Solar Energy

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Energy, Environmental Impacts, and Sustainability

Intersession Workshop

Solar Energy

Solar Electric

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Wave Power

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Ocean Power Delivery, Ltd.

Wind Energy

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Babcock/NREL

Hydroelectric

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Petroleum

ACS

Coal
Natural Gas

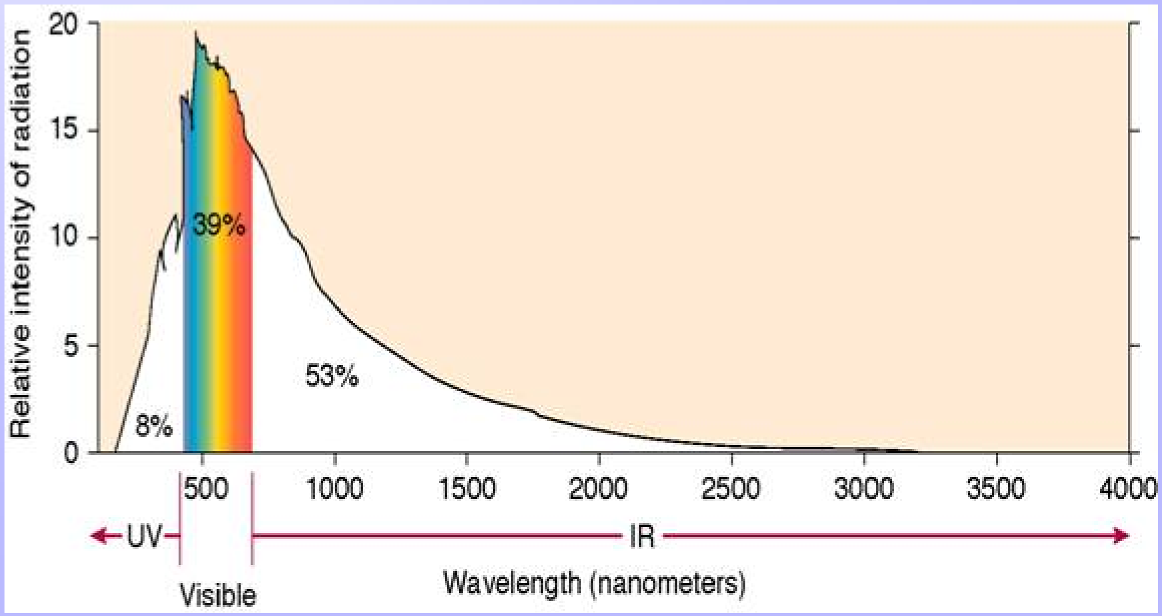
“Convenient” Access to Solar Energy

- Coal, Petroleum, Natural Gas
  - Coal: ≈ 20 MJ/kg
  - Petroleum: ≈ 48 MJ/kg
  - Natural Gas: ≈ 59 MJ/kg
- Problem:
  - It Takes Millions of Years to Form Fossil Fuels
  - Equivalent ≈ 8×10^9 metric tons of Petroleum/year
  - 5.4×10^9 metric tons Carbon Emitted/year
  - NOT Sustainable!

How Much Solar Energy?

- Energy used by Earth's Inhabitants:
  - 400 EJ in ONE YEAR
- Energy from the Sun:
  - 10,800 EJ in ONE DAY
  - 27X More than Used in One Year
- Photon Energy
  - in Visible:
  - 240 kJ/mole
  - 2.5 eV

1 EJ = 1×10^{18} J



Direct Solar

- Passive Solar
  - Greenhouse Effect
- Active Solar
  - Solar Thermal
    - Concentrate, Heat from Sun
  - Solar Electric
    - Photovoltaics
    - Sunlight --> Electricity

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Aitken/NREL

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SES/Boeing/NREL

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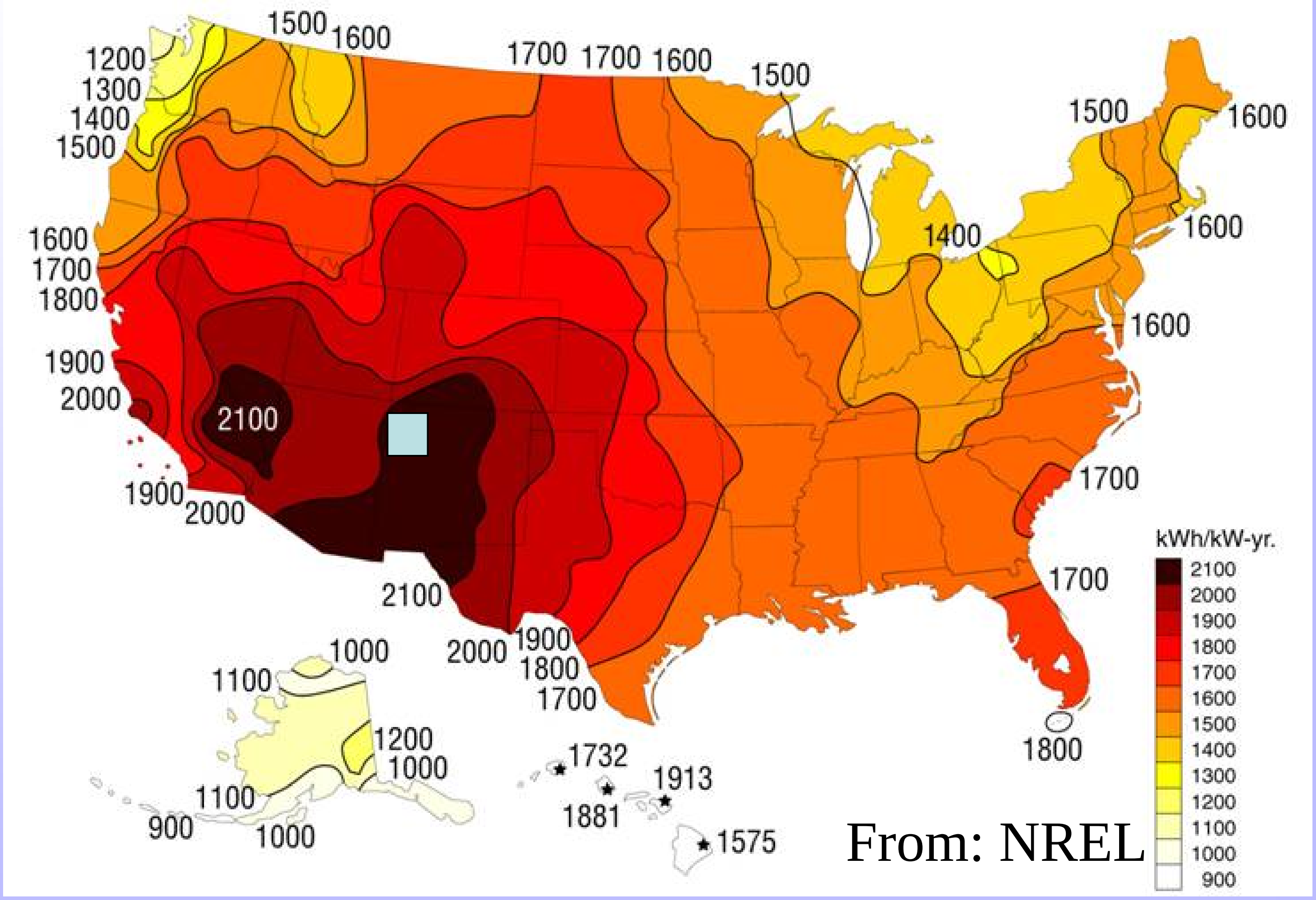
PowerLight/NREL

Solar - Where?

