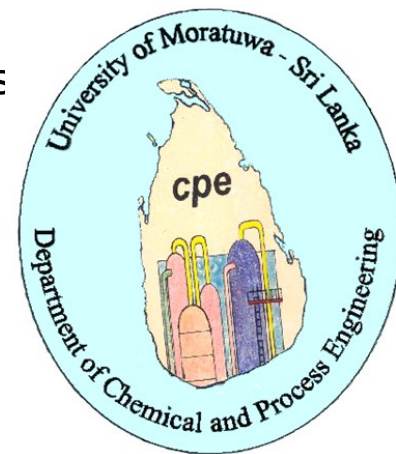


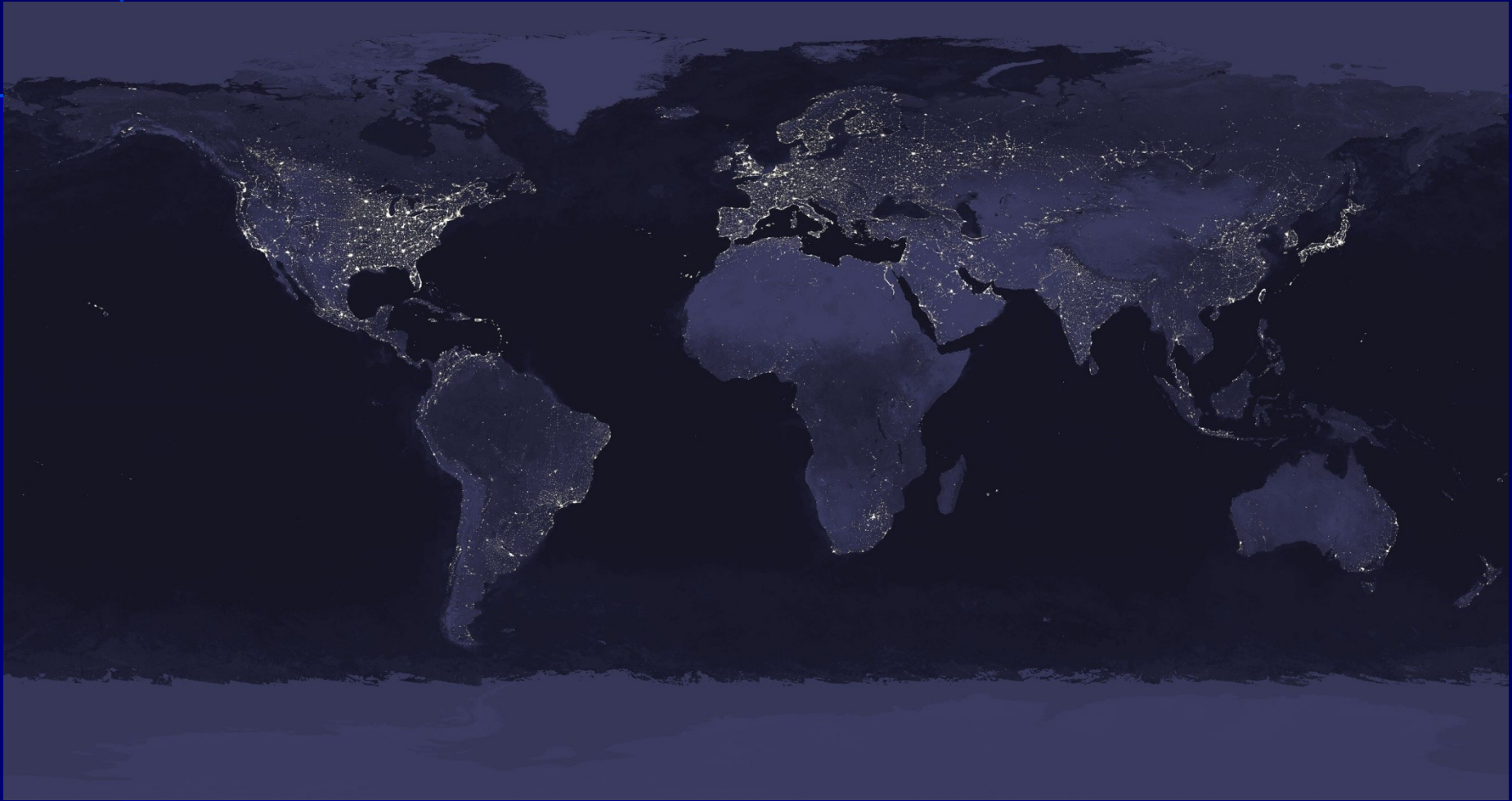
# Study of Novel Dyes to support DSSC Research

