Decades in the Installed Environment: Do Silicon Modules Really Last More than 20 Years? Preliminary Findings

NREL PV Module Reliability Workshop
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James M. Bing, PE
President
New Energy Options, Inc.
410 Great Road, B-6
Littleton, MA 01460
jbing@newenergyoptions.com

TOPICS

- Two Modules & Two Arrays
- Test & Measurement Procedures
- Test Results
- Conclusions & Future Work

Two Modules
&
Two Arrays

Two Modules

- Beverly, Massachusetts
- Solar Power Corporation
- G12-331CT
- 30.2W NOCT

- Gardner, Massachusetts
- Mobil Solar
- Ra-30-12H
- 30.0W STC

Solar Power Corporation Module G12-361CT

(Beverly, Massachusetts)

- Single Crystal
- 36 Cell (36 series/1 parallel)
- Potted junction box
- Bi-pass diode
- Type SO cable w/two-pin molded connector
- Dimensions: 1057 x 424mm (41.5 x 16.75in)
- 84 modules tested

Solar Power Corporation Module G12-361CT

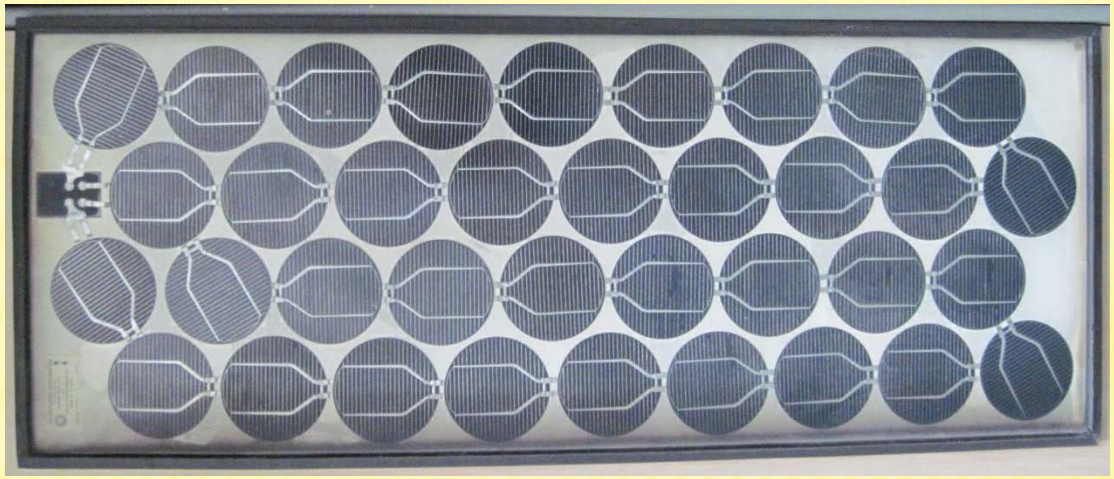
(Beverly, Massachusetts)

- Electrical Specifications:

Nominal Operating Cell Temperature (NOCT)	46°
Short Circuit Current at NOCT	2.15 Amp
Open Circuit Voltage at NOCT	19.6 Volt
Maximum Power Point Voltage at NOCT	15.1 Volt
Maximum Power Point Current	2.00 Amp
Maximum Power at NOCT	30.2 Watt
Total Module Power Density	6.19 Watt/ft^2
Temp Coefficient of Current	$\Delta I / \Delta T$= 0.46mA/ °C
Temp Coefficient of Voltage	$\Delta V / \Delta T$ =-78mV/ °C

Solar Power Corporation Module G12-361CT

(Beverly, Massachusetts)



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Mobil Solar Module
Ra-30-12H

(Gardner, Massachusetts)

- Polycrystalline
- 72 Cell (36 series/2 parallel)
- Separately installed bi-pass diode
- Screw cover junction box with brass threaded post terminals
- Dimensions: 905 x 412mm (35.5 x 16.25in)
- 70 modules tested

Mobil Solar Module
Ra-30-12H

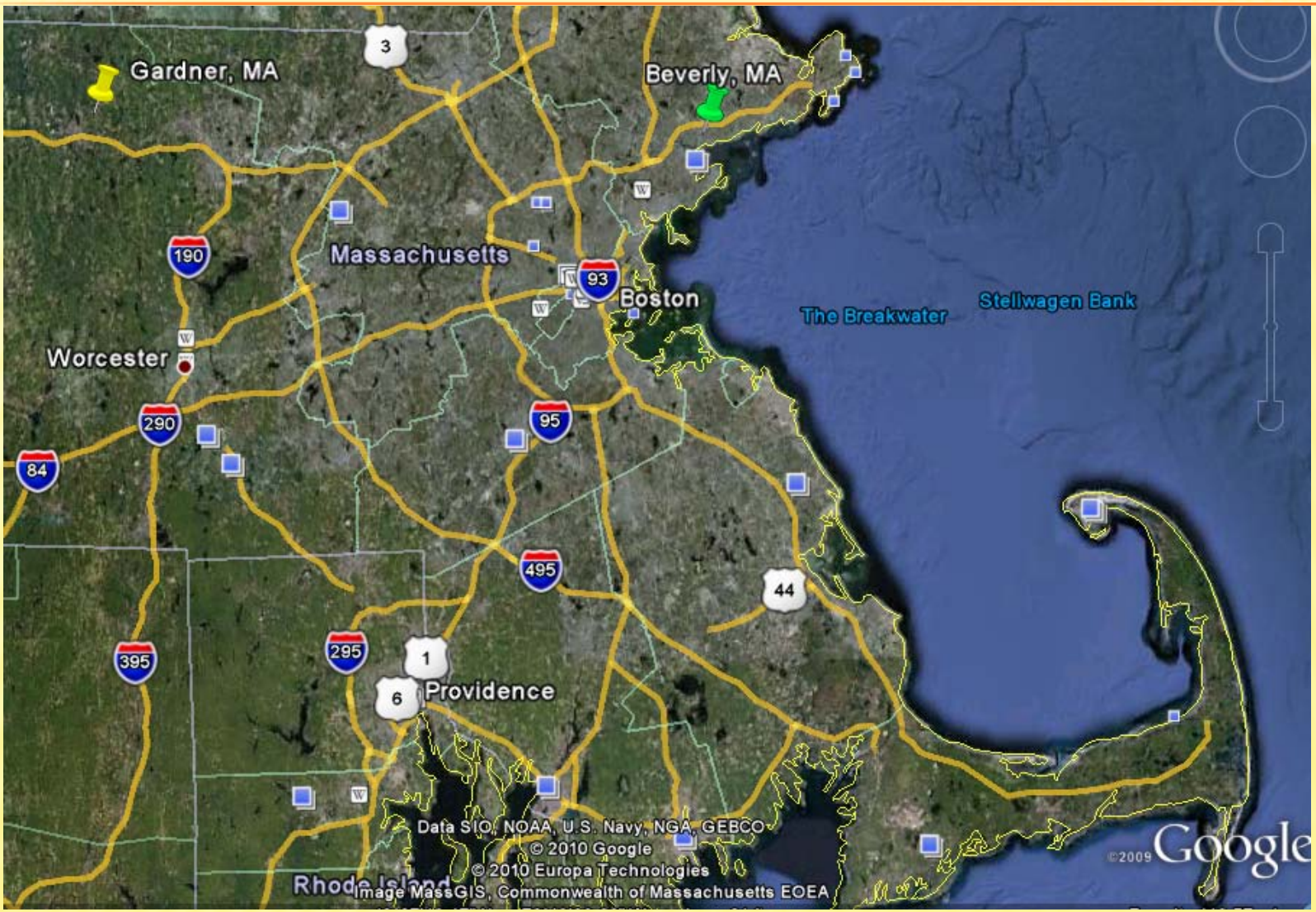
(Gardner, Massachusetts)