- In kWh/kW-yr

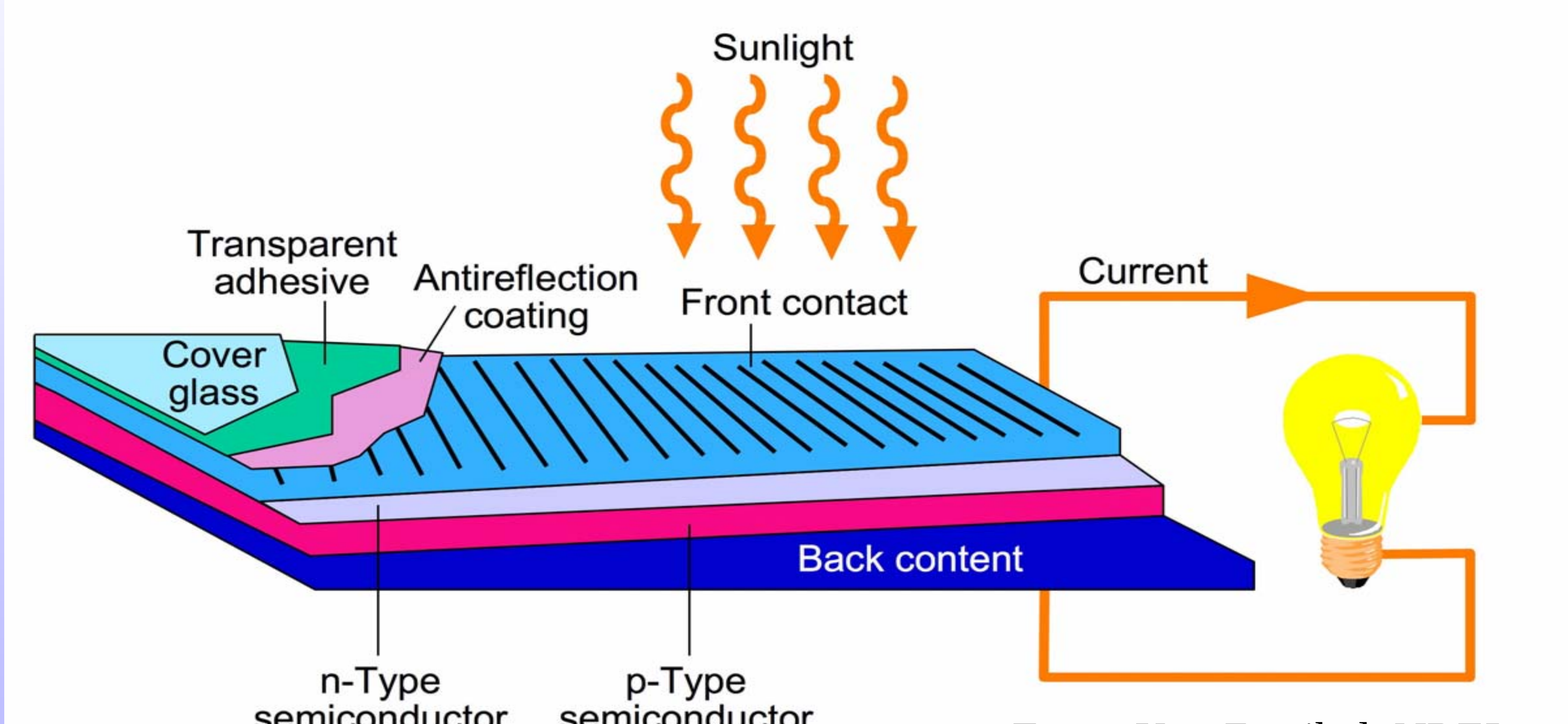


From: NREL

To Meet All Our Needs: Solar Area = 100x100 miles^2

Photovoltaic Cells

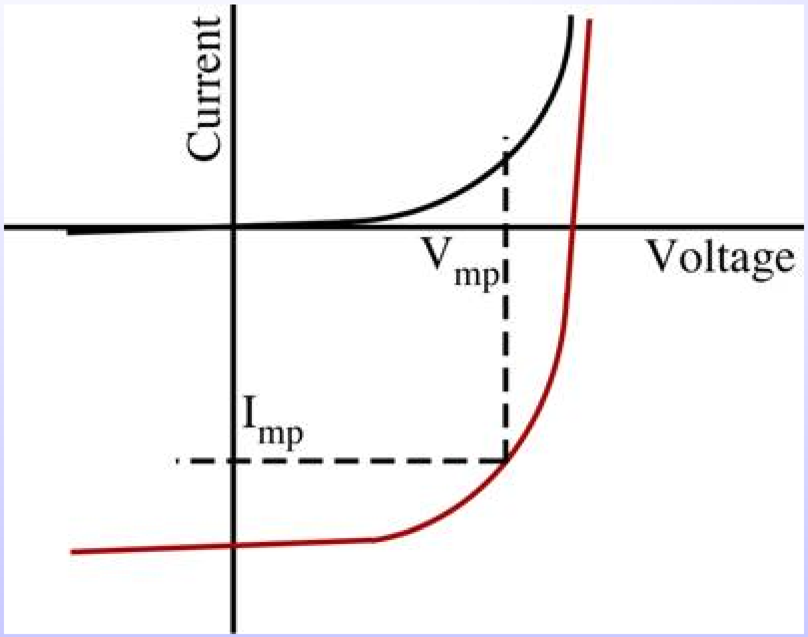
- Mostly Silicon
- Crystalline, Microcrystalline, Amorphous, Thin Film



From: Ken Zweibel, NREL

Photovoltaic Efficiency (Solar)

Limited by Photon Energy, Band Gap



$$E = \frac{I_{mp}V_{mp}}{P_{in}}$$

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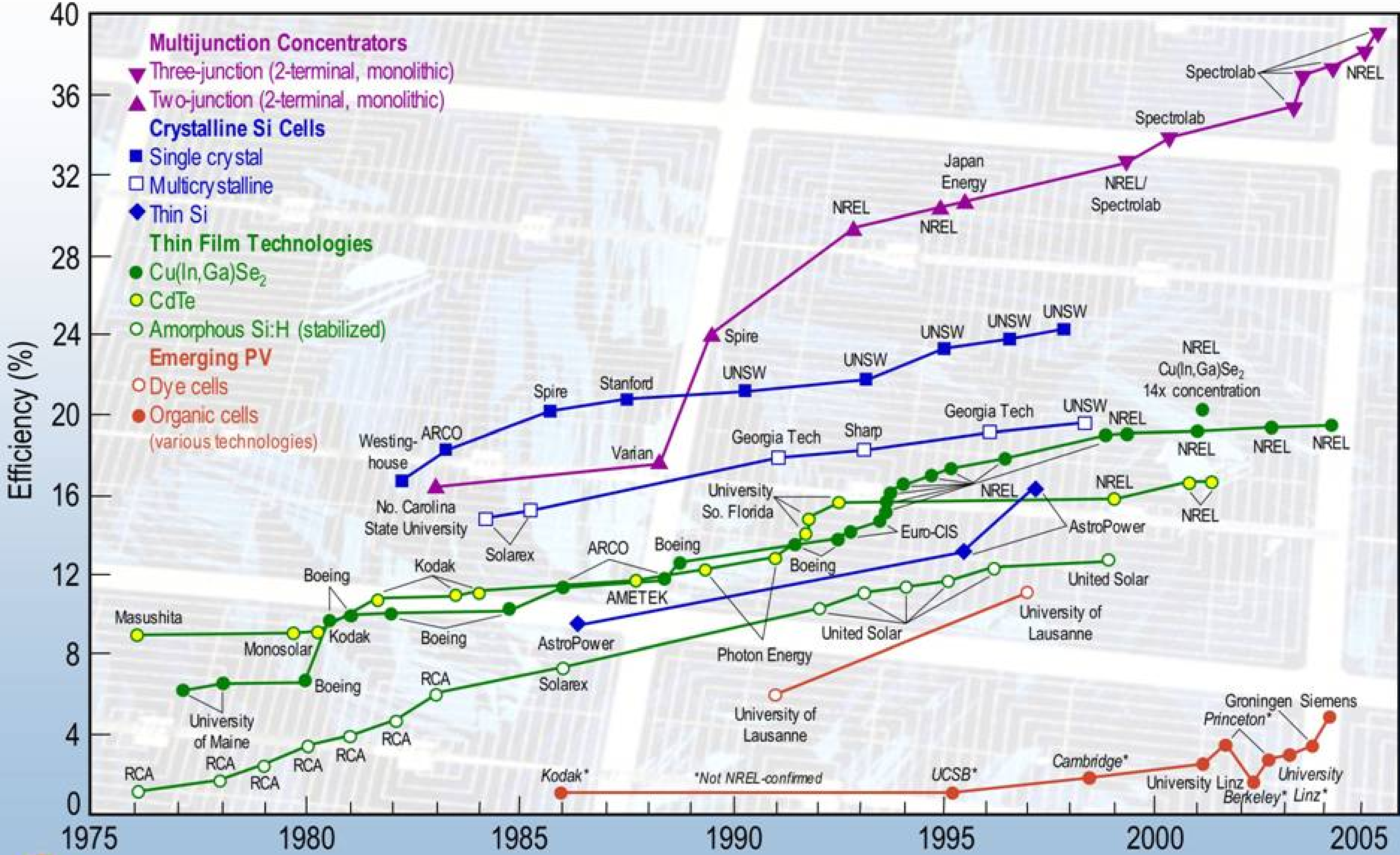
http://www.solarserver.de