*Cmde C. I. F. Attanayake*

University of Moratuwa & Institute of Fundamental Studies



# WORLD AT NIGHT

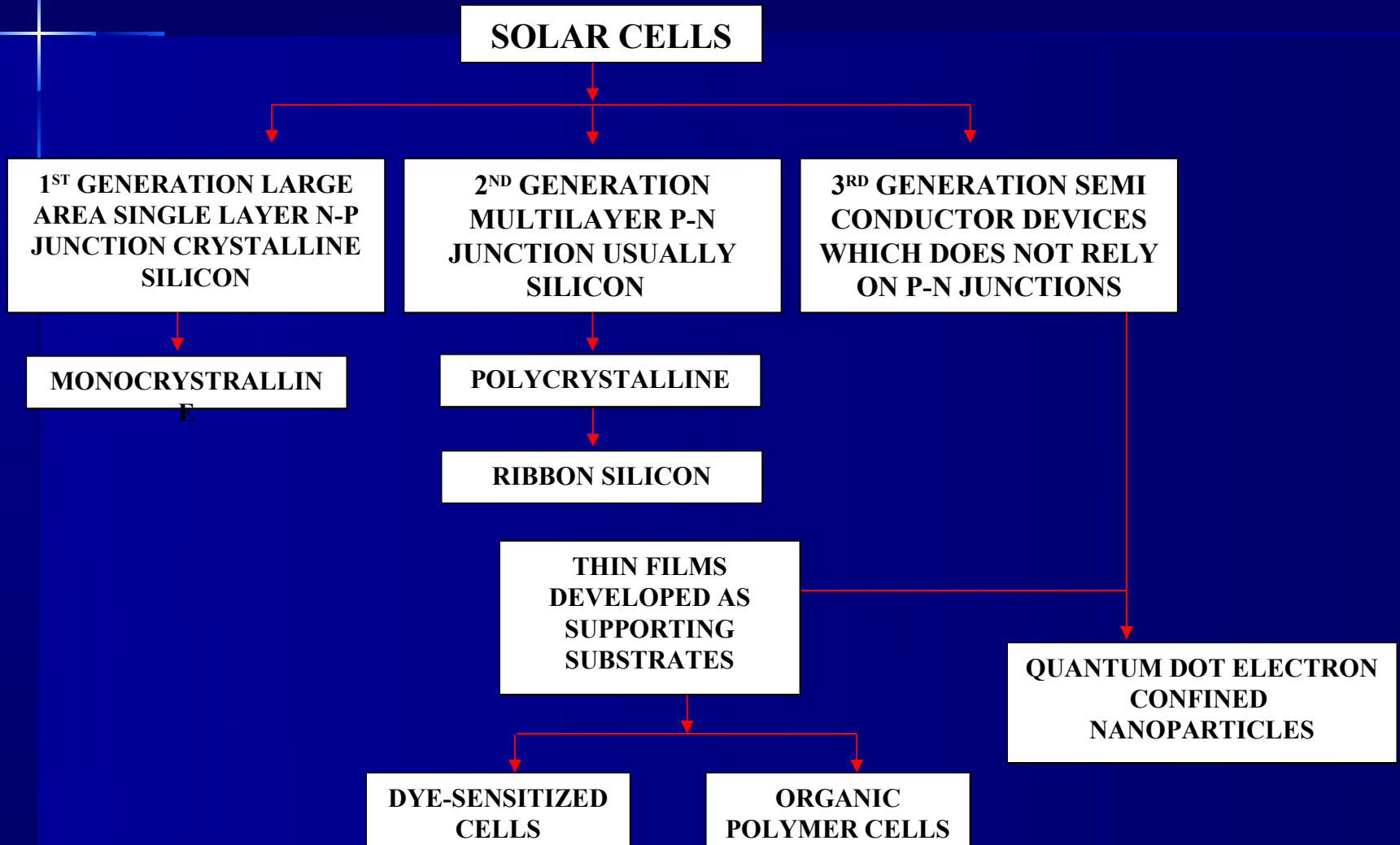


ABOUT 1.8 BILLION PEOPLE WITHOUT ELECTRICITY

# POWER GENERATION SOURCES IN SRI LANKA

❖	Hydro	19 %
❖	Thermal (Diesel)	80 %
❖	Renewables (Wind, Solar)	1 %

# SOLAR CELLS ARE CLASSIFIED INTO THREE GENERATIONS WHICH INDICATES THE ORDER OF WHICH EACH BECAME PROMINENT



WITH OIL, PETROL & DIESEL PRICES SHARPLY INCREASING DUE TO DWINDLING OF THESE SCARCE RESOURCES IN THE WORLD MARKET, VAST AMOUNTS OF RENEWABLE ENERGY SOURCES LIKE WIND, HYDRO, SOLAR (PV & THERMAL), BIO FUELS, TIDAL & WAVE POWER HAVE BEEN IDENTIFIED AS BEING MORE SUITABLE ALTERNATIVE ENERGY SOURCES FOR SRI LANKA.

AMONGST RENEWABLE ENERGY SOURCES IN SRI LANKA, PV'S HAS BEEN IDENTIFIED TO BE MOST TECHNICALLY SUITABLE & ECONOMICALLY VIABLE POWER SOURCE FOR SOLAR ENERGY TO ELECTRICITY CONVERSION IN FUTURE.