- Electrical Specifications:
  - Isc at STC 2.2 Amp
  - Voc at STC 18.9 Volt
  - Vmp at STC 15.5 Volt
  - Imp at STC 1.94 Amp
  - Pmp at STC 27.0 Watts (Min) 30.0 Watt (Typ)
  - TCI_{SC} 1.60 mA/ °C/Cell (Parallel)
  - TCV_{OC} -2.18 mV/ °C/Cell (Series)

Mobil Solar Module
Ra-30-12H

(Gardner, Massachusetts)

Two Arrays



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Two Arrays

- Beverly, Massachusetts
  - Record high temp: 38°C
  - Record low temp: -23°C
  - 20m above sea level
  - 3km to ocean
- Gardner, Massachusetts
  - Record high temp: 37°C
  - Record low temp: -37°C
  - 330m above sea level
  - 95km to the ocean

Two Arrays

- Beverly, Massachusetts
  - 100kW system
  - Solar Power Corp Modules
  - Ground mount
  - Open racks
  - Tilt 60° (approximate)
  - Azimuth 180°
  - 10 module panels in landscape
  - Six 15kW inverters (current configuration)
- Gardner, Massachusetts
  - 2.1kW system
  - Mobil Solar Modules
  - Open racks on flat roof mount
  - Tilt 60° (approximate)
  - Azimuth 165°
  - 5 module panels in portrait
  - Single Inverter

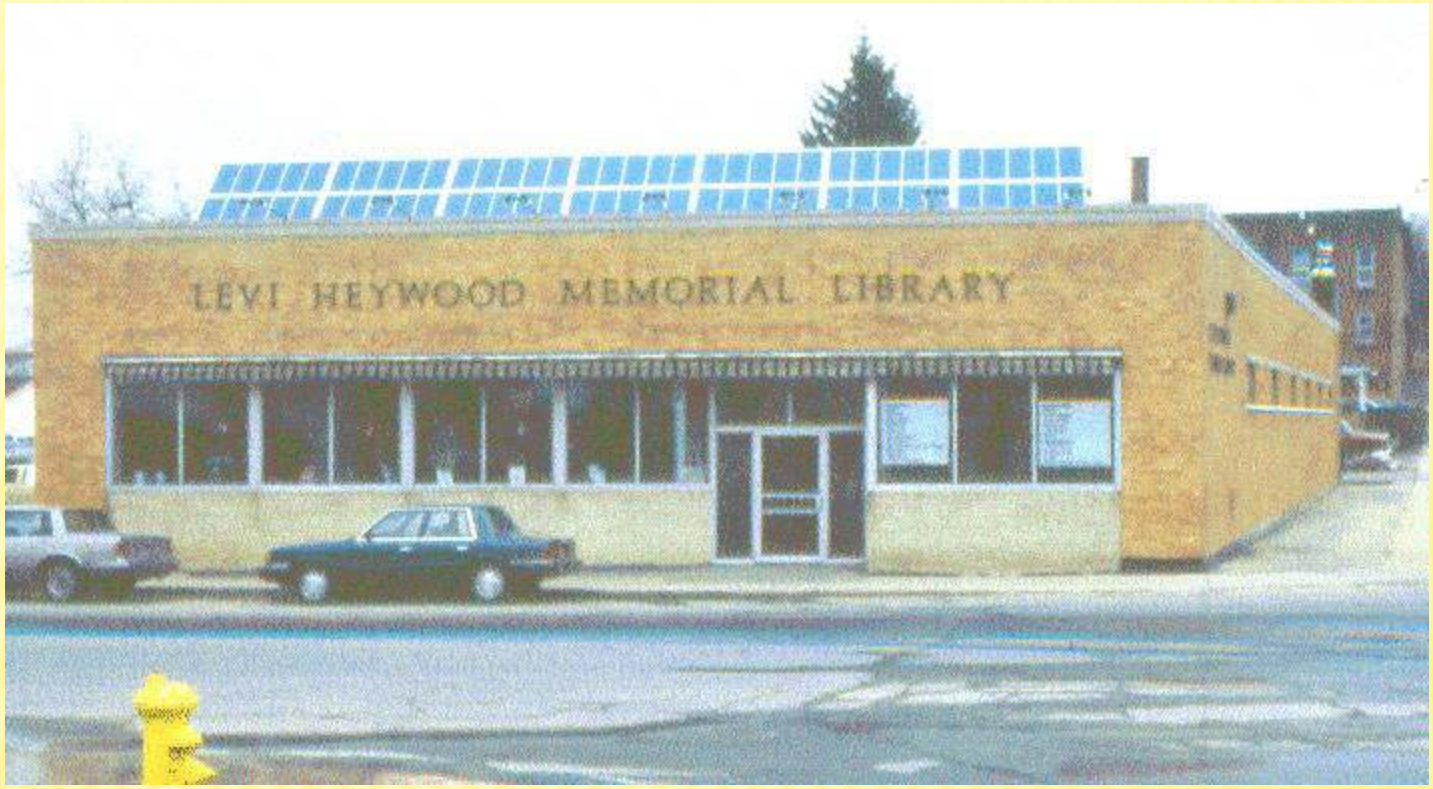
Two Arrays

- Beverly, Massachusetts
  - Commissioned 1981
  - 100kW system
  - One of 8 systems installed nationwide
  - Massachusetts Electric (now National Grid)
  - DOE Funded
  - Stone & Webster engineers
  - Current Status: Functioning with new inverters
- Gardner, Massachusetts
  - Installed 1986
  - 2.1kW system
  - One of 6 commercial & 28 residential systems
  - Massachusetts Electric (now National Grid)
  - EPRI Funded
  - Solar Design Assoc. eng.
  - Current Status: Decommissioned in 2007.

