THE PERFORMANCE OF PHOTOVOLTAIC TECHNOLOGIES UNDER JAMAICA'S CLIMATIC CONDITIONS

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ADVANTAGES OF PV

- The Sun is the world's primary energy resource
- Electricity is one of the predominant forms of energy used by modern society
- PV's direct conversion seems an ideal fit
- A PV system is light weight and static
  - Reduced installation and maintenance costs
- Short time frame from design to implementation

ADVANTAGES OF PV

- The efficiency of PV continues to increase as prices decrease

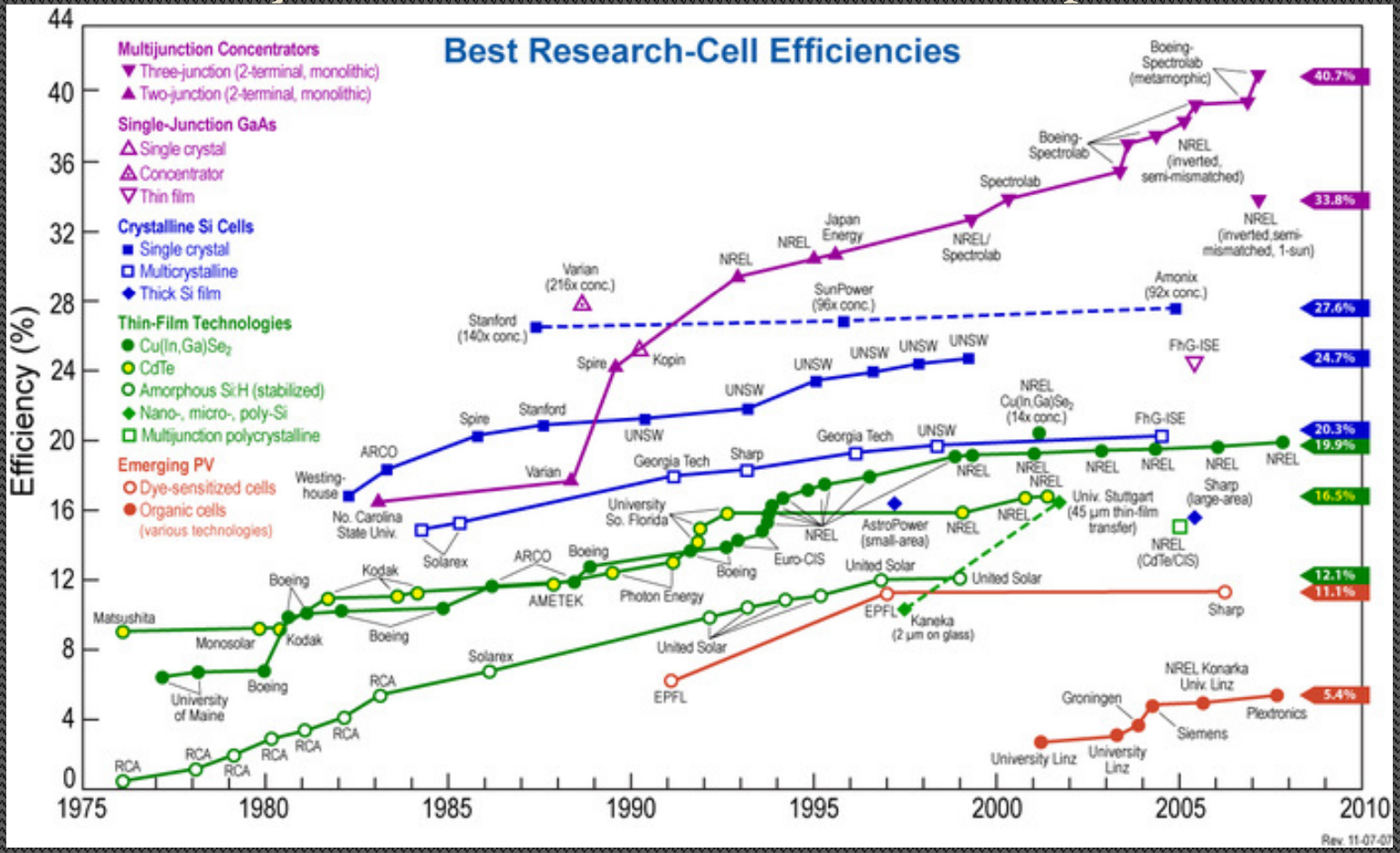
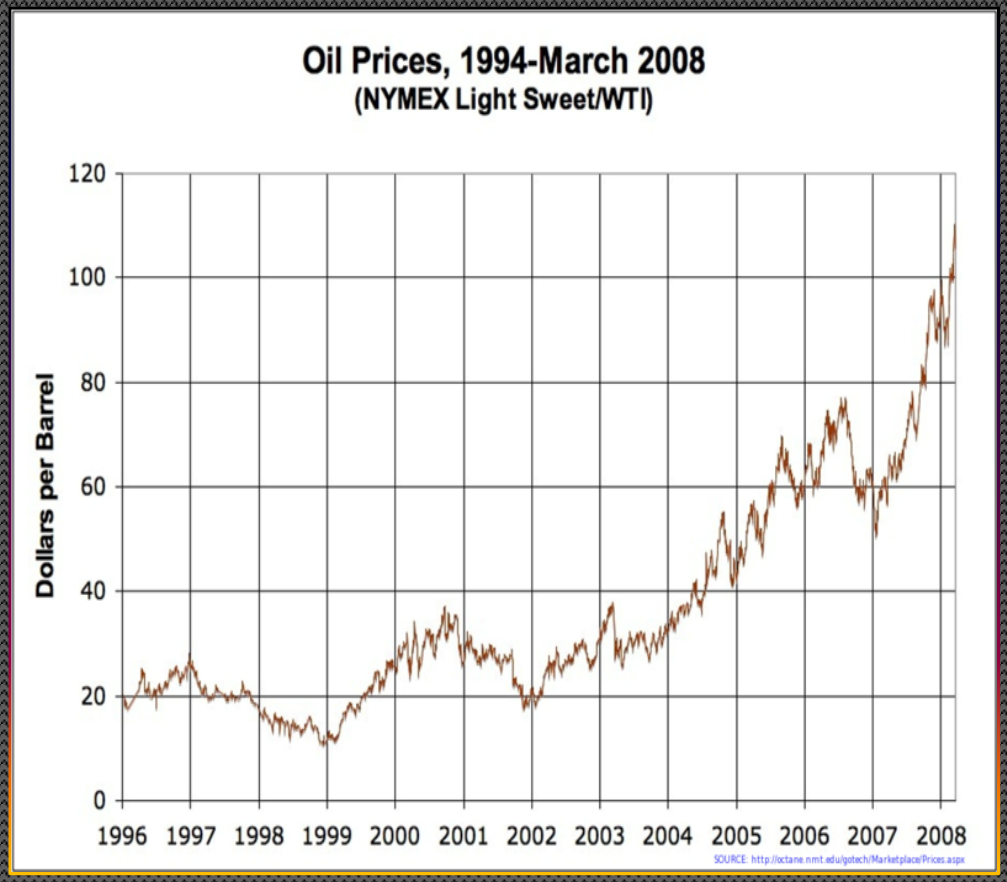