# SOLAR FUTURE

## MATERIAL PLATFORMS

PV TECHNOLOGY -

1<sup>ST</sup> GENERATION

THIN FILM PV TECHNOLOGY - 2<sup>ND</sup> GENERATION

ORGANIC PV -

3<sup>RD</sup> GENERATION

DSSC'S -

3<sup>RD</sup> GENERATION

QUANTUM DOT -ENHANCED DSSC'S-

4<sup>TH</sup> GENERATION

# NEW GENERATION PECs DYE SENSITIZED SOLAR CELLS (DSSC's)

Third generation Solar Cells

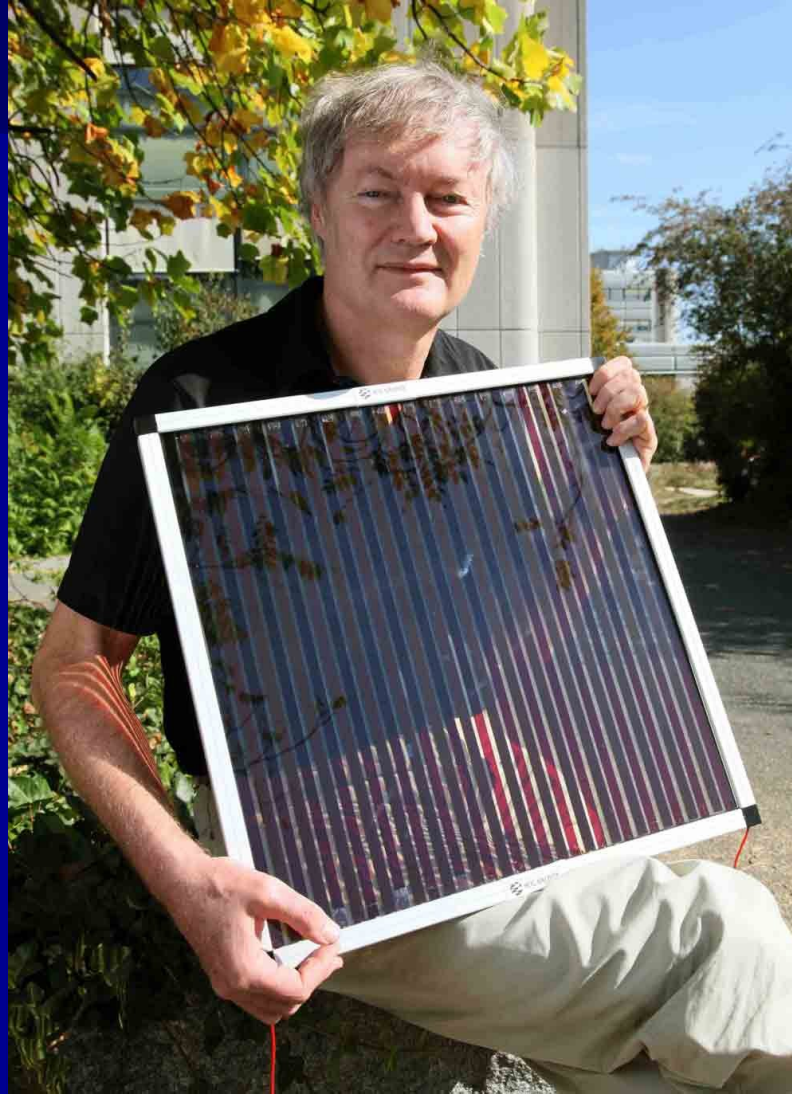
Mimics the **natural photosynthesis** process

Light absorption process is separated from charge transport process (unlike in older cells)

An organic dye absorbs the sunlight and a nanocrystalline wide band-gap semiconductor is used to transport the charges

Also called "Graetzel Cells". These cells were invented by Prof. Michael Graetzel in Switzerland in 1991.

# Michel Gratzel - Inventing the DSSC in 1991



# DYE SENSITIZED SOLAR CELLS (DSSC's)

DYE SENSITIZED SOLAR CELLS BASED ON NANO STRUCTURES BELONG TO A GROUP OF THIN FILM SOLAR CELLS, AND ARE CURRENTLY THE MOST EFFICIENT THIRD GENERATION SOLAR TECHNOLOGY, WITH MAX EFFICIENCY OF AROUND 11% USING VERY EXPENSIVE AND SCARCE RUTHANIUM SYNTHETIC DYES , BUT AROUND 1% WITH CHEAP, ABUNDANT AND ENVIRONMENTALLY FRIENDLY NATURAL DYES .

# The DSSC research strategy at UOM

- **Multi Disciplinary Research Team**
- Extending the knowledge base with respect to natural dyes
- Demonstrating Potential to instill interest
- Recyclable Solar Cell – building integrated to small power systems

# Solar Characterization Equipment to measure Current - Voltage characteristics of solar cells



# Table of Results

(In decreasing Efficiency values )

S/ No	Dye	Open Circuit Voltage $V_{oc}$ (mV)	Short Circuit Current $I_{sc}$ (mA)	Current Density $I_D$ (mA/cm <sup>2</sup> )	Fill Factor (ff)	Efficiency ( $\eta$ )	Solvent
1	Fire Fern + HCL	405.1	1.032	4.128	47.97	0.802	Ethanol
2	Ekkiriya Wood	414.2	0.58	2.32	56.86	0.547	Ethanol
3	Egg Plant	410.4	0.524	2.096	56.42	0.485	Ethanol
4	Fire Fern (14 days)	365.7	0.584	2.336	51.77	0.442	Ethanol
5	Purple Fruit (Karawala Kobilla)	443.5	0.348	1.395	58.58	0.362	Ethanol
6	Banana Flower Inflorescence	414	0.477	0.763	45.2	0.357	Ethanol