Best Research-Cell Efficiencies

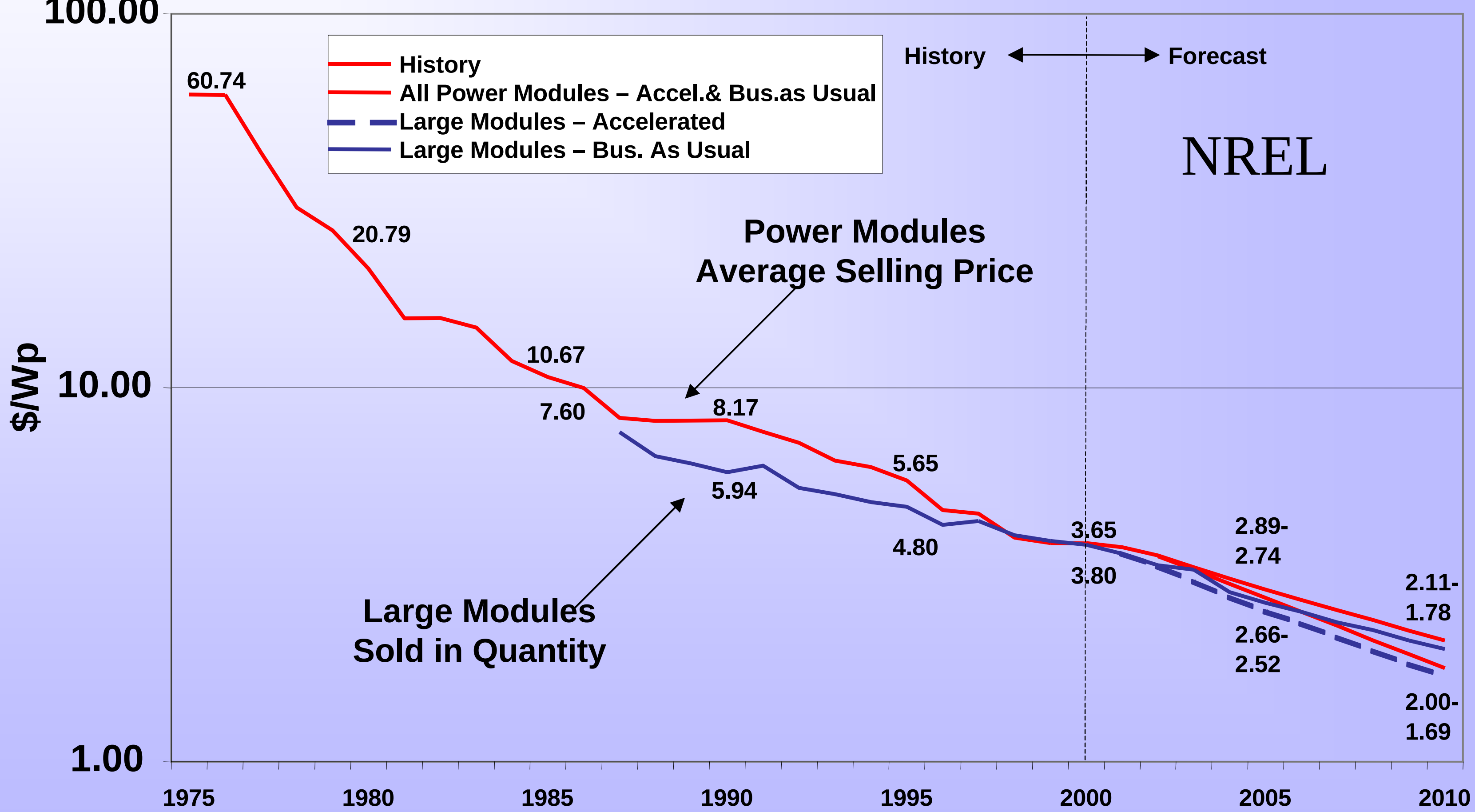


Component/Cost Issues

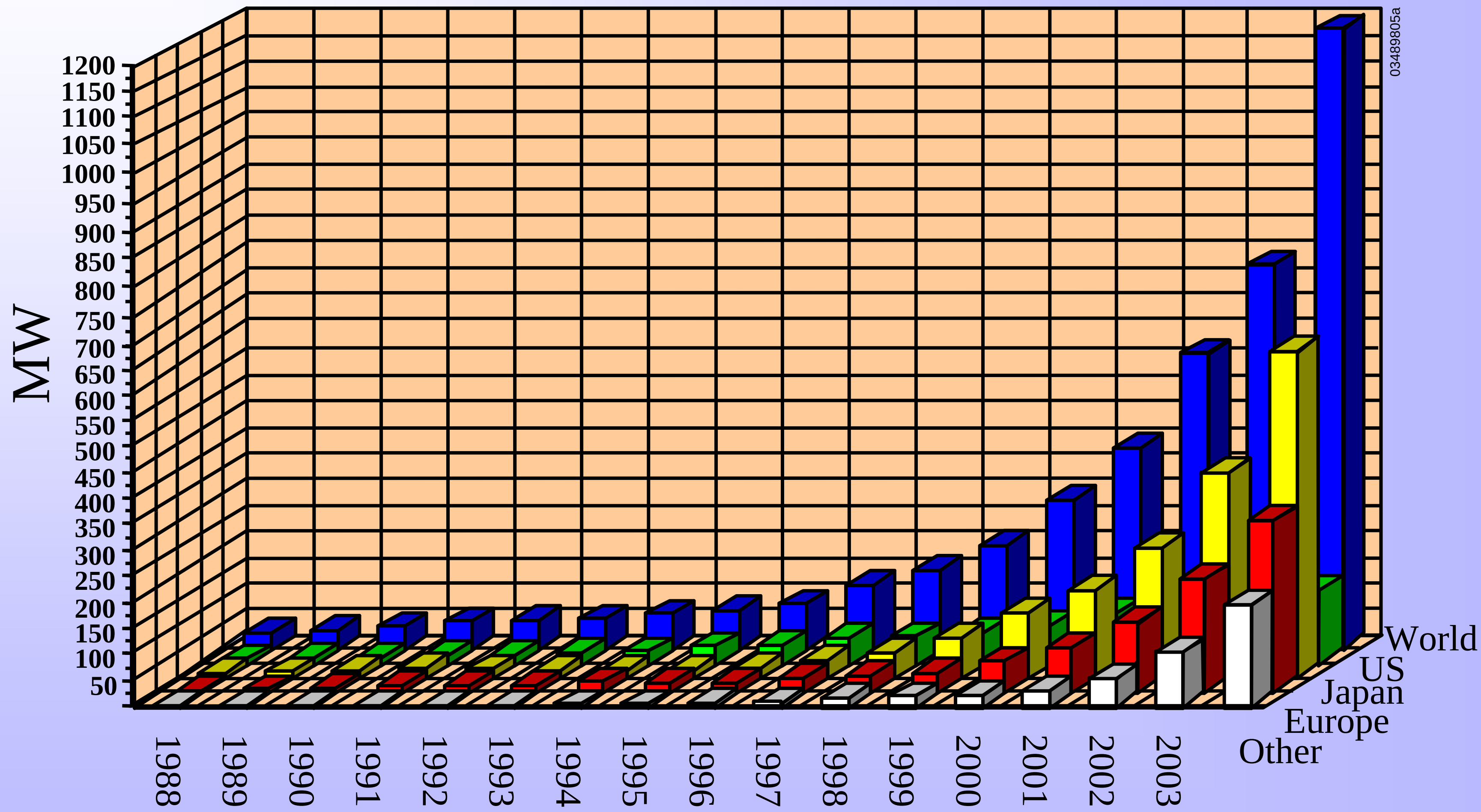
- Solar Photovoltaics
  - ≈ $3-4/Wp
  - ≈ $0.15-$0.30/kWh
- Biggest Factor-
  - PV Module
  - Materials/Efficiency
- Challenge:
    - Large Area PVs
    - CHEAP!

First Solar Thin-Film PV Module

System Costs



Photovoltaic Production

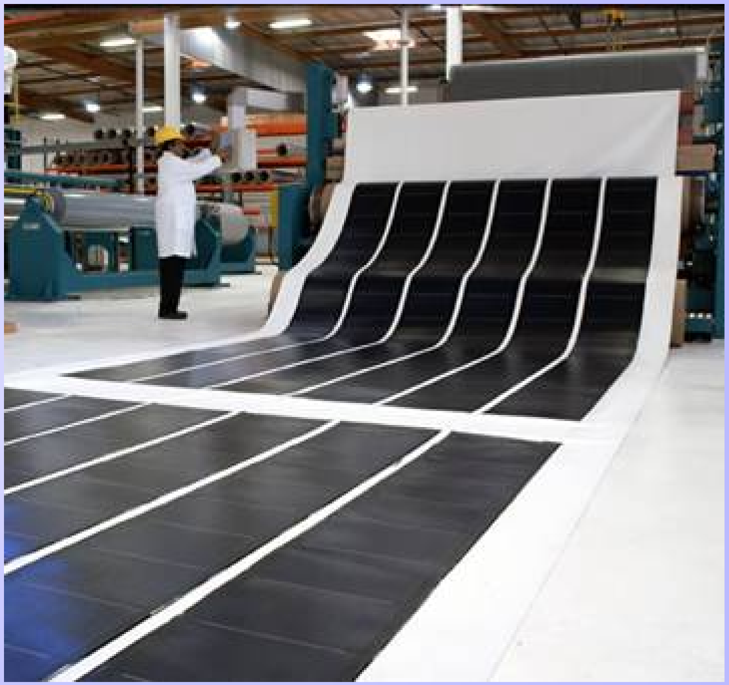


From NREL - Derived from PV News

Reducing Cost - Emerging Materials

- Organic Semiconductors
  - Semiconducting Polymers
  - Small Molecule Organics
  - Dye-Sensitized
  - Composite Devices
- Advantages
  - Coat Arbitrary Surfaces
  - Photovoltaic “Paint”?
  - Less Expensive Materials
- Challenges
  - Less Efficient
  - Different Mechanism (Tightly Bound Excitons)