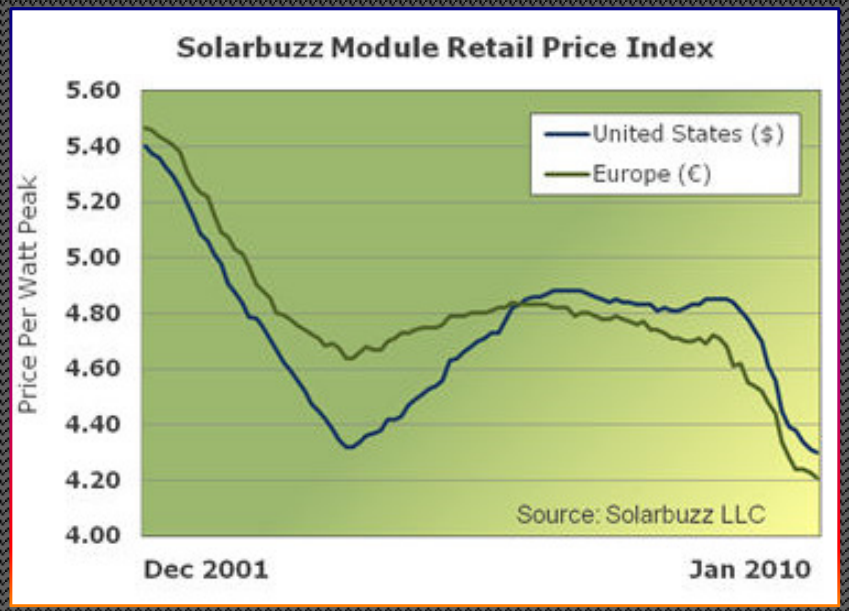
Image Credit: http://www.observatorynano.eu/project/filesystem/images/2en.po4.jpg

ADVANTAGES OF PV

- Trends in costs show electricity from fossil fuel show a local annual average increase of 8.02% [3] while world PV costs show average annual decrease of 1.2% [4]



http://octane.nmt.edu/gotech/Main.aspx



http://www.solarbuzz.com/ModulePrices.htm

CLASSIFICATION OF PV TECHNOLOGIES

- There are three main types in the commercial market
  - Crystalline
  - Thin film
  - Emerging including dye sensitised or organic cells
- Classification is based on
  - raw materials
  - Manufacture processes
- Parameters used to determine PV performance
  - Short circuit current, I_{SC}
  - Open circuit voltage, V_{OC}
  - Current and Voltage at Maximum Power(I_{MP}, V_{MP})
  - Efficiency

TEST CONDITIONS

- Efficiencies are quoted at standard test conditions (STC)
  - Solar Irradiance (Insolation) 1000Wm^{-2}
  - Module Temperature 25°C
  - Air Mass (AM) 1.5.
- STC do not occur under normal operational conditions
- Efficiencies of PV vary
  - Based on the technology
  - Based on the environmental conditions

JAMAICAN CONDITION

- Jamaica
  - 18˚ north of the equator
  - daily average of eight (8) available sunlight hours.
  - average solar radiation 14 $MJm^{-2}day^{-1}$ to 21 $MJm^{-2}day^{-1}$.
  - mean ambient temperature 30˚C.