7	Mangoostin 2	638.2	0.194	0.778	68.46	0.34	Ethanol
8	Fire Fern + Acetic Acid	442.2	0.333	1.332	55.03	0.325	Ethanol
9	Beetroot	441.2	0.328	1.312	55.36	0.32	Ethanol
10	Turmeric	601.9	0.16	0.64	68.31	0.264	Ethanol

**Many New Materials  
Studied**

**Selection of the most  
Promising**

# Absorption Spectra obtained from various Fruits & Vegetables

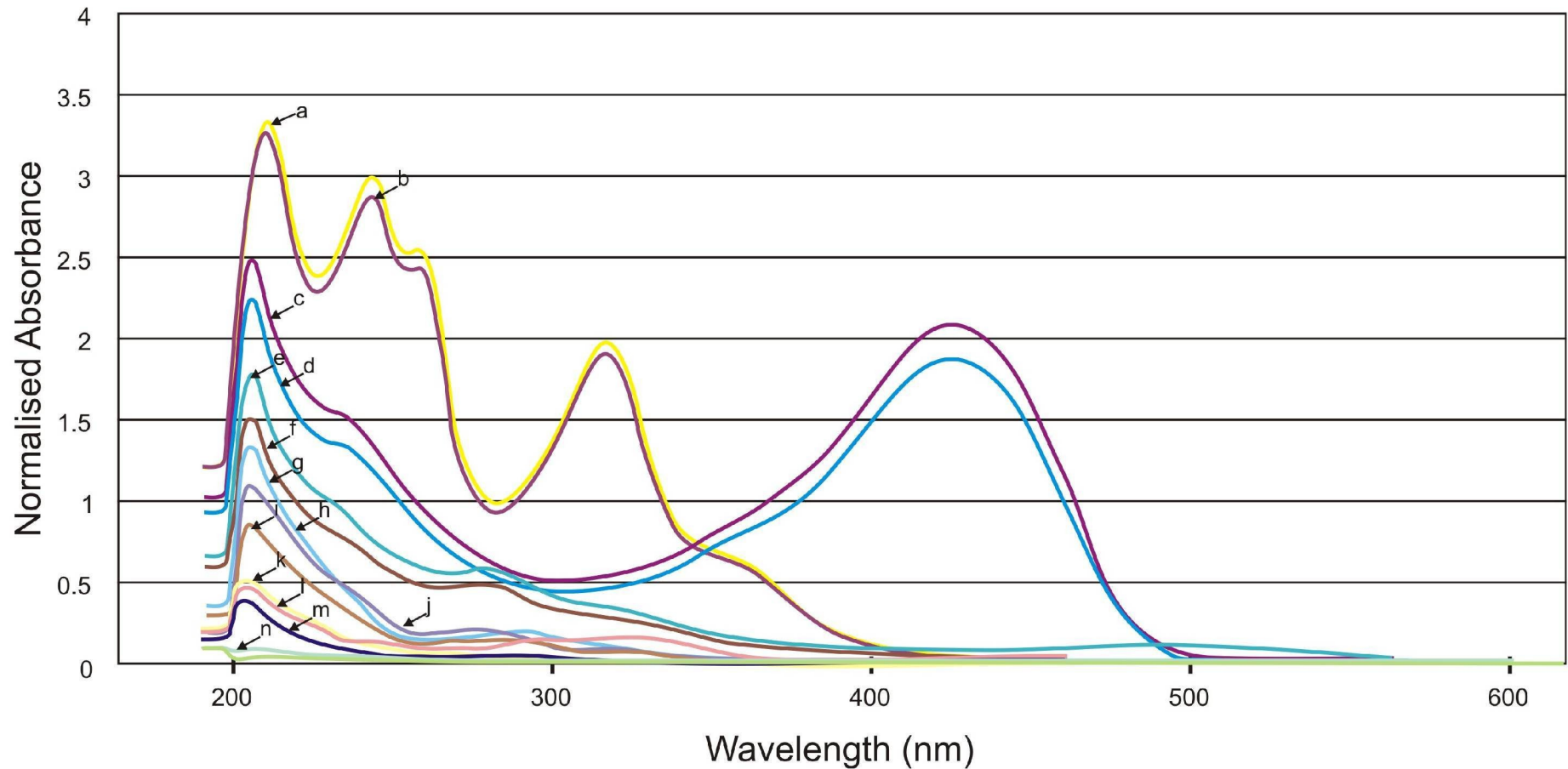


Figure 2. Absorbance of Spectra dye solutions extracted from (a) Mangoostin + HCL (b) Mangoostin (c) Turmeric + HCL (d) Turmeric (e) Ekiriya + HCL (f) Ekiriya (g) Purple Fruit + HCL (h) Purple Fruit (i) Red Plum (j) Red Plum + HCL (k) Black Grape (l) Beetroot (m) Egg plant (n) Spinach