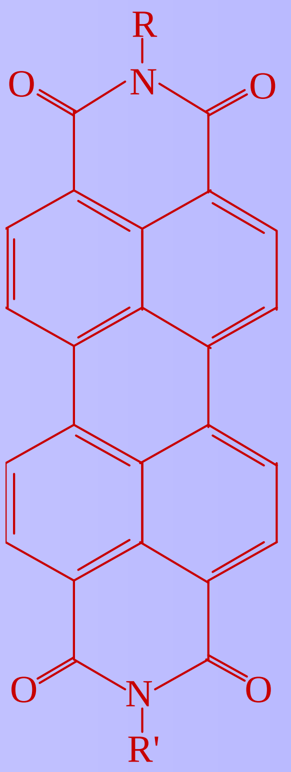
Like Thin-Film Inorganics



Ken Zweibel, NREL

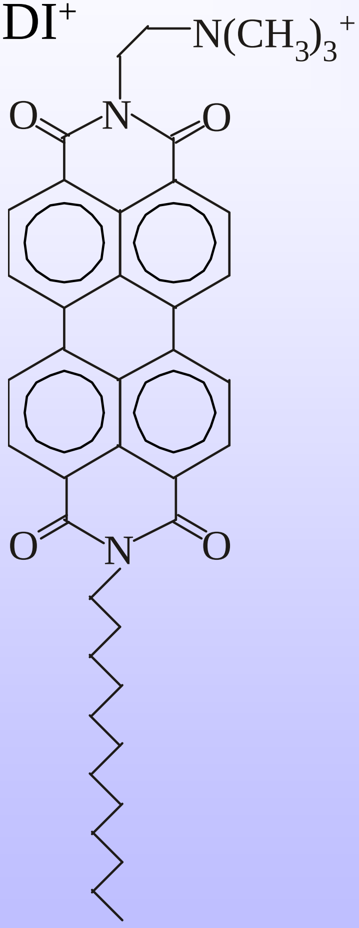
New Photoactive Organic Films - KSU

- *Previously:*
  - Symmetric Diimides
  - Crystalline or Liquid Crystalline (at High Temperatures)
  - Polymer-Diimide Composite Films
    - Optoelectronic Properties: From Chromophore
    - Mechanical/Morphological(?) Properties: From Polymer
- *Our Proposal:*
  - Asymmetric Water Soluble Diimides
  - Polyelectrolyte-Surfactant Composites - as Thin Films
    - Optoelectronic Properties: From Perylene Diimides
    - Mechanical Properties: From Polymer + Surfactant
    - Solution Processible - Casting from AQUEOUS Solutions!
    - Self-Assembled Lamellar Phases - “Self Healing”

