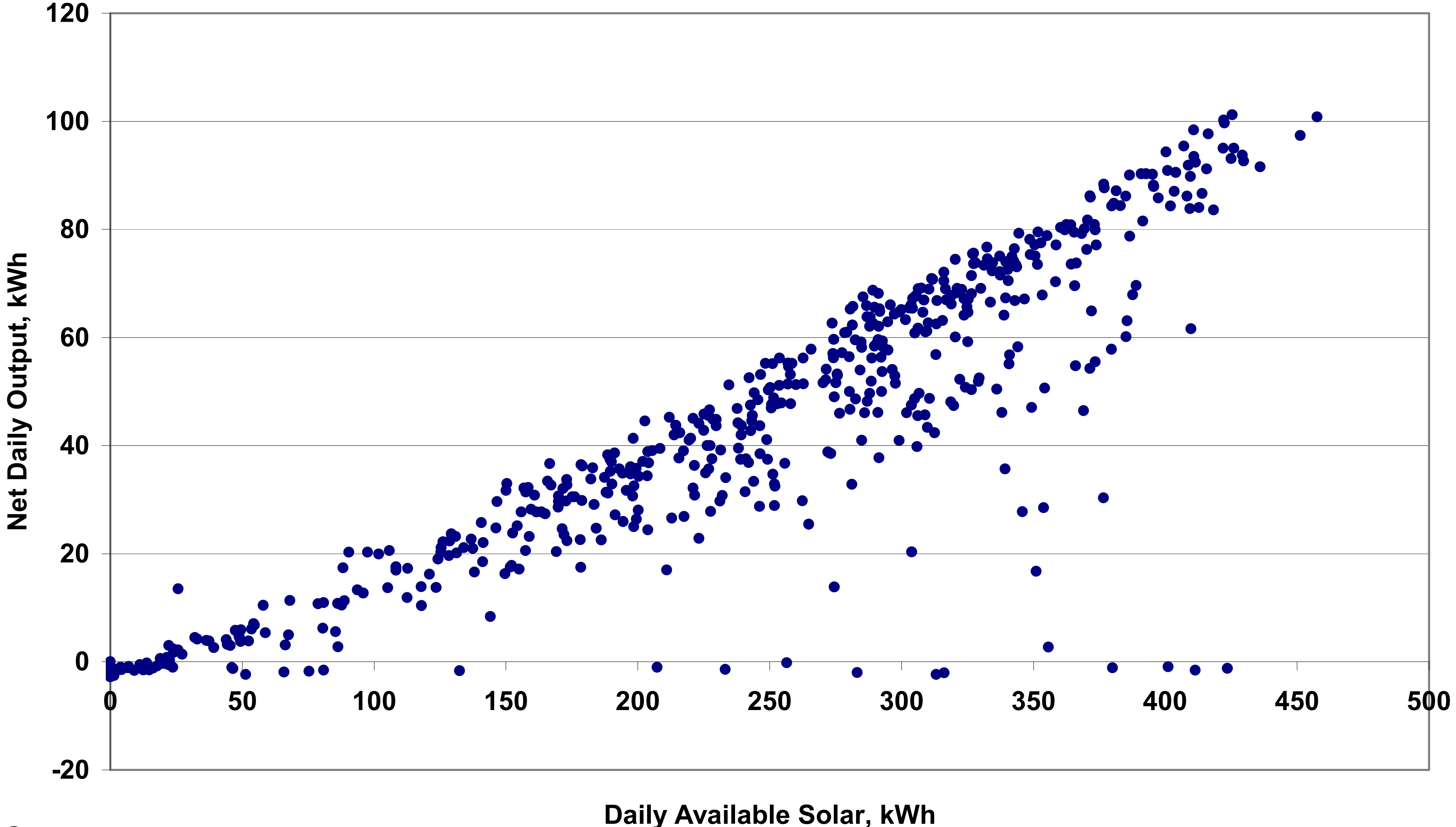
# Mod 1 Daily and Cumulative Availability
## Aug 1, 2001 – Mar 9, 2003




**Availability = (net positive hours)/(hours weather conditions in specification)**

**During 2002 Mod 1 availability was 91.4%**

# Mod 1 Daily Net Output vs. Available Solar
# Aug 1, 2001 - Mar 9, 2003



# Reliability Improvement on a Developmental System

- Reliability improvement is a continuous process
  - System design, fabrication, and installation represents about 10% of the development process
  - Different types of failures occur during the different stages of component and system life
  - Requires reacting to issues as they occur
- Reliability and other requirements are interrelated
  - Improving maintainability improves availability
  - Switching to hydrogen improved performance/cost and improved reliability