## Current-Voltage Characteristics of Dye-Sensitized Solar Cells

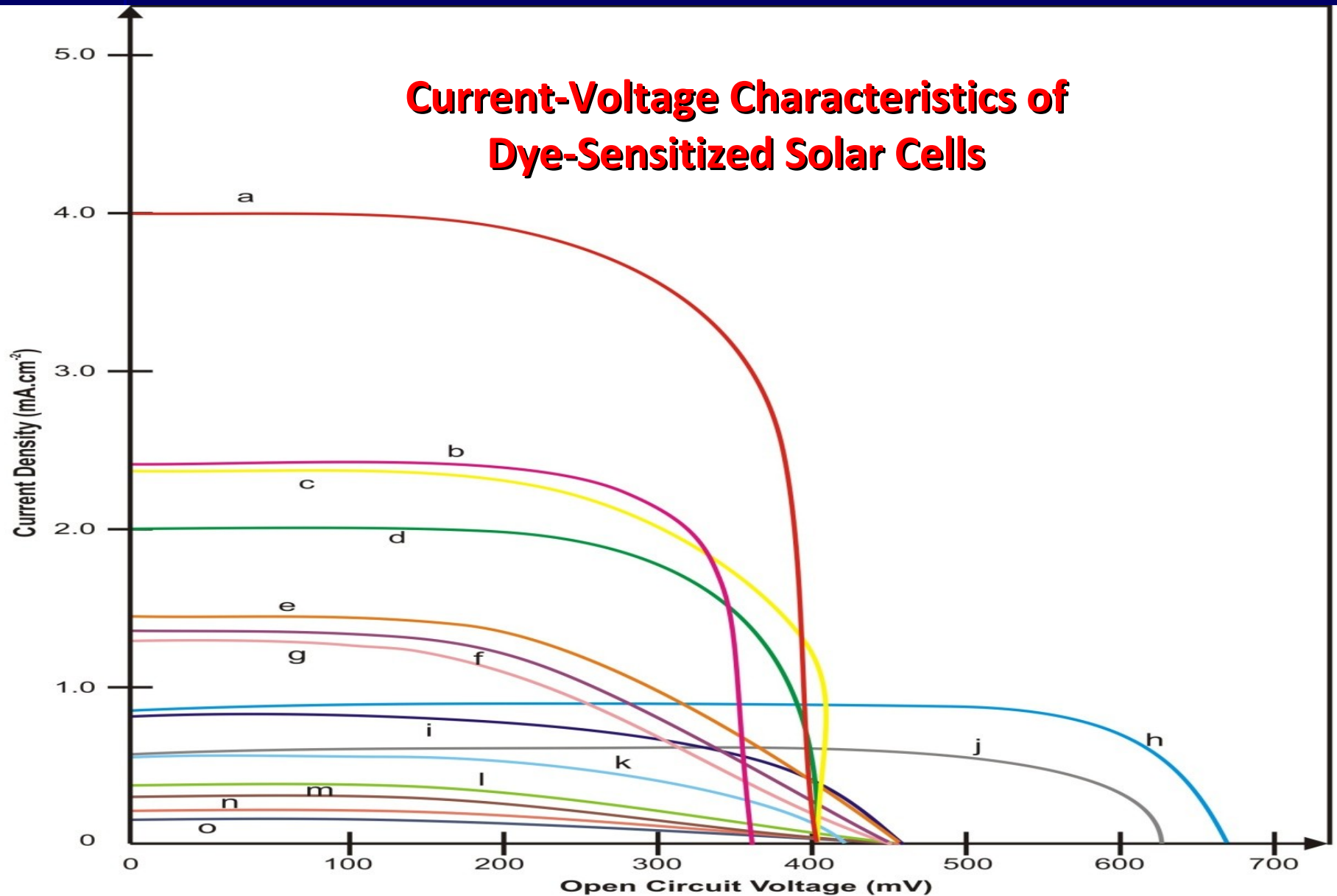
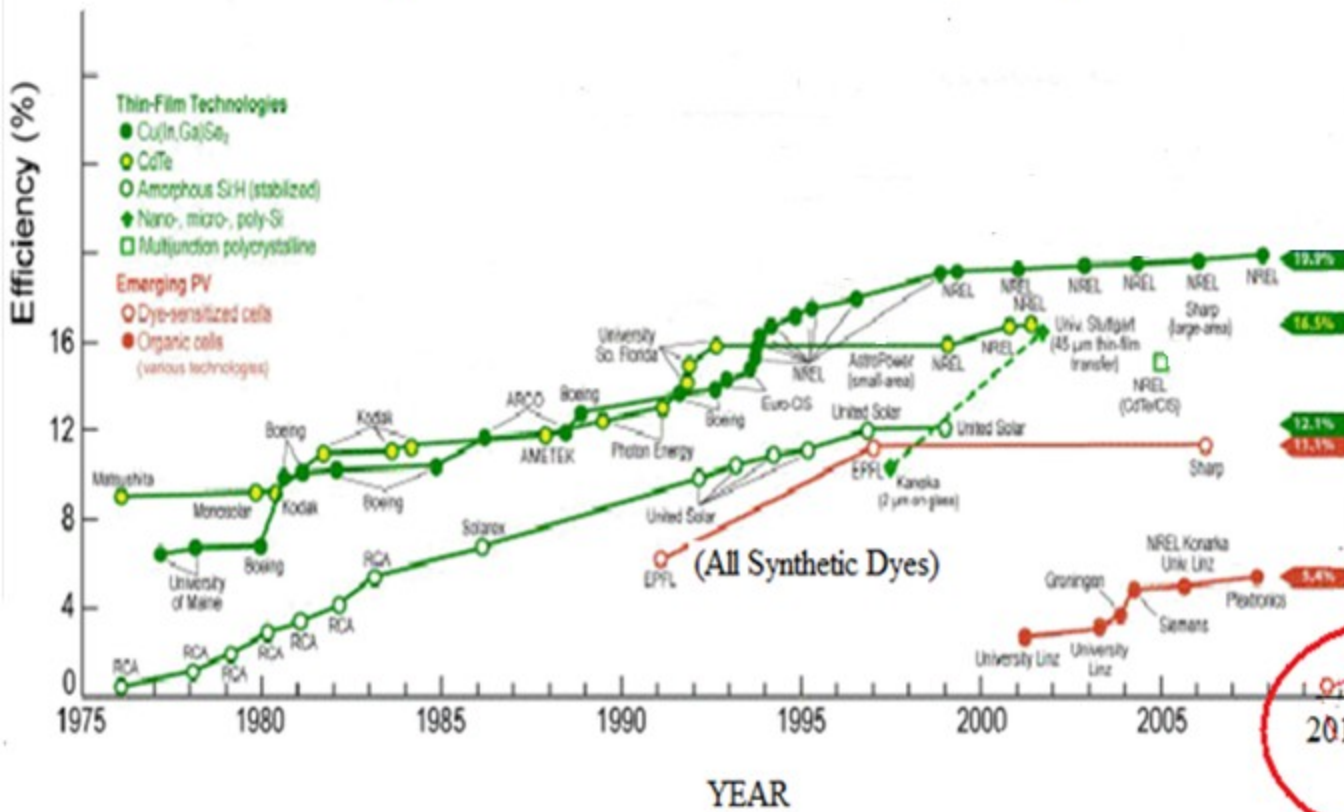