Beverly, Massachusetts 100kW PV Array 1980 to 2010

BEVERLY ARRAY

Gardner, Massachusetts 2.1kW PV Array 1986 to 2007



Gardner Massachusetts
Mobil Solar Ra-30-12H Modules

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Test & Measurement Procedure

Test & Measurement Procedure

- EKO MP-170 I-V Curve Tracer
  - Sweeps I&V from Isc to Voc
  - Plane of array irradiance (POA)
  - Cell temperature (Tc)
  - Ambient temperature (Ta)
- Cleaning prior to measurement
- POA irradiance 700W/m^2 or greater
- Gardner retested with measurements confirmed with secondary data logger:
  - POA, Tc, Ta, Voc, Isc

EKO MP-170 I-V Curve Tracer

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Module Testing

(Beverly, Massachusetts)

- Fixed tilt& azimuth (true south)
- Single thermocouple location
- Molded modular two pin connector for connection of module to EKO
- Modules with shattered glass or with “stuck” connectors were not tested.
- Nominal irradiance: 1000W/m2
- Ambient temperature: -5°C

Gardner Massachusetts

Module Testing

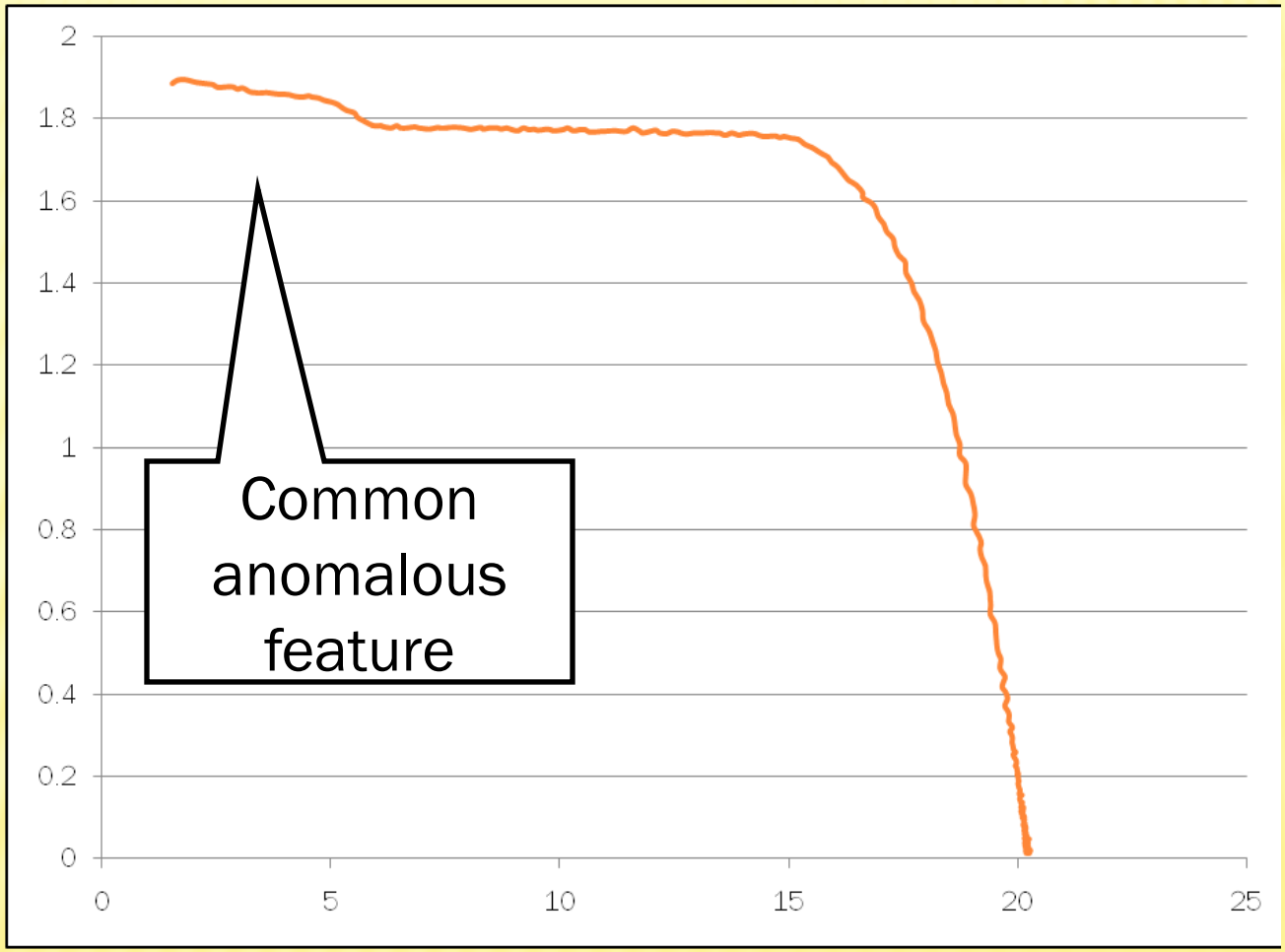
- Changed thermocouple for each 5-module panel
- Adjustable tilt & azimuth
- Alligator clips for EKO curve tracer

- For Retest:
  - Campbell Scientific CR800
  - Licor200SZ
  - Two type K thermocouples for Tc and Ta