Previous Studies

ONE PV TECHNOLOGY DIFFERENT OPERATIONAL CLIMATES

- Double-junction amorphous silicon PV systems were investigated by Gottschalg et al [7] in
  - Florianopolis, Brazil
  - Hong Kong, China
  - Mallorca, Spain
  - Neuchâtel, Switzerland
  - Oxford, United Kingdom
- All modules were made by the same manufacturer and were of similar age

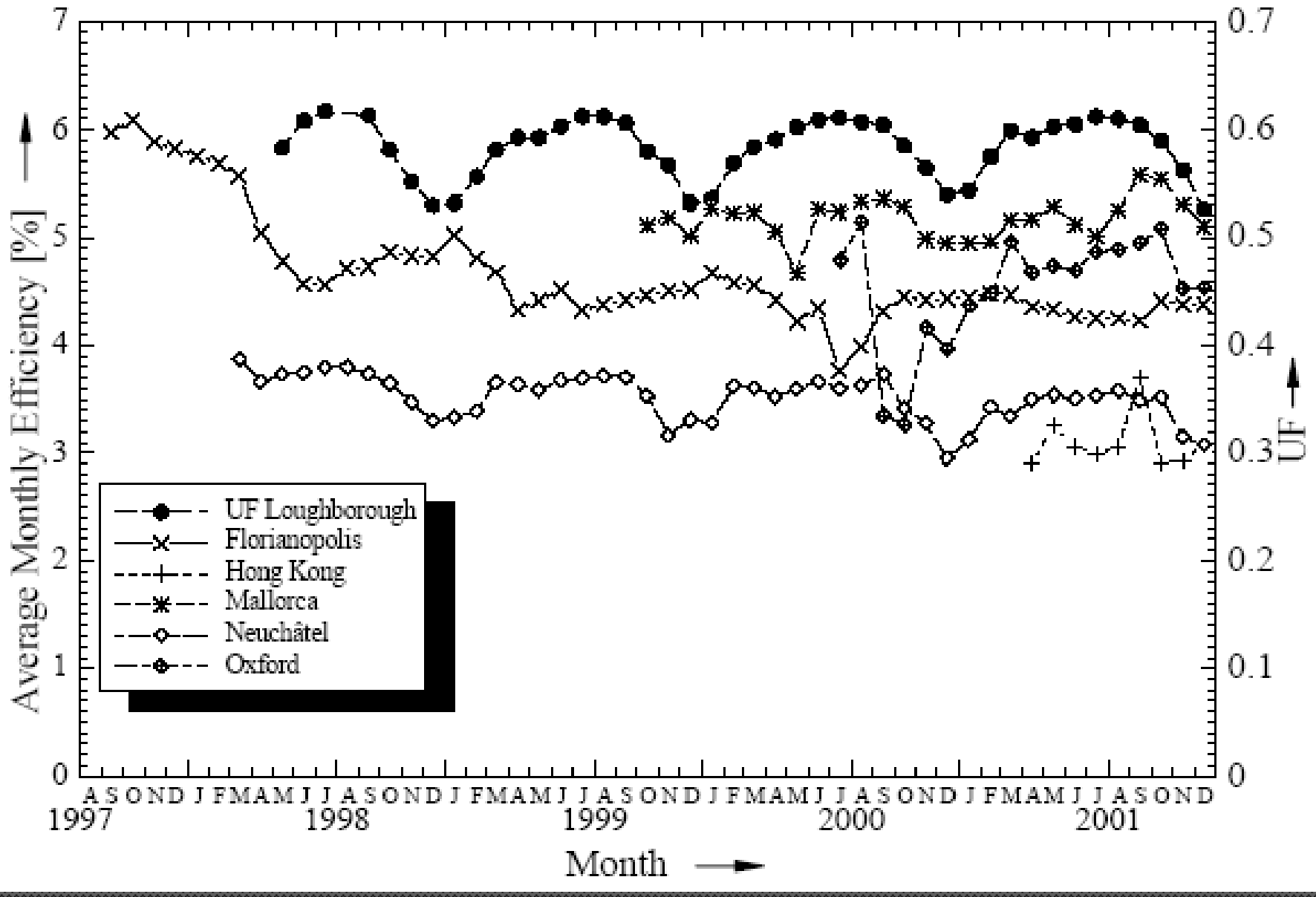
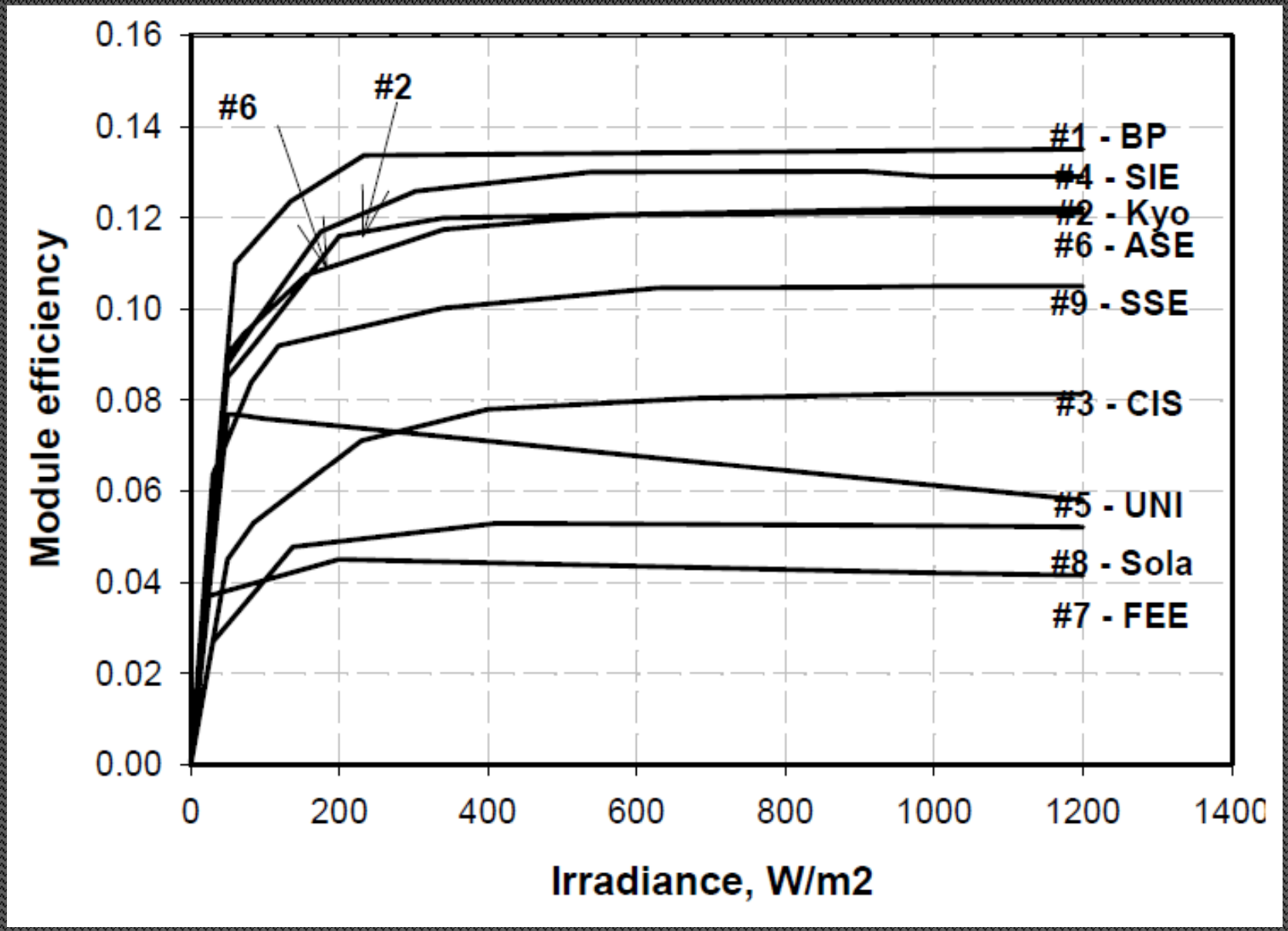