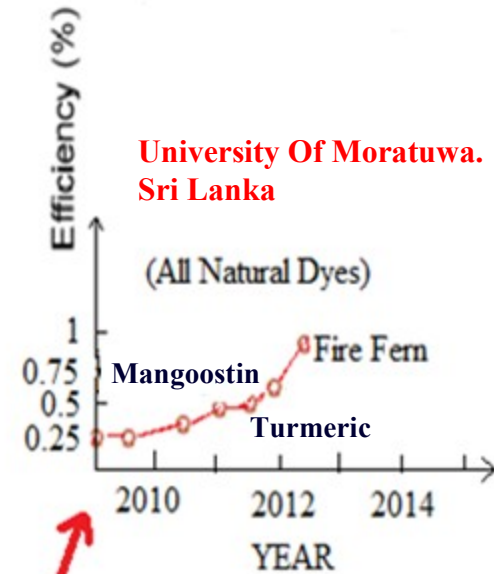
Figure 4. Current Voltage Characteristics of Dye Sensitized Solar Cells

(a) Fire Fern + HCL (b) Fire Fern (c) Ekkiriya wood (d) Egg Plant (e) Karawila Kabilla (f) Fire Fern + Acetic acid (g) Beet root (h) Mangoostein (i) Banana inflorescence (j) Turmeric (k) Black grapes (l) Croton (m) Begonia BV (n) Walmadata (o) Venival

# BEST RESEARCH CELL EFFICIENCIES (FROM NREL - COLORADO, USA)



**University Of Moratuwa,  
Sri Lanka**



**University Of Moratuwa,  
Sri Lanka (All Natural Dyes)**



# CHEMICAL STRUCTURE OF MOST SUITABLE NATURAL DYE SENSITIZERS IDENTIFIED

## *FIRE FERN LEAF (OXALIS HEDYSCAROIDES)*

Fire Fern a rare exotic garden plant which grows in Columbia, Equador and Venezuelar in Central America has been imported to Royal Botanical Gardens , Peradeniya, Royal Botanical Gardens , SriLanka recently .

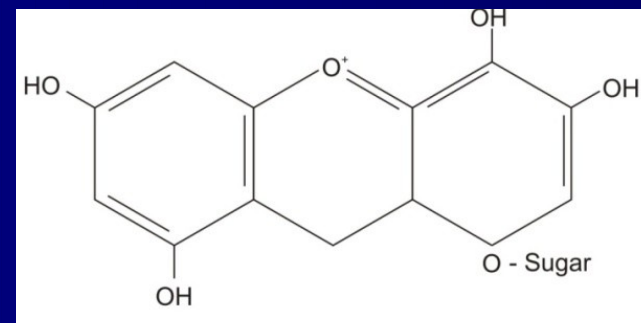
Leaves are maroon - red in colour and contains Anthrocyanins ,yellow Xanthophylls , yellow Carotenes and orange -red Lycopenes.

Anthrocyanins are water soluble vacuole pigments and they appear red, blue , purple or magenta depending on pH.