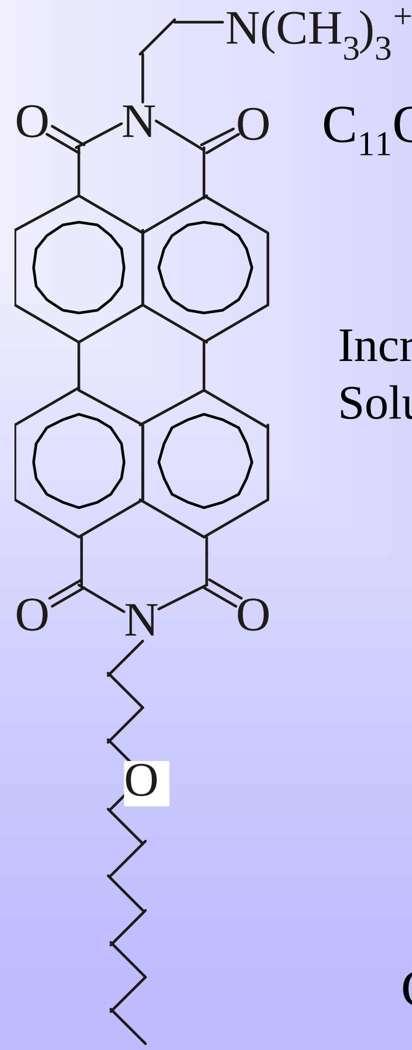


Compounds Synthesized - KSU

C_{12}-PDI$^+$

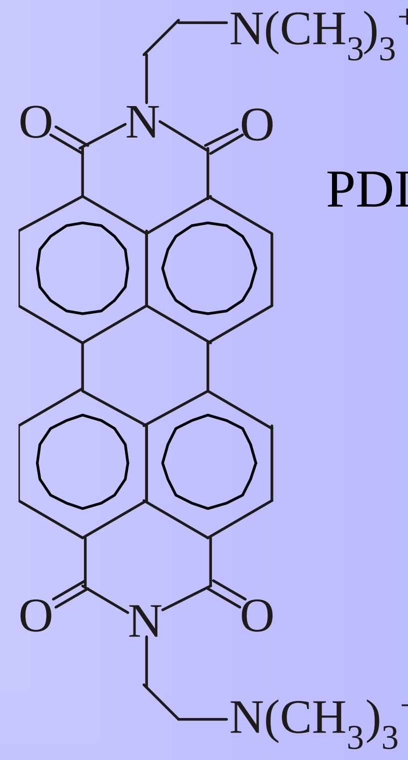


C_{11}O-PDI$^+$



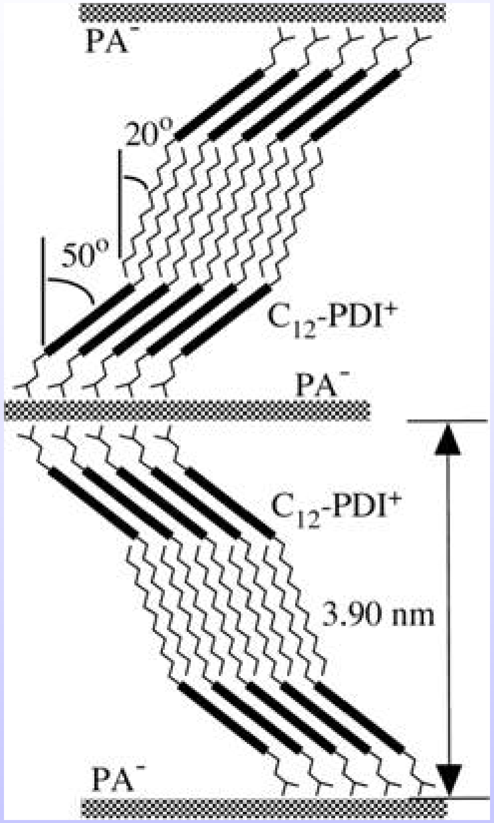
Increased Solubility

PDI^{2+}

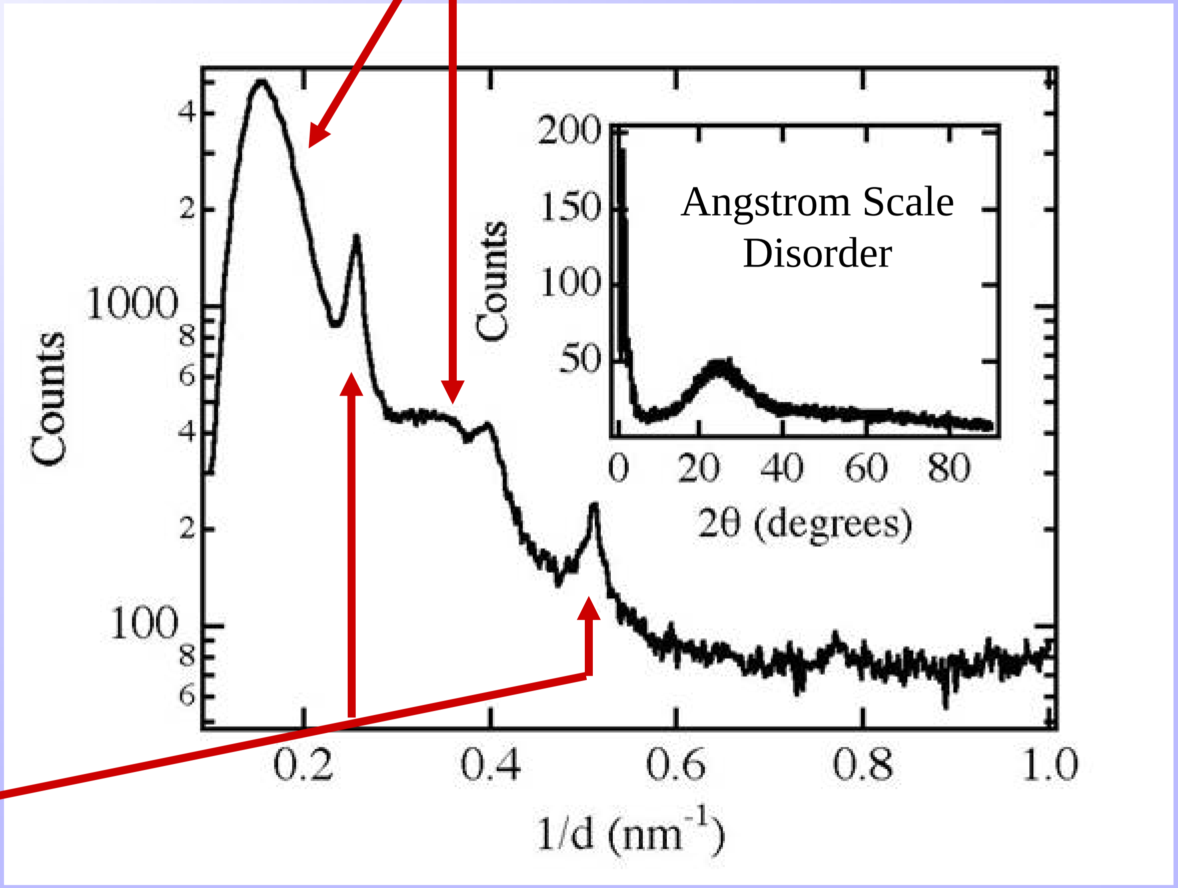


Credits: Sarah Barron, Amy Twite, Jeff Hall, Duy Hua

C_{12}-PDI^{+}/PA^{-} Thin Film Structure - SAXS



More Complex Structure Present? Polymorph?