# Advanced Dish Development System
# Our Approach to Reliability Improvement

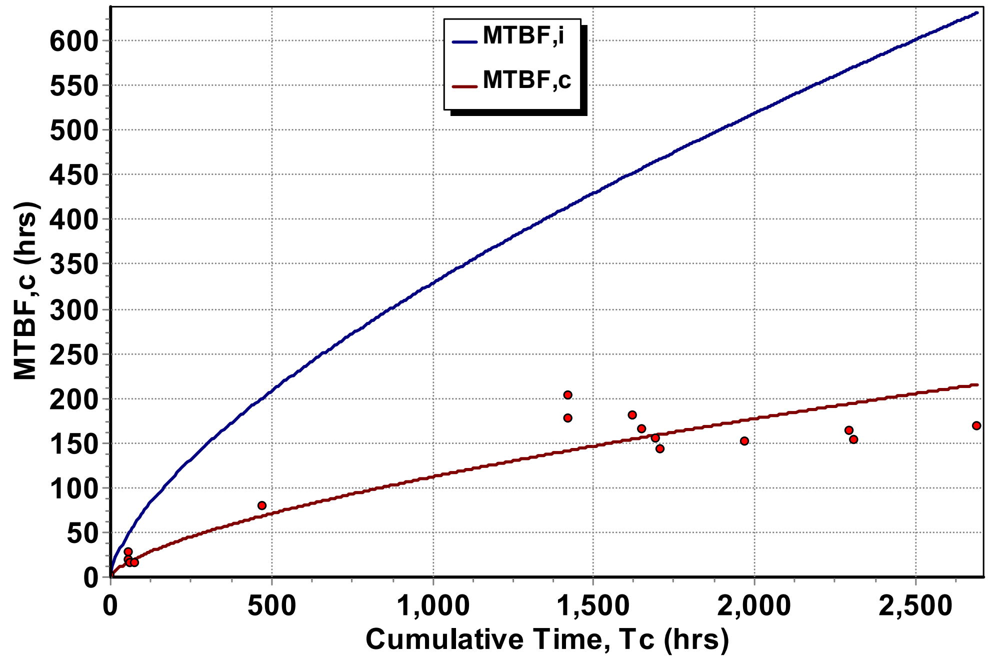
- Accrue operational hours
  - Unattended operation yields more hours
  - More hours means more failures
  - Failures are our friend
- Document everything
  - Data acquisition system features automated documentation
  - Web based experimenters log book
  - SunLab Reliability Data Base
- Incidents are addressed
  - Establishing “root cause” is a top priority
  - Engineer participation in repairs to make sure evidence is not lost
  - Cost effective solutions sought

# Reliability Improvement

- All incidents recorded in the SunLab Reliability Data Base
  - Mod 1 since Jan 6, 2000
  - Mod 2 since Feb 7, 2002
  - Mod 2-2 since Apr 22, 2003
- Incidents assigned a severity level
  - Level 1 can be responded to remotely
  - Level 2 through 4 require a site visit and are scored according to severity and cost of repair
- Early issues tended to be controls related

# Advanced Dish Development System Reliability Improvement

- **Initial reliability goals at beginning of project**
  - 80% availability
  - 600 hour MTBF
- **Reliability achieved**
  - 91.4% avail. for Mod 1
  - 89.9% avail. for Mod 2
  - MTBF ~ 150 for level 1 and above
  - MTBF > 400 hours level 2 and above
- **Reliability has stagnated recently with minimal funding**



# Reliability Improvement

- SunLab Reliability Tracking Data Base has limitations
  - Cumbersome to input data
  - Does not allow for tracking root causes
  - Designed for tracking reliability growth
- Systematic failure reporting and corrective action system (FRACAS) process needed
  - Track and prioritize issues and corrective actions
  - Need disciplined process
- Root cause analysis and correction is key
  - Need to understand underlying mechanisms
  - Utilize "Scientific Method" of developing and testing hypothesis
  - Practical solutions required

# Advanced Dish Development System
# Maintainability

- Maintainability and ease of use were issues highlighted by Ft. Huachuca and work with Native American Application Partners
  - Automotive-like Stirling engine and dish
- Concentrator design influenced by maintainability
  - 38 degree/min slew rate
  - Dish knells down below the horizon for PCU access
  - Safe slewing and enhanced user interfaces implemented
- Maintainability is critical for high availability


# Advanced Dish Development System
## Summary

- Integration of the ADDS has been a valuable experience
  - First opportunity for SNL to integrate a CSP system
  - Excellent way to identify key technology development needs
  - Working with Native American APs useful
  - Many insights and lessons learned
- ADDS potential is promising
  - Technology bought by Stirling Energy Systems
  - Sandia is supporting the development of the SES 25 kWe system
  - Ready for concerted cost reduction work
- Reliability improvement requires a long-term concerted effort

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