Image Credit: Performance of Amorphous Silicon Double Junction Photovoltaic Systems in Different Climatic Zones by Gottschalg et al

PERFORMANCE OF DIFFERENT PV TECHNOLOGIES, ONE CLIMATE

- Studies performed by Eikelboom et al [8] on seven PV technologies (9 modules) at the ECN building in the The Netherlands

Number	Manufacturer
1	BP Solarex (c-Si)
2	Kyocera (mc-Si)
3	Siemens (CIS)
4	Siemens (m-Si)
5	UniSolar (a-Si)
6	ASE (Si)
7	FEE (a-Si)
8	BP Solarex (a-Si)
9	Shell Solar Energy (mc-Si)

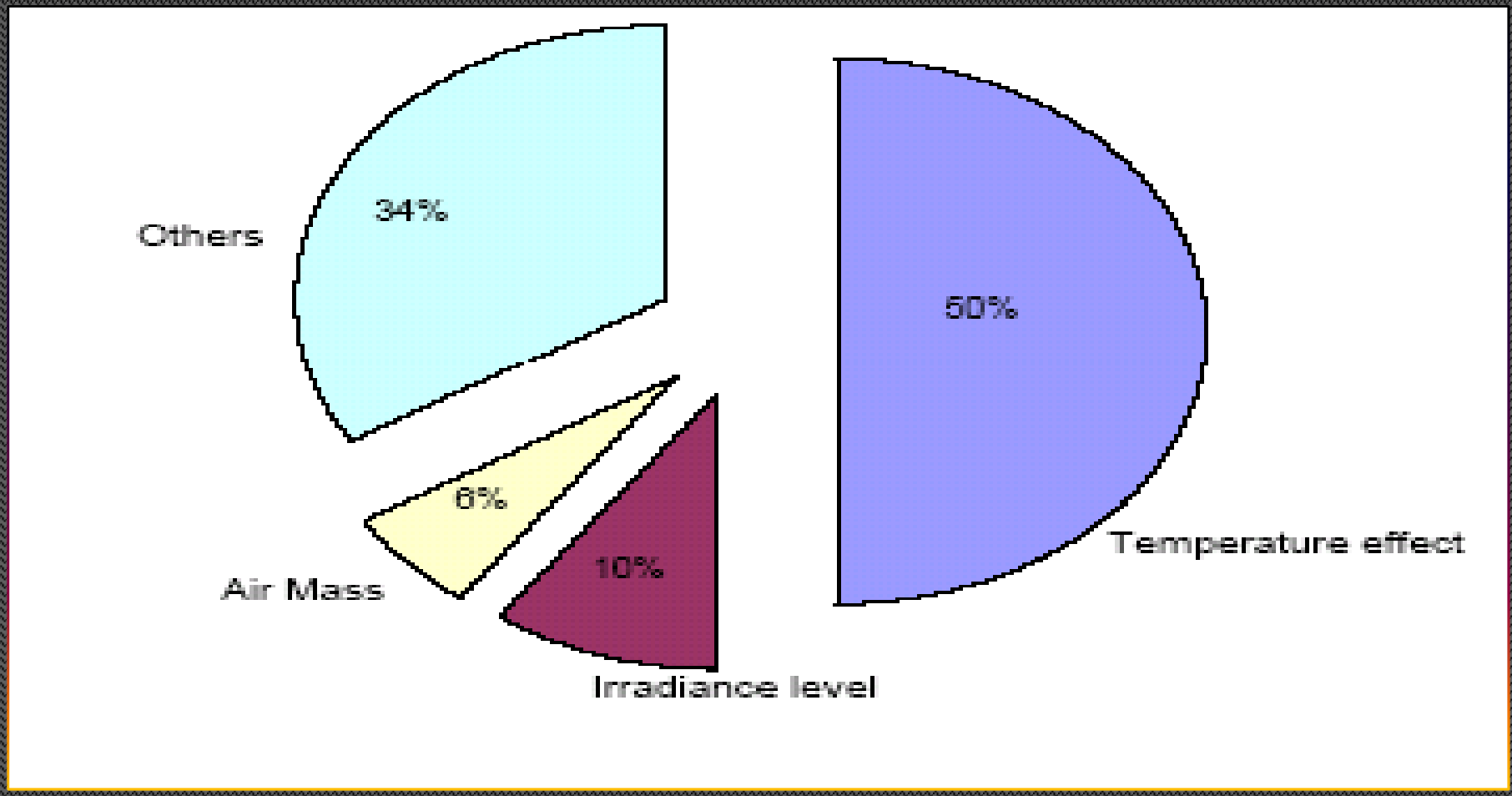

Module efficiency
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
200
400
600
800
1000
1200
1400
Irradiance, W/m2
#6
#2
#1 - BP
#4 - SIE
#2 - Kyo
#6 - ASE
#9 - SSE
#3 - CIS
#5 - UNI
#8 - Sola
#7 - FEE

LOCAL STUDIES

- Studies performed by Sheryl Williams in 2001 [9], at the UWI, Mona Campus, on a 720 W stand alone polycrystalline PV system (tilt 19˚).

- Performance was determined based on the performance ratio, PR_t of the modules, where PR_t is the ratio of efficiency at the instantaneous insolation to efficiency at STC

LOCAL STUDIES RESULTS



Temperature has the greatest effect on performance loss. Irradiance and load mismatching (other) are the major factors.

LOCAL STUDIES RESULTS

- A comparison of the performance of commercially available polycrystalline silicon (poly-Si) and single junction amorphous silicon (a-Si:H) was also by Williams.

	Poly-Si Modules	a-Si:H Modules
Research Cell Efficiency	15%	10%
Observed Efficiency	8%	3.5%
Percentage deviation from STC values	37%	42%
Percentage deviation from Research Cells Values	47%	67%

DEDUCTION

- From previous study we deduce that the major factors affecting performance are
  - Insolation
  - Temperature
  - Load Mismatching
- Configured to eliminate load mismatching
- We therefore focused on the effects of insolation and temperature on the module performance

METHODOLOGY

- Seven (7) PV technologies (8 PV modules) were fitted onto a wooden frame facing south and inclined at 18° to the horizontal.
- Each module was connected to operate at maximum power by setting load equal to module's internal resistance
- Module voltage and temperature were taken at five minute intervals between 6 a.m. and 7 p.m. using an Omega OM-320 data logger