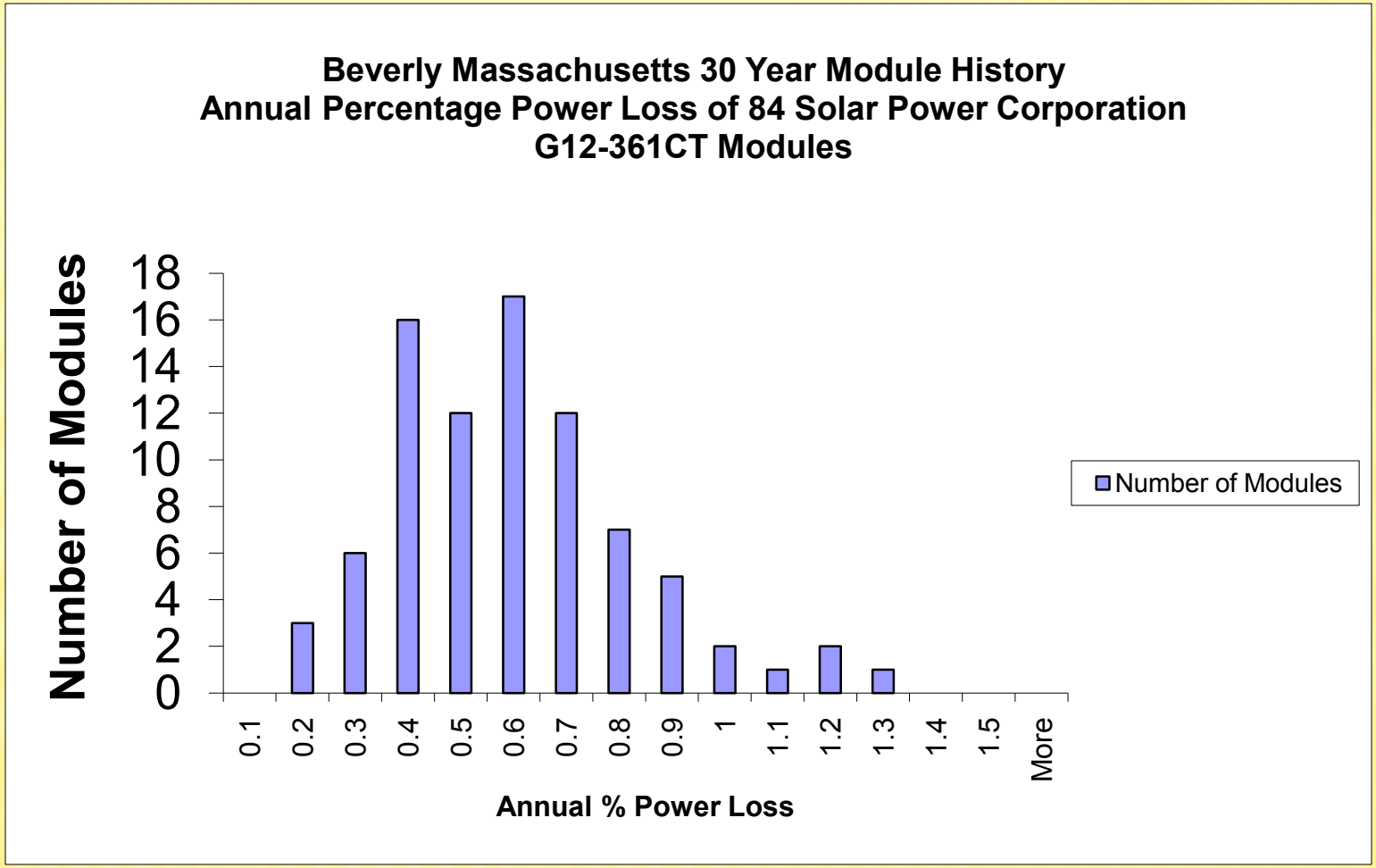
Test Results

Typical I-V Curves

Solar Power Corporation G12-361CT Modules



Percentage Power Loss Per Year
Solar Power Corporation G12-361CT Modules

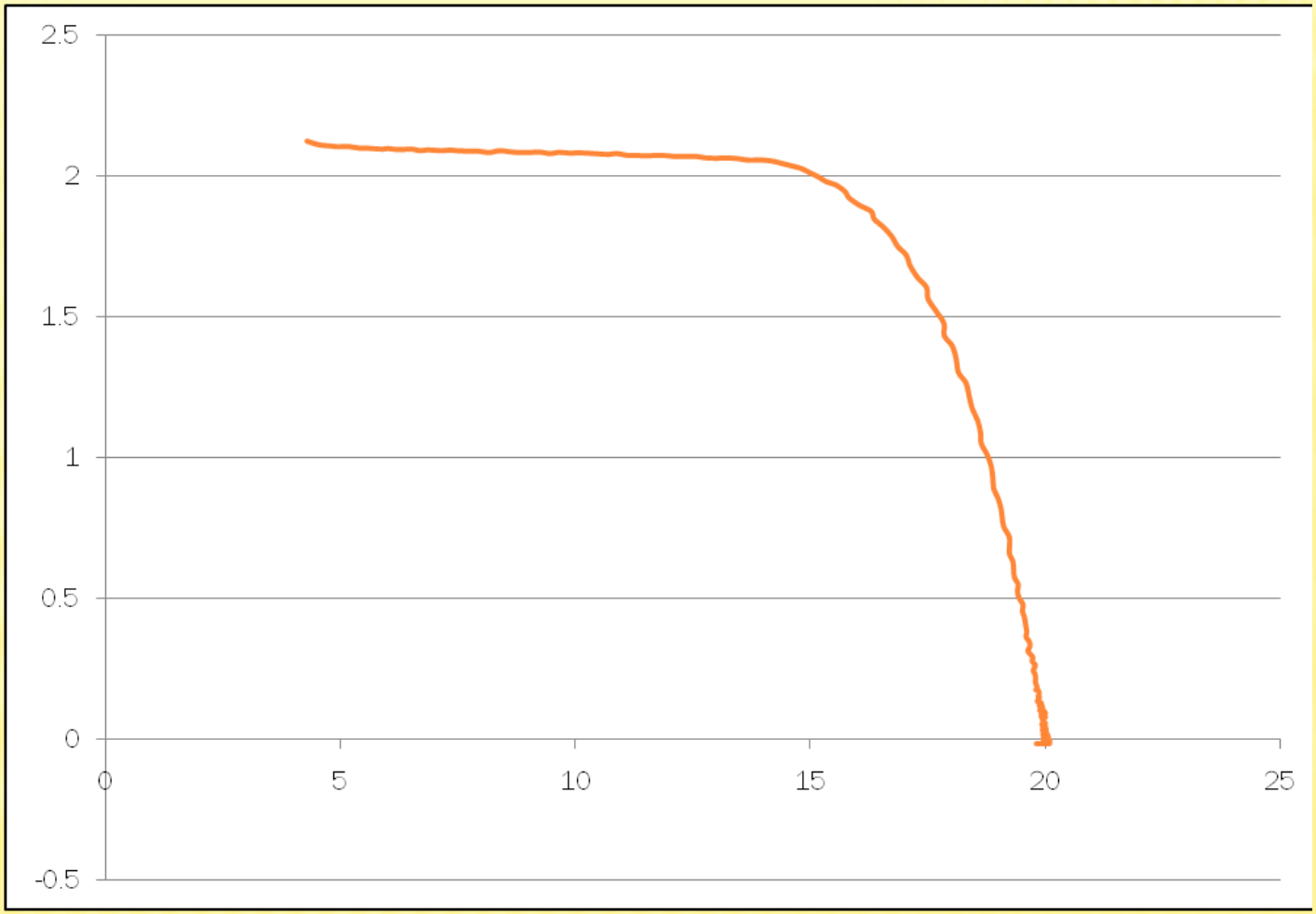


Percentage Power Loss Per Year
Solar Power Corporation G12-361CT Modules

(Beverly, Massachusetts)

- Average annual power loss from original NOCT rating for 30.2W for all tested modules: 0.539%
- Median annual power loss from original NOCT rating for 30.2W for all tested modules: 0.546%