**Cynodin Anthrocyanin**

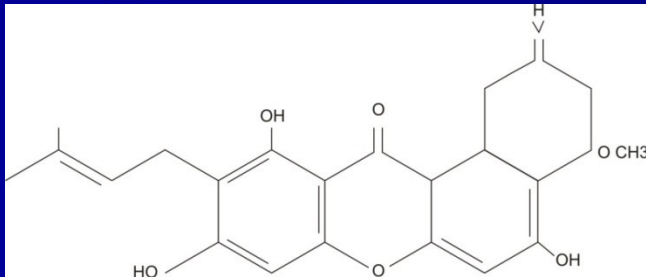


Red	at PH	< 3
Violet	at PH	= 7 - 8
Blue	at PH	> 7 - 8



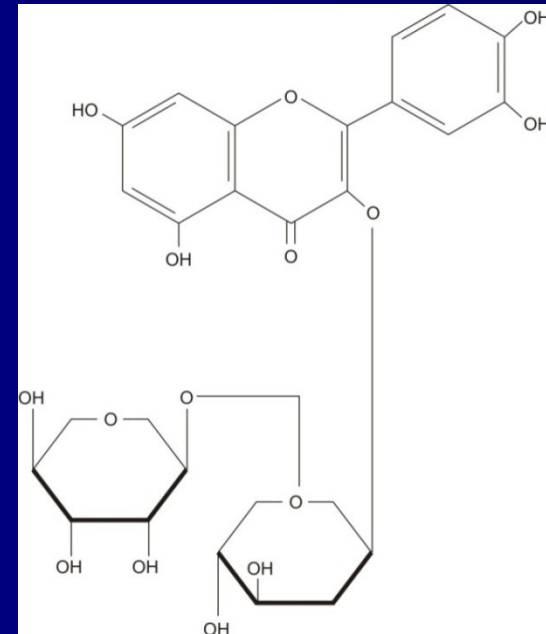
# MANGOOSTEEN (*GARCINIA MANGOSTANA*)

Mangoostin fruit is endemic to South East Asia (including Sri Lanka ) and produces a fruit with white sweet pulp covered by reddish brown rind rich in antioxidants of 39 different Xanthenes , other Flavanoids including reddish brown Rutin , Pyroanthrocyanains and EGEC Catechins.



**Mangosteen**

Molecular formula  $C_{24}H_{26}O_6$



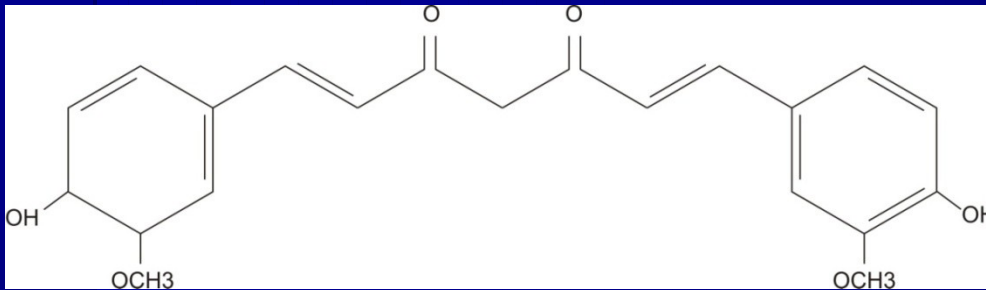
**Rutin**

Molecular formula  $C_{27}H_{36}O_{16}$

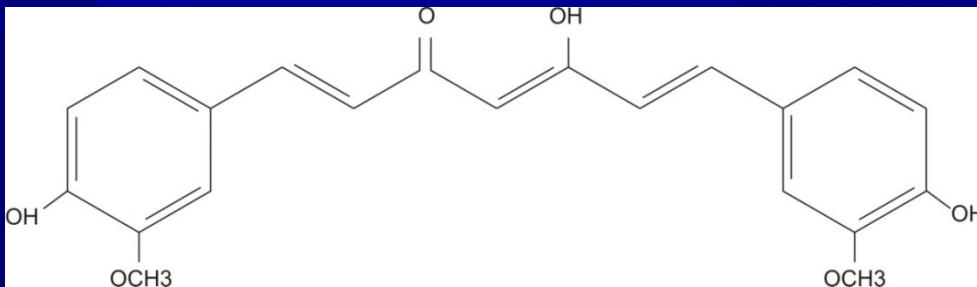
# TURMERIC (*CURCUMA LONGA*)

Turmeric rhizome root contains essential oils and Curcumin a phenol. It exists in at least two tautomeric forms -- Keto and Enol . Curcumin is a PH indicator and in acidic solutions (pH < 7.4 ) it turns yellow, whereas in basic (pH . 8.6) it turns bright red .

The extract of Turmeric root yields a deep orange yellow dye.



Curcumin – Keto Form



Curcumin – Enol Form



# LATEST DEVELOPMENTS ON DSSC's / SOLAR PHOTO VOLTAICS

- WORLD'S FIRST SAILBOAT POWERED BY DSSC's OPERATING A PROPULSION MOTOR



Robert Swan from Cardiff, Wales, UK is currently sailing around the world since 8<sup>th</sup> December 2008 utilizing DSSC's which have been integrated into the sail of his boat made from recycled plastic bottles.