METHODOLOGY

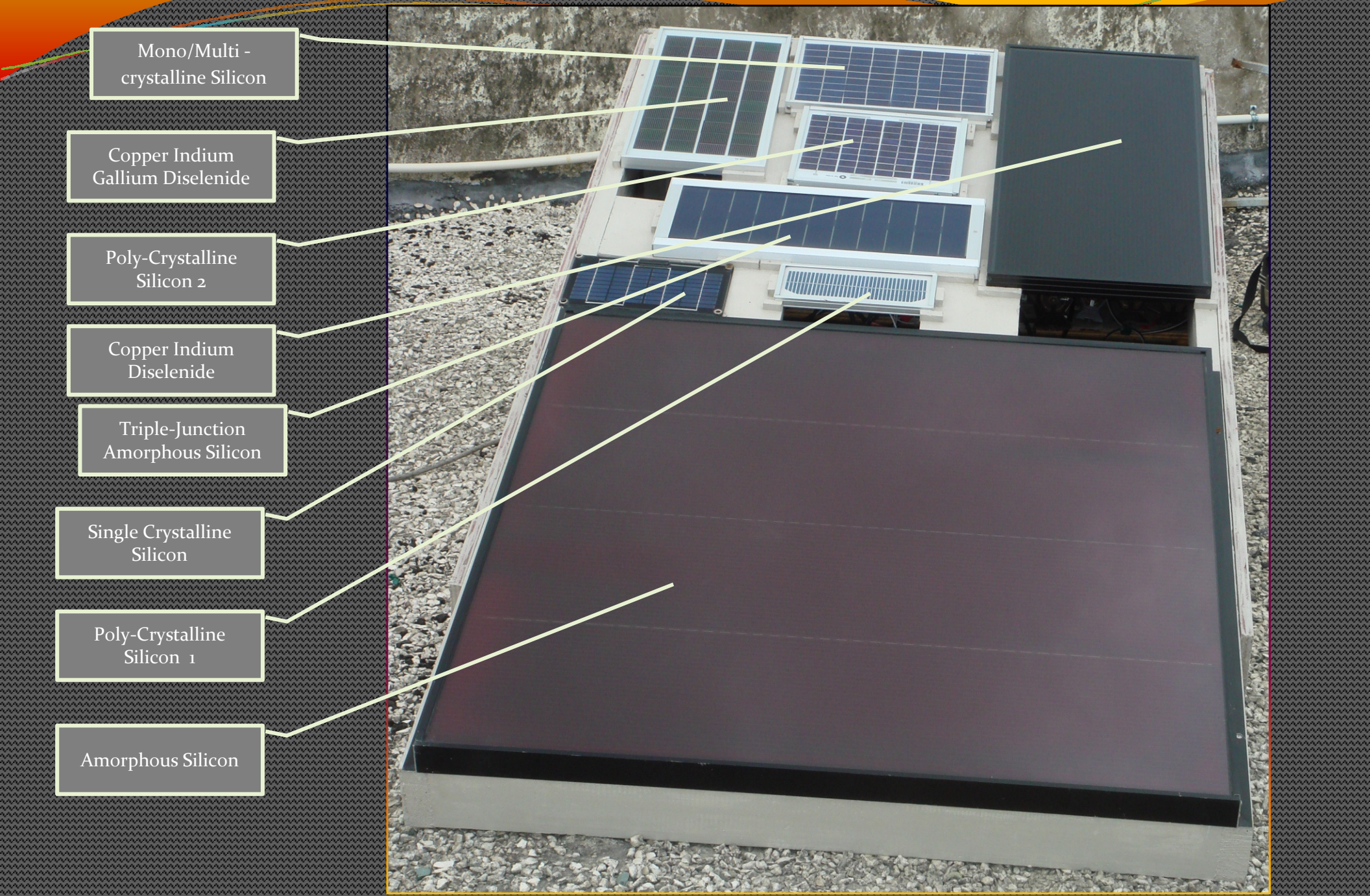
- Minutely planar insolation was recorded on site by a LICOR pyranometer connected to a Campbell Scientific CR1000 data logger

- Minutely climatological data which included horizontal insolation and ambient temperature were collected using a Davis Instruments VantagePro2 weather station.

TECHNOLOGIES USED IN THE STUDY

STC Specifications of Modules Used in this Study

Technology	Rated Power/W	V_{MP}/V	I_{MP}/A	V_{OC}/V	I_{SC}/A
Mono/Multi -crystalline Silicon	8	16.5	0.49	20.0	0.55
Triple Junction Amorphous Silicon	5	16.5	0.62	23.8	0.37
Copper Indium Gallium Diselenide	6	15.8	0.38	23.0	0.45
Single Crystalline Silicon	3	18.7	0.15	22.4	0.16
Copper Indium Diselenide	20	15.6	1.29	22.9	1.54
Multi-crystalline Silicon 1	1	16.7	0.075	21.0	0.09
Multi-crystalline Silicon 2	4.5	16.5	0.27	20.5	0.30
Amorphous Silicon	50	16.5	3.03	23.0	3.67



Modules of various sizes and power ratings were used in this study

CURRENT DATA

- Data collected from July to August 2009 (referred to as current data)
- Module voltage, insolation and ambient temperature were obtained from different data loggers and are therefore asynchronous
- In order to obtain synchronous data of module voltage, ambient temperature and insolation, the data were averaged over 20 minutes.

PREPARATION OF NOISY ARCHIVAL DATA

- Hourly data of insolation and ambient temperature were obtained for 1996

- Insolation
  - Missing data were obtained using a cubic spline interpolation

- Ambient Temperature
  - Missing data were obtained using linear interpolation of temperatures at the respective hours.
  - Values from 22°C and 35.5°C were accepted based on a combination of temperatures from the Vantage Pro2 weather station and the MET office Jamaica [6].
  - Values outside of this range were discarded and replaced with an interpolated value.