Typical I-V Curve
Mobil Solar Ra-30-12H Modules

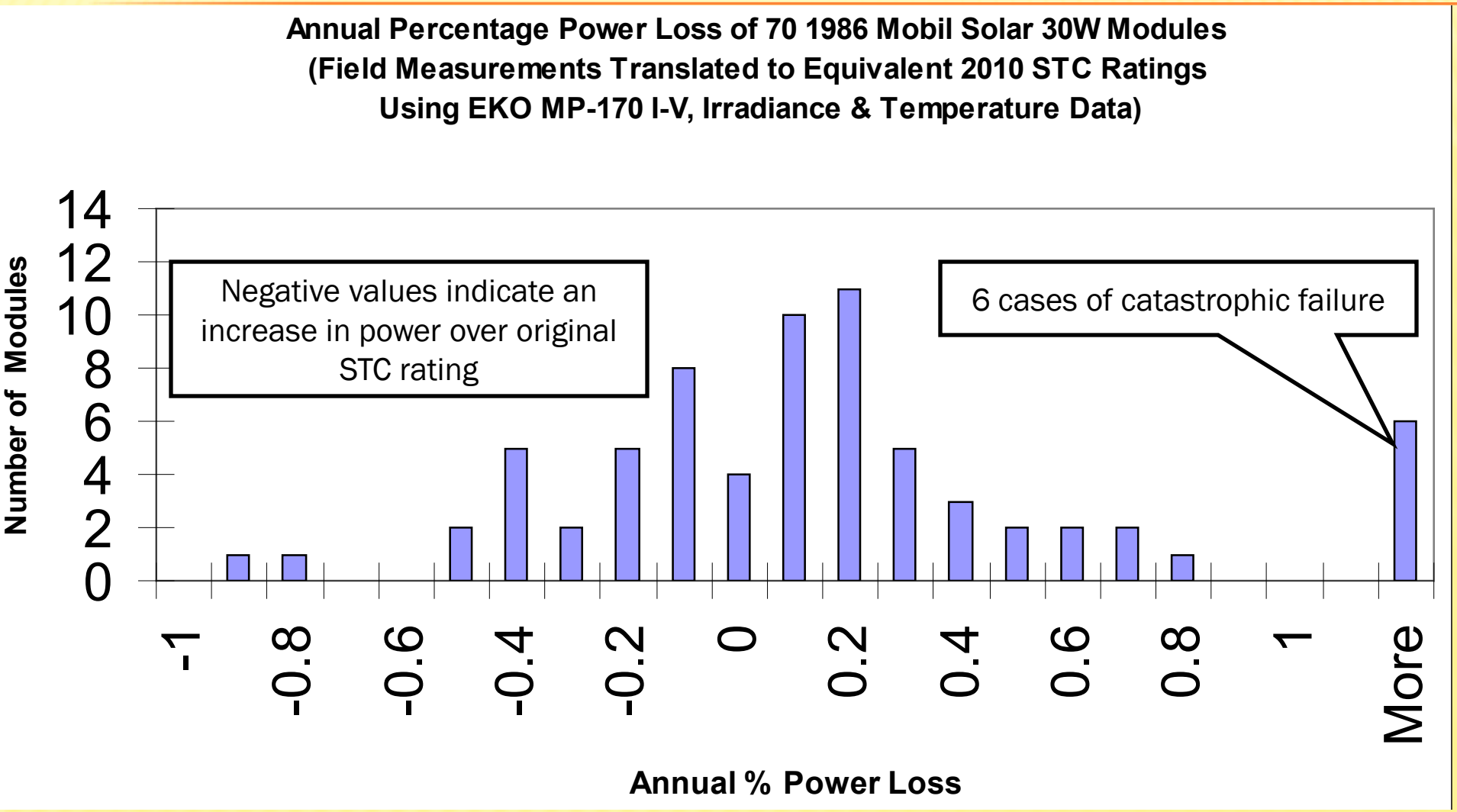


Percentage Power Loss Per Year
Mobil Solar Ra-30-12H Modules

(Gardner, Massachusetts)

- Average annual power loss from original STC rating for 30.0W for all tested modules: 0.180%
- Median annual power loss from original STC rating for 30.0W for all tested modules: 0.082%