G24 Innovations  
Personalizing Wireless Power

- WORLD'S FIRST  
DSSC SOLAR BAG



# SOLAR POWERED MODEL CATAMARAN SAIL BOAT



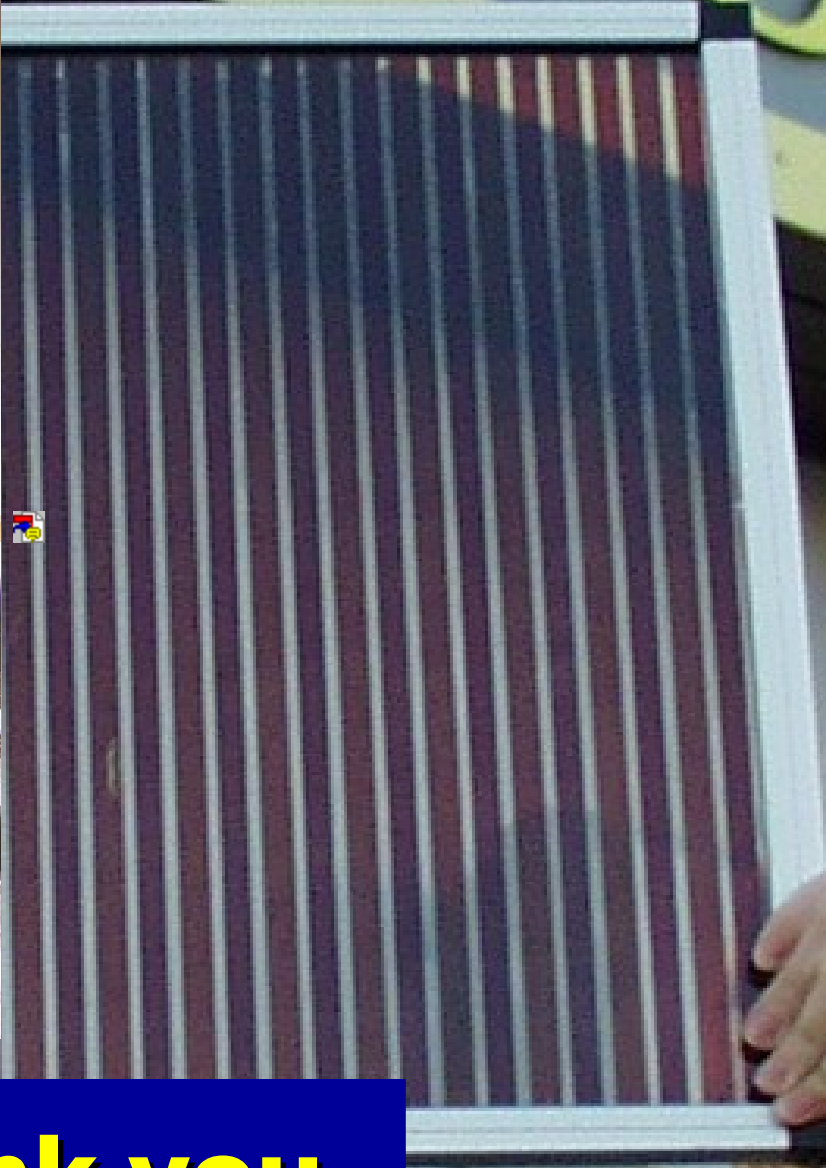
# CONCLUSIONS

- About 145 Natural pigments extracted from Fire Fern leaf, Mangostin fruit rind , Turmeric root , Ekkiya wood, Egg Plant fruit ,Karawala Kabilla , Bannana flower inflorescence , Beetroot ,Black Grape, Croton leaf, Begonia Black Velvet leaf, Red Plum, Anthurium flower ,Spinach, Orange fruit rind, Red Hart leaf, Rambutan, Venivel etc and a mixture of these in equal proportions have also been used as photo sensitizers.
- About 3 years ago it was found at the University of Moratuwa that **Mangostin fruit rind extract was the best natural dye sensitizer in Sri Lanka.**
- About an year ago a research article published by the Dalian University of Technology in China has confirmed that it is the **best natural dye sensitizer amongst all plants and trees growing in Asia.**

- Extracts of Turmeric root, Mangostin fruit rind, Egg Plant fruit, Ekkiriya Wood and Fire Fern(endemic to Central America) have achieved solar energy conversion efficiencies of 0.264%, 0.340%, 0.485%, 0.547% and 0.802% respectively.
- It was observed that darker the colour of the dye, greater would be their conversion efficiencies.
- Natural dyes based solar cells appear to be limited by low Voc and Isc.
- The way forward would be to find different additives to dyes such as conc. Acetic acid, Hydrochloric acid etc. which when doped in trace amounts would cause alteration of pH to  $<1$ , and alteration of their chemical structure ,hence to darken their colours and possibly result in larger conversion efficiencies.

# FUTURE DEVELOPMENTS IN PROGRESS.....

- A 18 feet long Catamaran type fibre glass Boat is being developed in the Department of Chemical & Process Engineering, University of Moratuwa to be propelled by Solar power generated by DSSCs sensitized with Mangostin fruit rind extracts.
- DSSC powered portable battery chargers to energize mobile telephones and ipods are also being developed.
- Military uniform Fabric- integrated DSSCs for powering of portable radio communications equipment is also being studied.
- The concept of operating LED diffused lighting systems in Building Integrated Photovoltaic (BIPV) Systems in high-rise buildings using DSSCs is also being investigated.



**Thank you**