DATA ANALYSIS

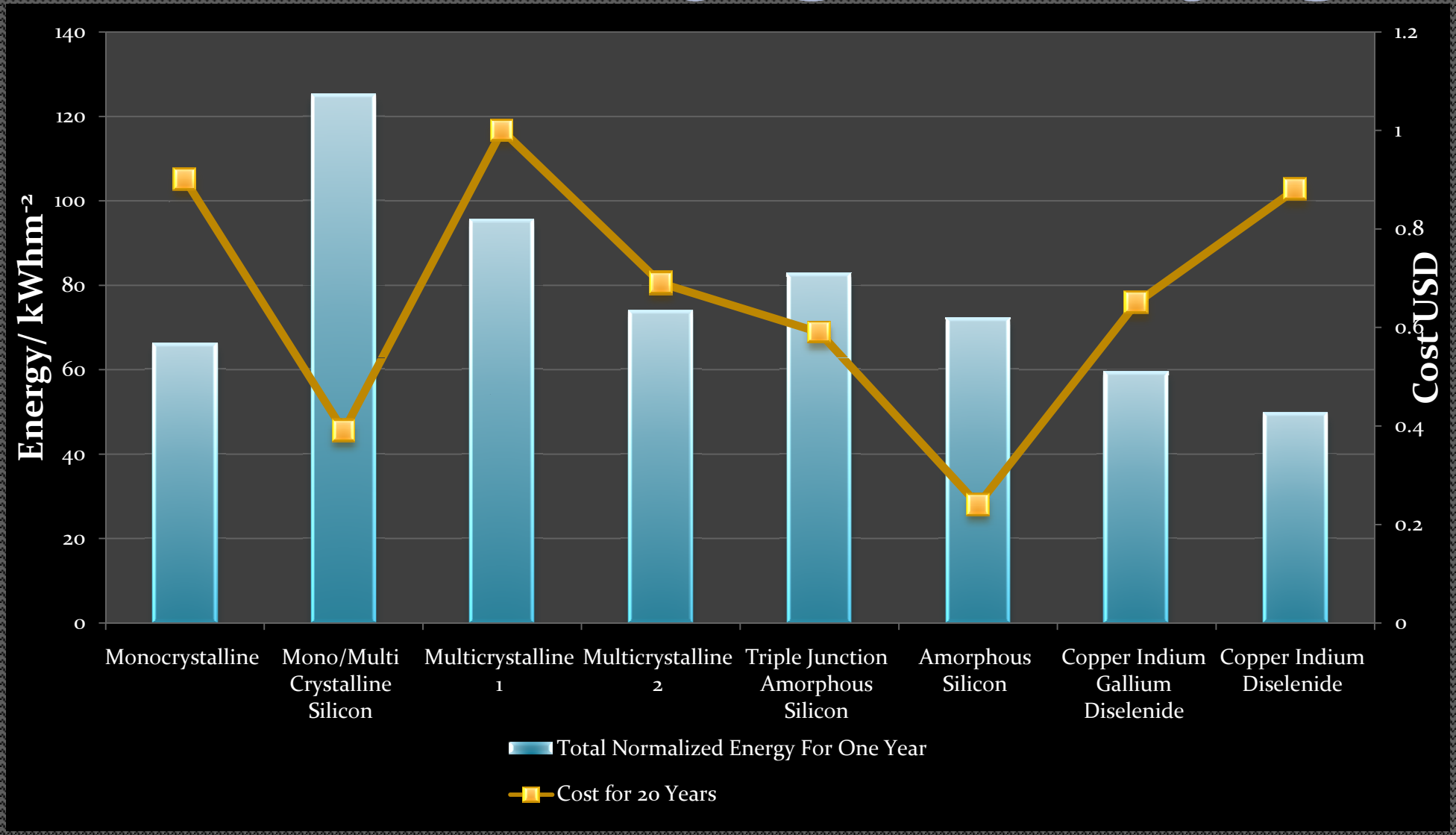
- Voltage readings for 1996 were obtained by performing a 2-D interpolation of the insolation and ambient temperature for 1996 data onto the current data using MATLAB
- Hourly power for 1996 voltage data were computed from the load resistance
- The total power for 1996 was obtained by integrating the power over all hours of the year

RESULTS AND OBSERVATIONS

Technology	Total Energy for 1996 in /kWh	Normalized Total Energy (kWh)	Cost per square metre (USD)	Cost Per kWh for the year 1996 (USD)	Cost Per kWh over the Module's lifetime (20 years)
Monocrystalline	2.50	66.1	1190	18.00	0.90
Mono/Multi Crystalline Silicon	7.73	125.1	971	7.76	0.39
Multicrystalline 1	1.25	95.5	1914	20.06	1.00
Multicrystalline 2	5.77	74.0	1013	13.70	0.69
Triple Junction Amorphous Silicon	6.10	82.7	975	11.79	0.59
Amorphous Silicon	58.67	72.2	342	4.74	0.24
Copper Indium Gallium Diselenide	4.23	59.5	774	12.99	0.65
Copper Indium Diselenide	10.41	49.6	871	17.58	0.88

Mono/Multi produced the highest energy for 1996, however amorphous silicon was the most cost effective

RESULTS AND OBSERVATIONS



- Amorphous silicon is most cost effective
- Performance of multicrystalline silicon varies with manufacturer