Percentage Power Loss Per Year
Mobil Solar Ra-30-12H Modules



Mobil Solar Ra-30-12H Retest

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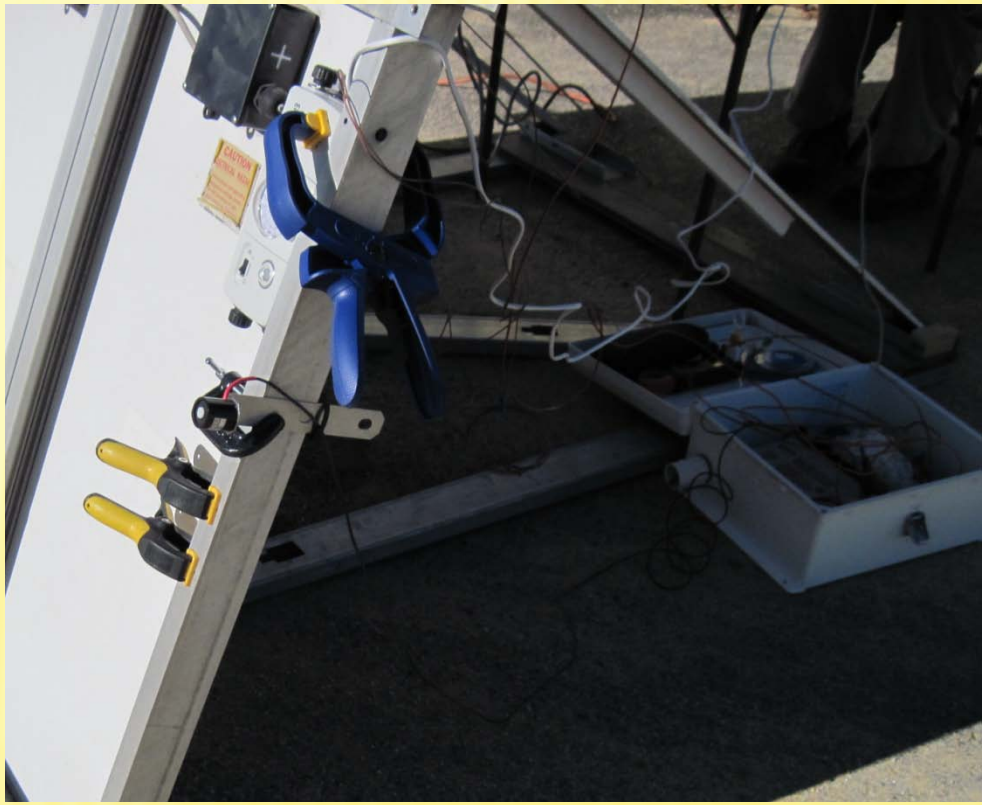
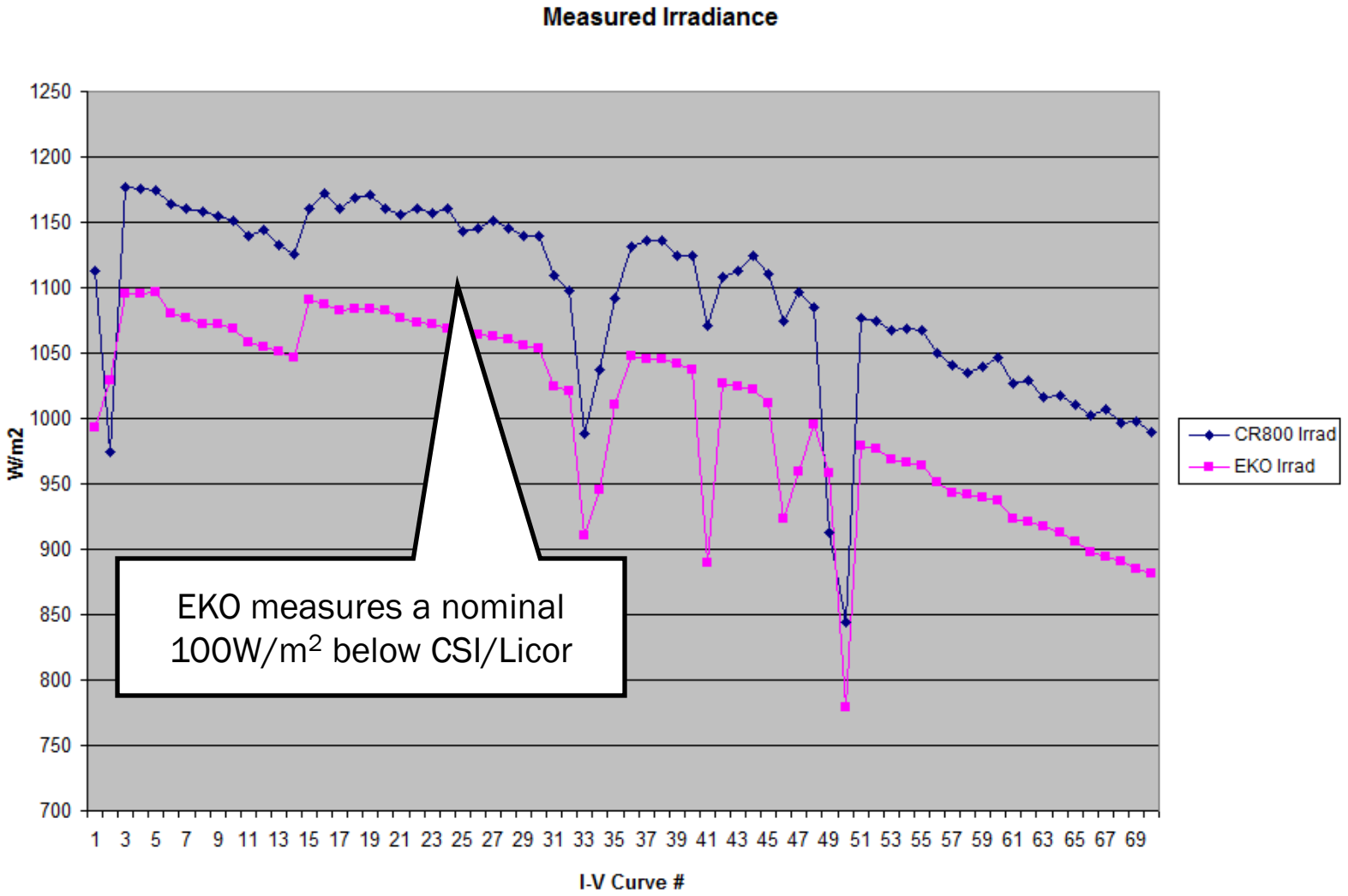
Gardner Massachusetts

Module Testing

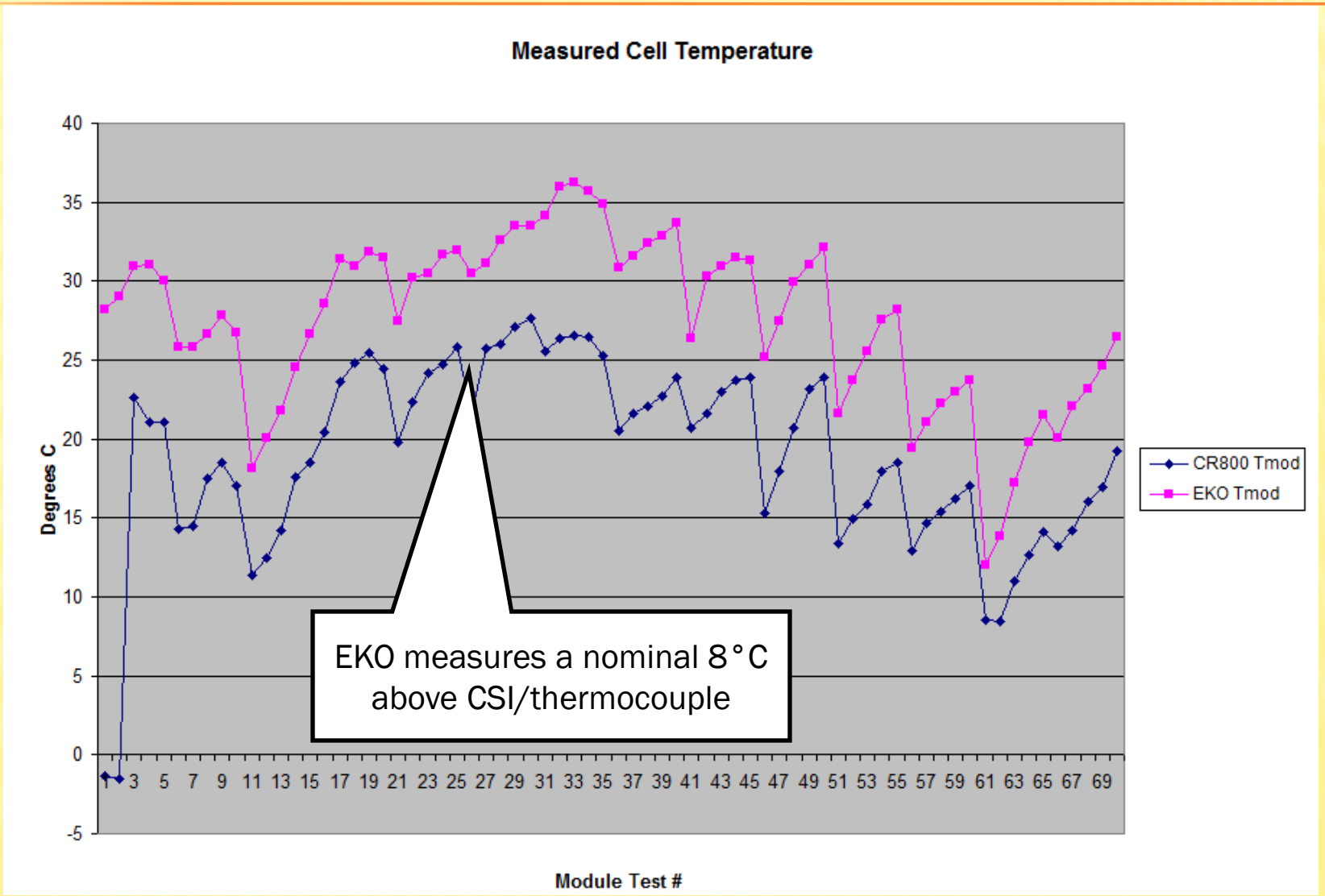
- For Retest:
  - Campbell Scientific CR800
  - POA Licor 200SZ
  - Two type K thermocouples
    - Cell temperature (Tc)
    - Ambient temperature (Ta)
  - Measure Isc & Voc