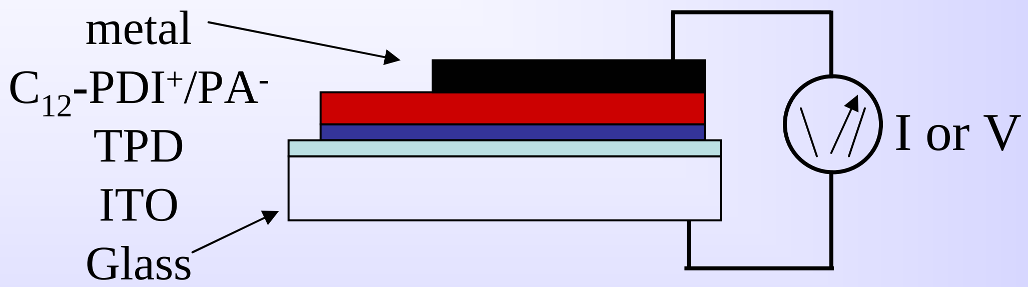


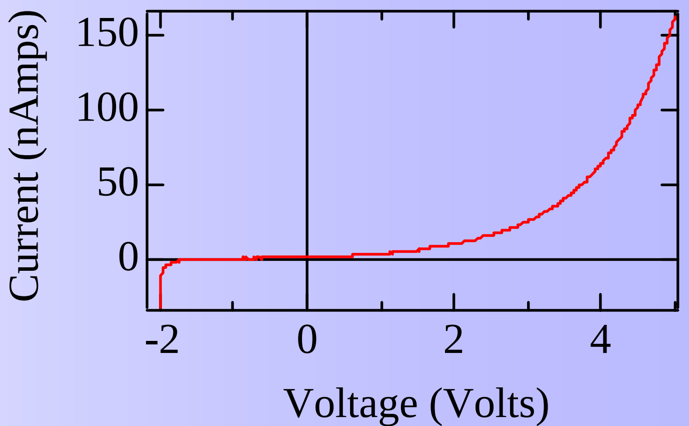
Bilayer Spacing: 3.9 nm

Xie, Liu, Hall, Barron and Higgins, *Langmuir*, **2005**, *21*, 4149.

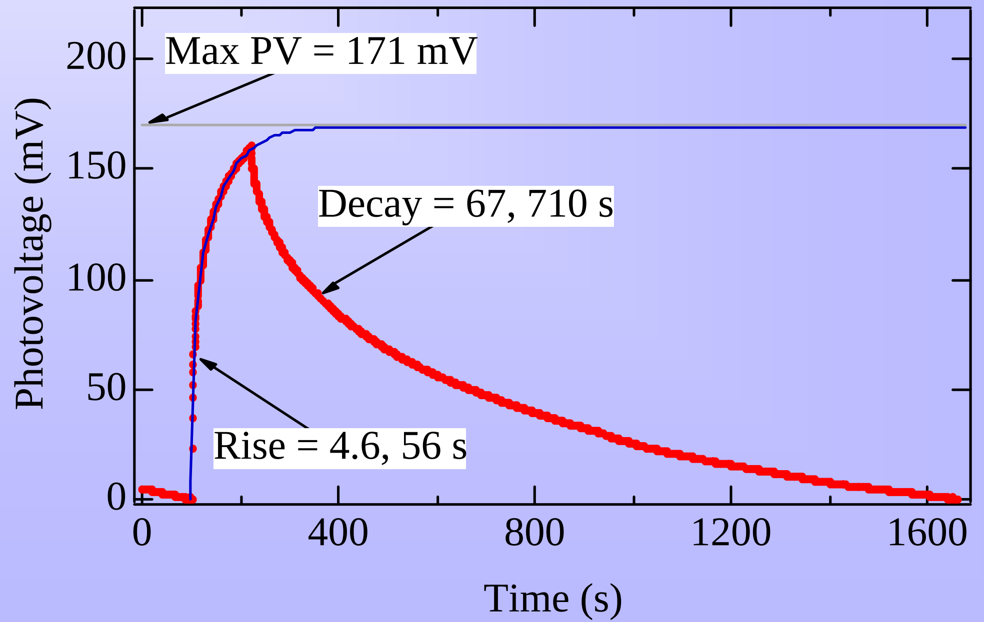
C_{12}-PDI^{+}/PA^{-} Devices

p-n Heterojunction Devices





0.6 W/cm^2 at 488 nm



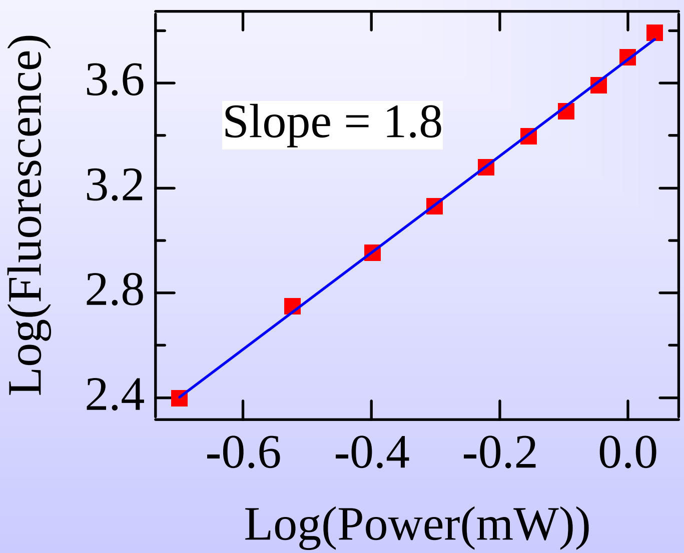
Present Characteristics:
- < 200 mV Photovoltage
- Nanoamp Photocurrents
- Long Rise/Decay

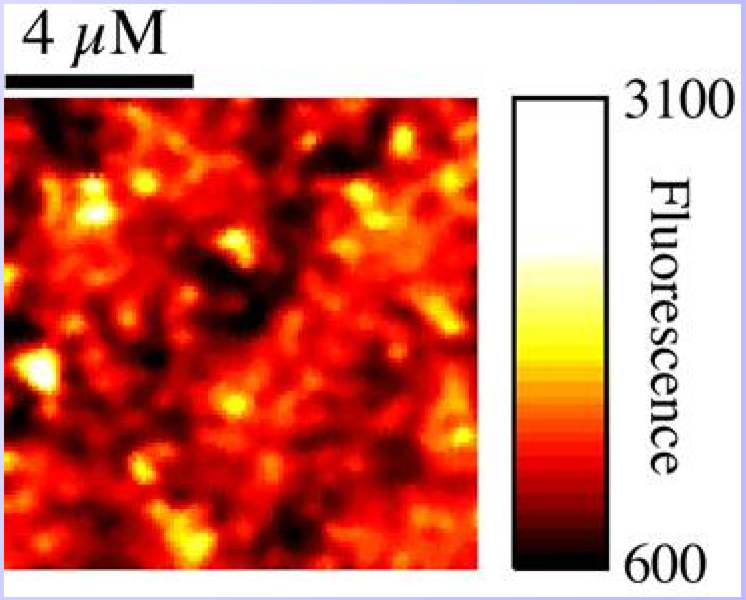
Due to:
- High Series Resistance

MP Fluorescence - PDI Films

Low Loading (≈ 2% C_{12}-PDI^{+} in PA^{-})