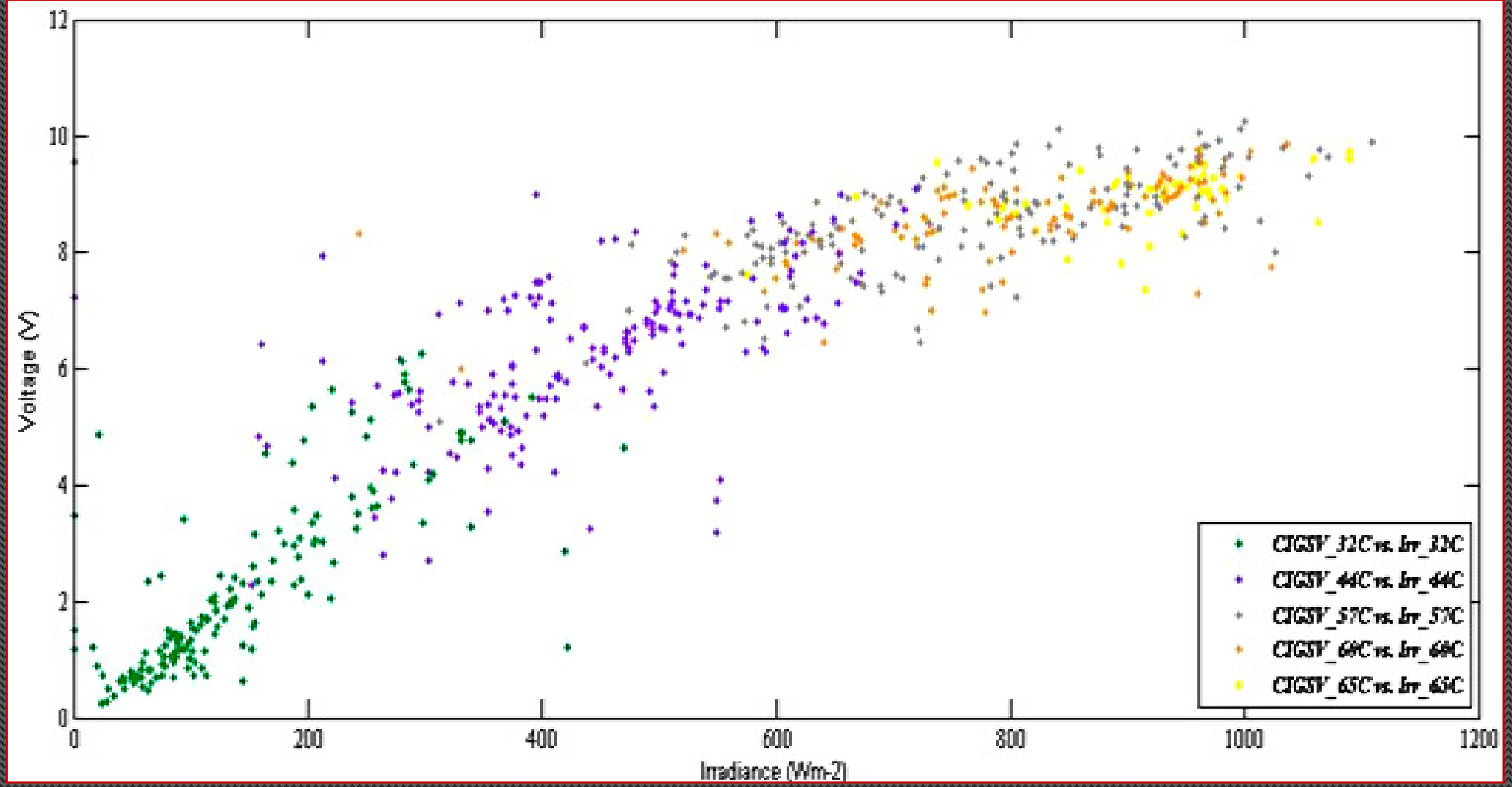
FINDINGS USING 1996 DATA

- Currently Jamaican consumers pay about US $0.31 per kWh of electricity
  - This does not include the fact that this cost incurs an average annual increase of 8%
- The electricity generated by commercially available PV technologies range from USD $0.24 to USD $1.00 per kWh
  - This does not include the additional costs involved with conversion and storage
- Amorphous silicon and mono/multi crystalline silicon are the only two technologies which showed promise toward grid parity

1996 INTERPOLATED ENERGY VS CURRENT ENERGY VALUES

Technology	Total Energy for 1996 in kWh	Total Energy Generated from July 2009 to June 2010 (kWh)
Mono	2.50	1.99
Mono/Multi	7.73	9.00
Poly:Si-1	1.25	1.37
Poly:Si-2	5.77	7.08
3-a:Si	6.10	6.19
a:Si	58.67	61.97
CIGS	4.23	3.99
CIS	10.41	21.84

VOLTAGE AGAINST IRRADIANCE



IRRADIANCE AT VOLTAGE SATURATION

Technology	V_{MP} at STC/V	Saturation Voltage/V	Irradiance at which Voltage Saturates/W m^{-2}	Module Temperature at which Saturation begins/˚C
Mono	18.7	12.0	500	53
Mono/Multi	16.5	14.0	800	57
Poly:Si-1	16.7	15.5	750	44
Poly:Si-2	16.5	15.5	800	53
a:Si	16.5	12.0	750	61
3-a:Si	16.5	14.5	800	53
CIGS	15.8	9.0	650	57
CIS	16.5	16.2	700	57

STC AND ACTUAL AVERAGE EFFICIENCIES

Technology	Efficiency at STC	Average Daily Efficiency	Percentage Reduction
Mono	**7.42**	**2.74**	63.07
Mono/Multi	**13.09**	**6.64**	49.27
Poly:Si-1	**9.59**	**4.84**	49.53
Poly:Si-2	**5.71**	**3.61**	36.78
a:Si	**6.15**	**2.91**	52.68
3-a:Si	**6.70**	**3.88**	42.09
CIGS	**8.44**	**2.88**	65.88
CIS	**9.59**	**5.43**	43.38

CONCLUSION

- Noisy Archival data can be used to determine the local performance of various PV technologies
- All the technologies showed voltage and hence power saturation well below 1000 W/m^2
- STC efficiency does not accurately reflect the local performance of any PV technology
- The average efficiencies show reduction of 37-66 % of the STC values
- The most cost effective technologies are within grid parity for grid tied systems.

Thank You

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