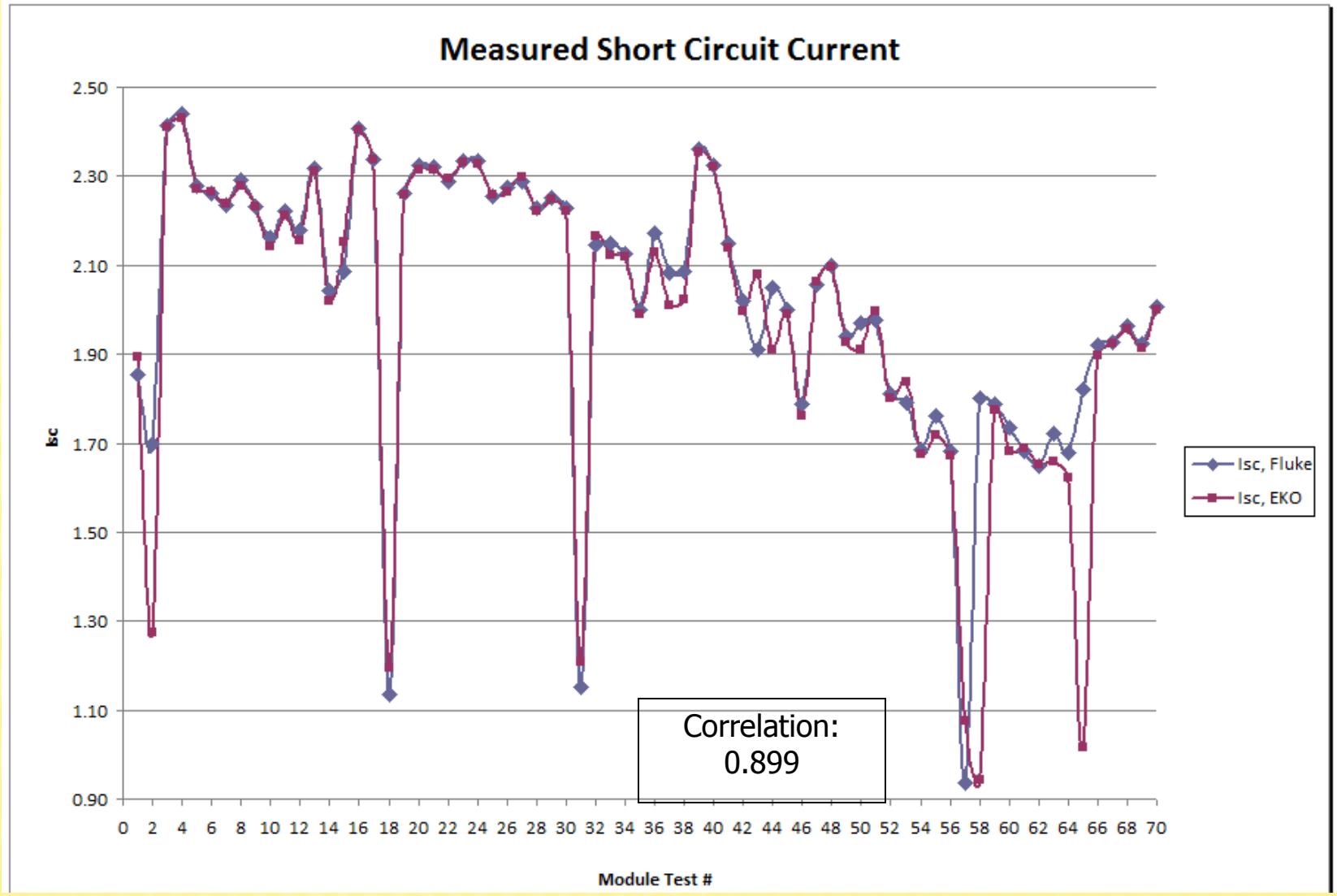
Comparison of Incident Irradiance: EKO I-V Curve Tracer vs. Campbell/Licor



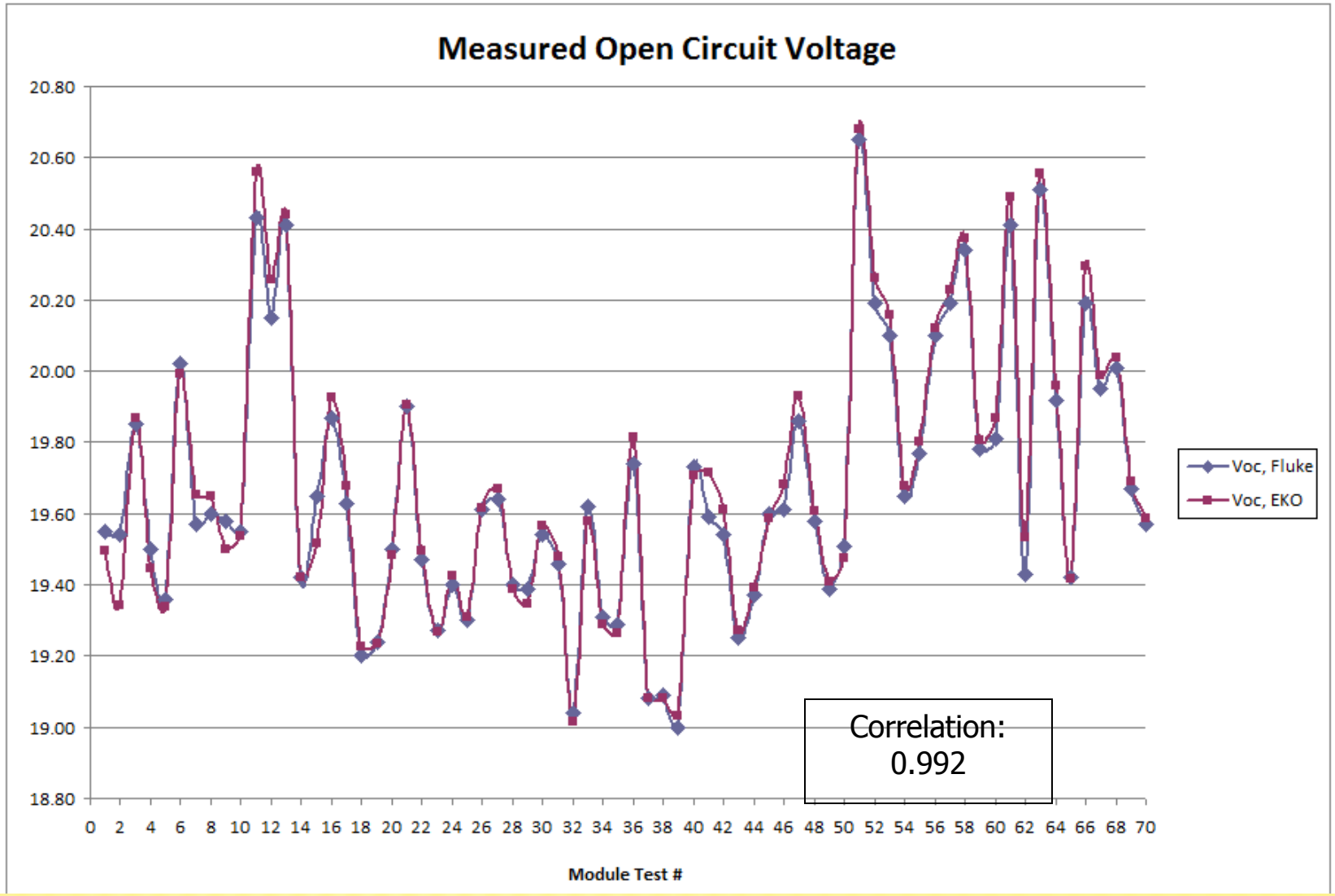
Comparison of Cell Temperature: EKO I-V Curve Tracer vs. Campbell/K Thermocouple