Two Photon Excitation of PDI





300 μW Incident

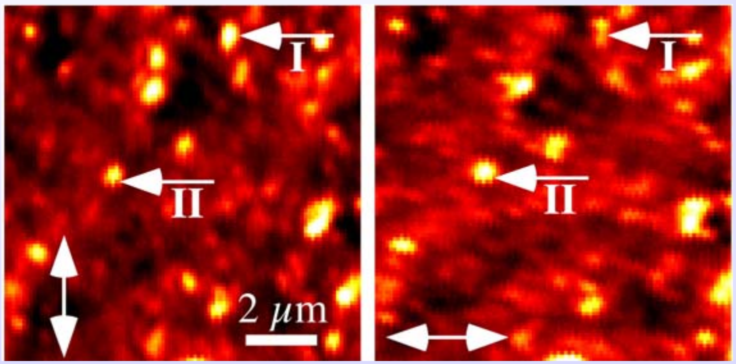
Broad Emission Spectra

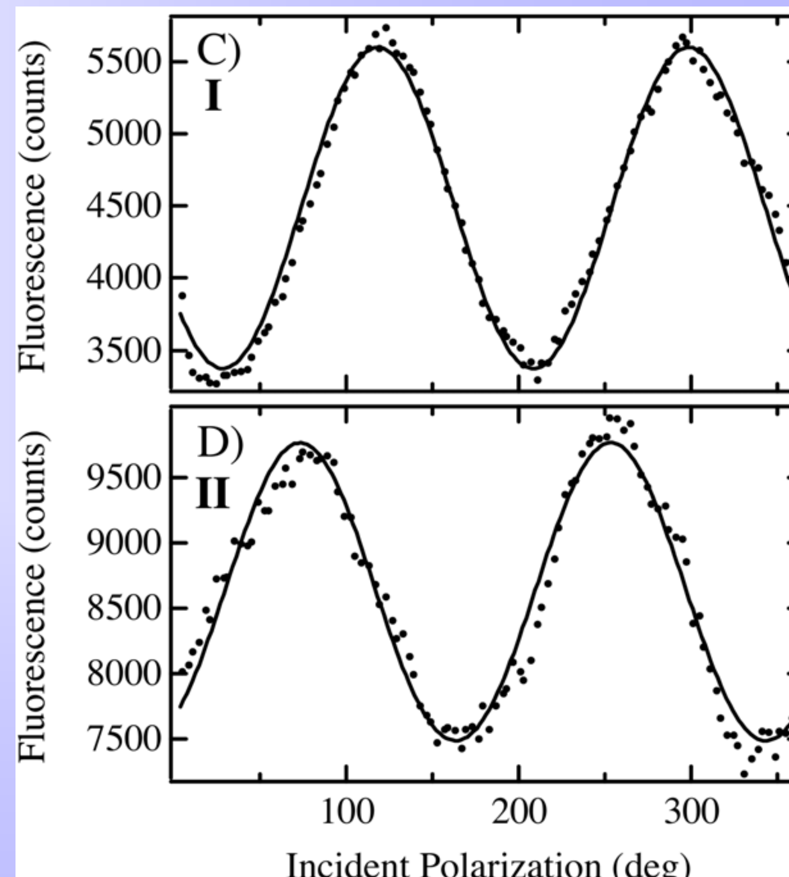
Monomer and CT Exciton Emission

Heterogeneous

Polarization Dependent MP Excitation

- Nanometer Scale Organization
  - C_{12}-PDI^{+}/PA^{-} Composites Ordered?



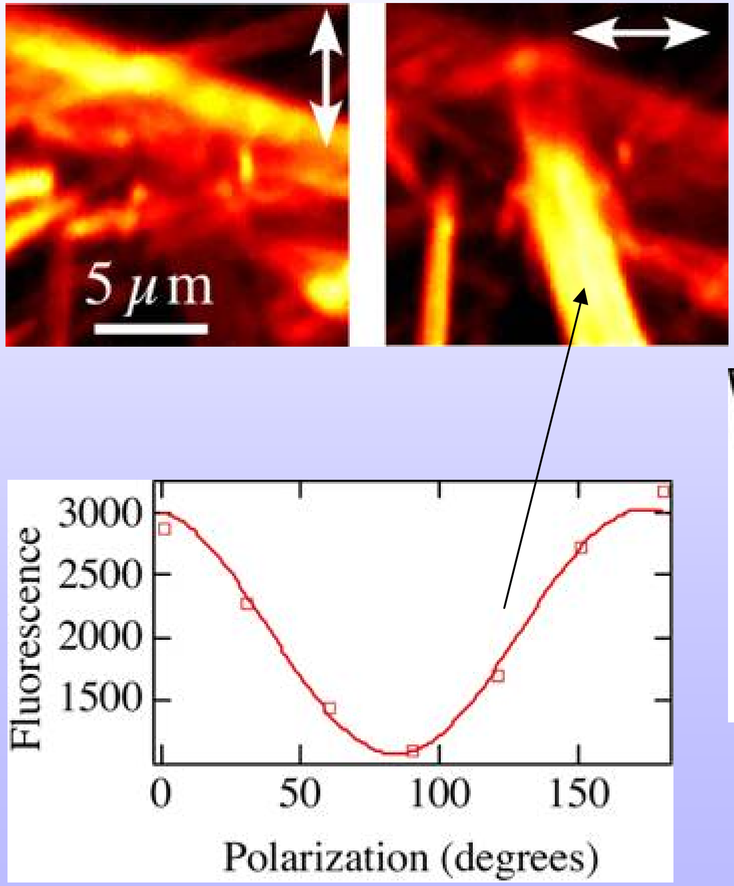


- Order Parameter: $s = \left\langle \frac{3\cos^2\theta - 1}{2} \right\rangle$
  - Measure 0.09
  - 1.0 = Perfect Order
  - 0.0 = Random Organization

Xie, Liu, Hall, Barron and Higgins, *Langmuir*, **2005**, *21*, 4149.