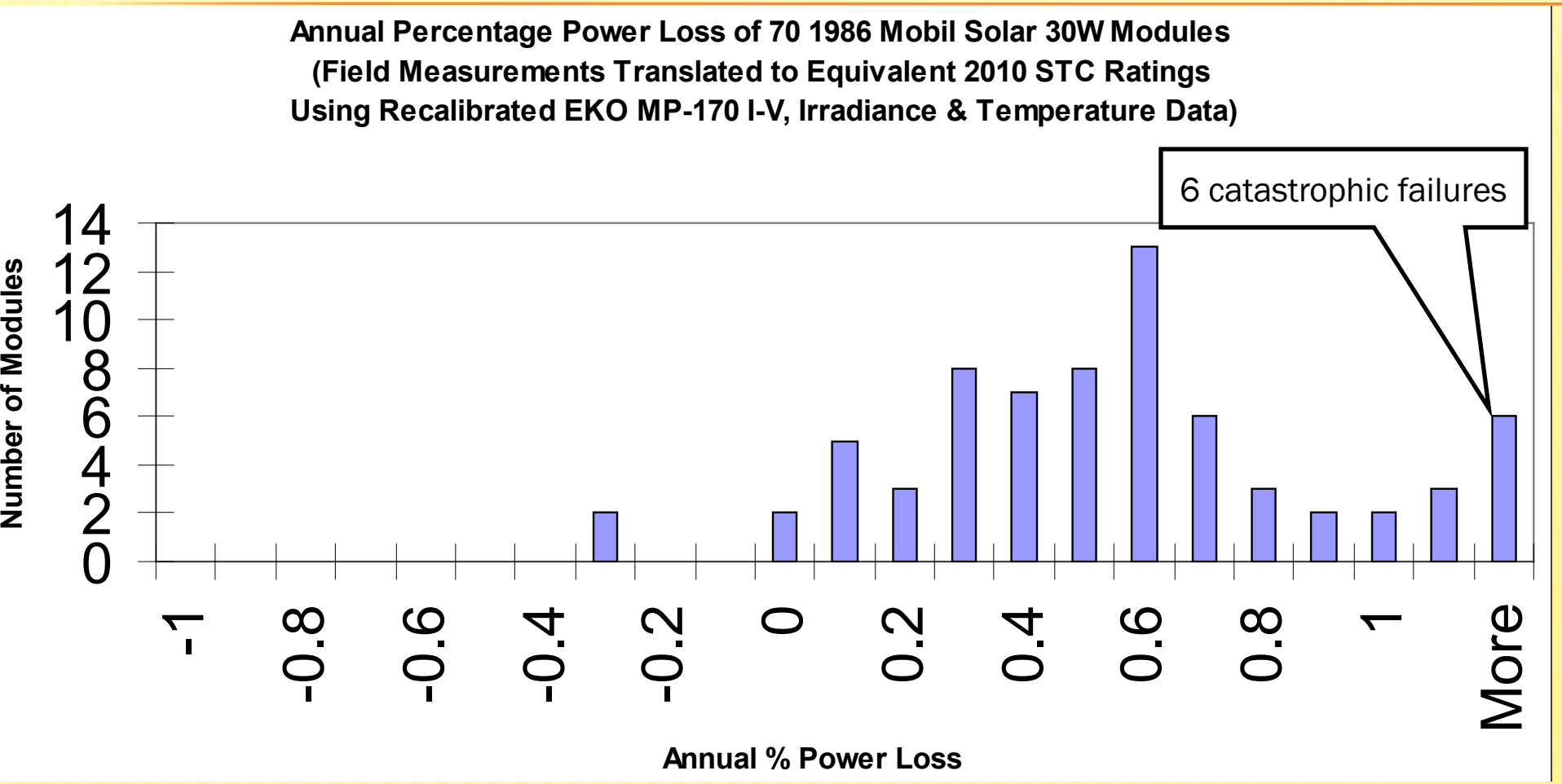
Comparison of Short Circuit Current: EKO I-V Curve Tracer vs. Fluke 83 III



Comparison of Open Circuit Voltage: EKO I-V Curve Tracer vs. Fluke 83 III



Percentage Power Loss Per Year
Mobil Solar Ra-30-12H Module Retest



Percentage Power Loss Per Year
Mobil Solar Ra-30-12H Modules

(Gardner, Massachusetts)

- Average annual power loss from original STC rating for 30W for all tested modules: 0.575%
- Median annual power loss from original STC rating for 30W for all tested modules: 0.499%

Conclusions
&
Future Work

Conclusions

- Yes, silicon modules –at least the ones that we looked at-- really do last more than 20 years.
- It may be the case that some of the Mobil Solar modules that we examined started out their lives with substantially higher STC ratings than their data sheets indicated.
- Quantifying a rate of power loss is difficult if you are not certain of the original rating. You can't tell how far you have come unless you know where you started from.
- Know your instruments.

Future Work

- Calibration of EKO and Licor pyranometers
- Recalculation of annual % power loss for Solar Power Corp single crystal modules using corrected irradiance data from calibration
- Recalculation of annual % power loss for Mobil Solar polycrystalline modules using corrected irradiance data from calibration
- Three samples of each module will be flash tested at NREL
- Possible destructive testing of sample modules at NREL

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jbing@newenergyoptions.com
www.newenergyoptions.com