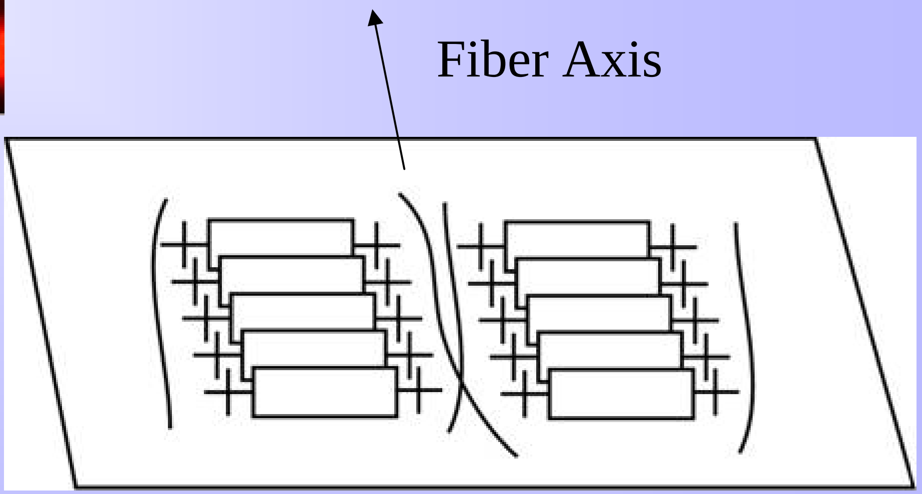
MP Polarization Dependence

Stoichiometric PDI^{2+}/PA^{-}



Ordered Fibers
And
Polarized Excitation

Fiber Axis



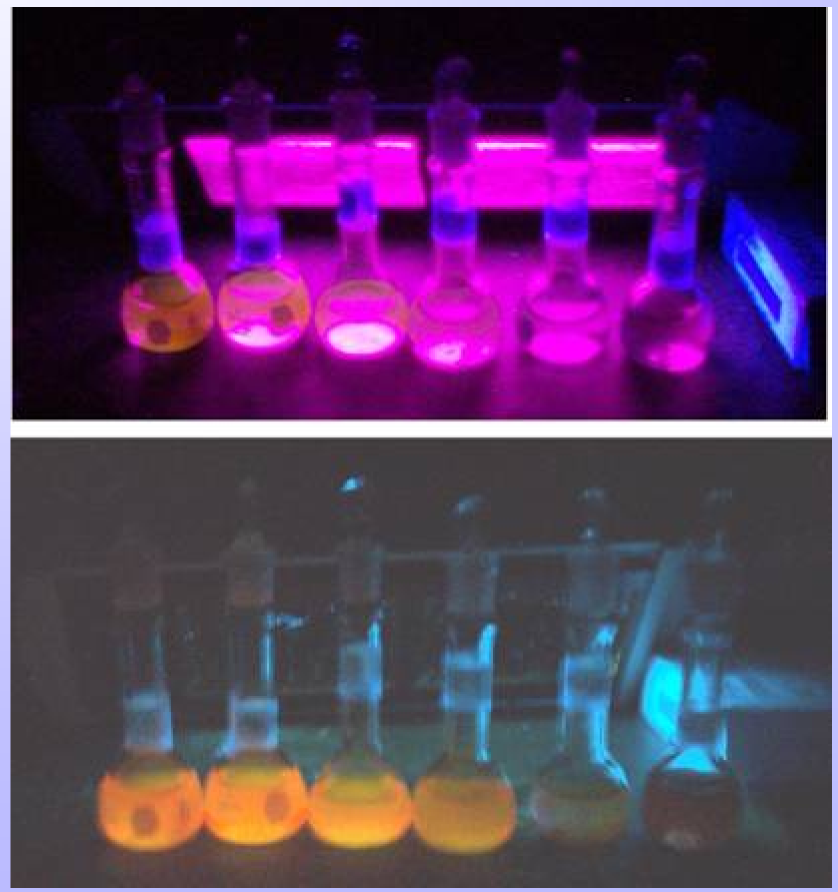
Summary and Future Directions
New Organic Photovoltaics

- Today:
  - Silicon, Others: Crystalline, Amorphous, Films Viable
  - Costs Still High
  - Materials Costs Reductions Possible with Organics
  - At KSU:
    - Perylene Diimide Polyelectrolyte Composites
    - Prepared from Aqueous Solutions
- Future:
  - Energy Storage an Issue
  - Improvements in Thin Film Characteristics
  - Development of Simple Coating Procedures
  - Increased Emphasis Needed at National Level

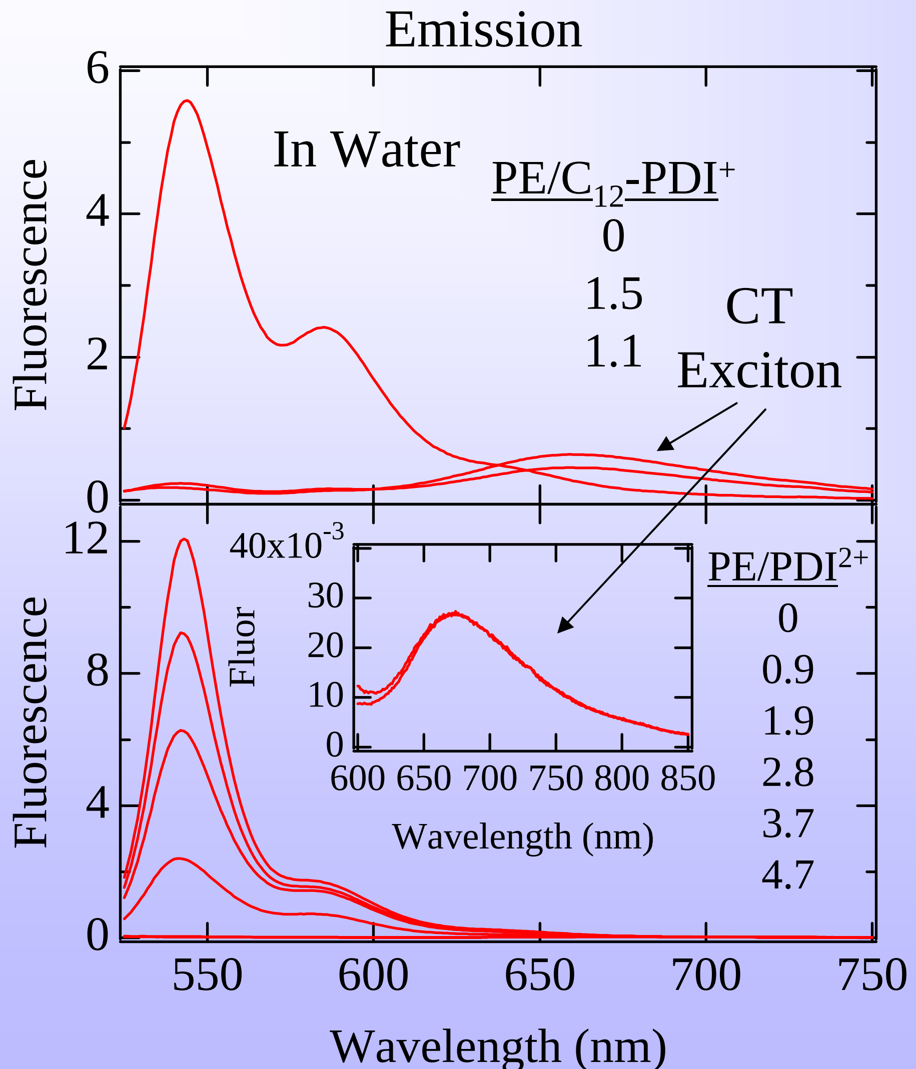
PDI^{2+}/PA^{-} Fluorescence

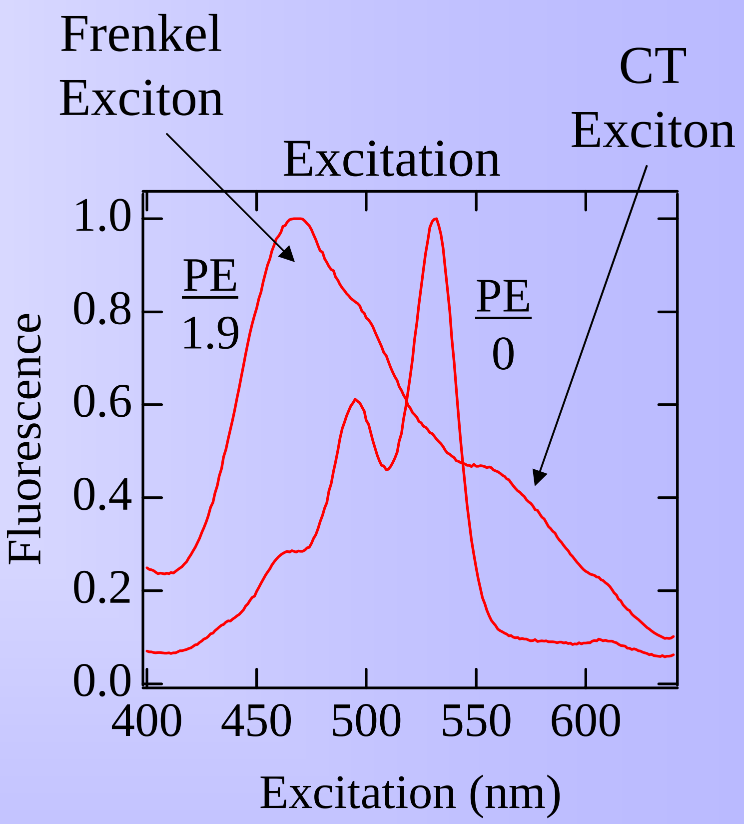
No PA^{-}

Stoichiometric Complex



C_{12}-PDI^{+}/PA^{-} and PDI^{2+}/PA^{-} Aggregation





CT Exciton:
Weak Emission ($\phi < 0.01$)

Xie, Liu, Hall, Barron and Higgins, *Langmuir*, **2005**, *21*, 4149.

Multiphoton Microscopy

Sample-Scanning
Confocal Microscope

- High Resolution Imaging
- Low Background
- Depth Discrimination