

Metrology for renewable energy sources : Indian perspective and APMP activities

Venu Gopal Achanta

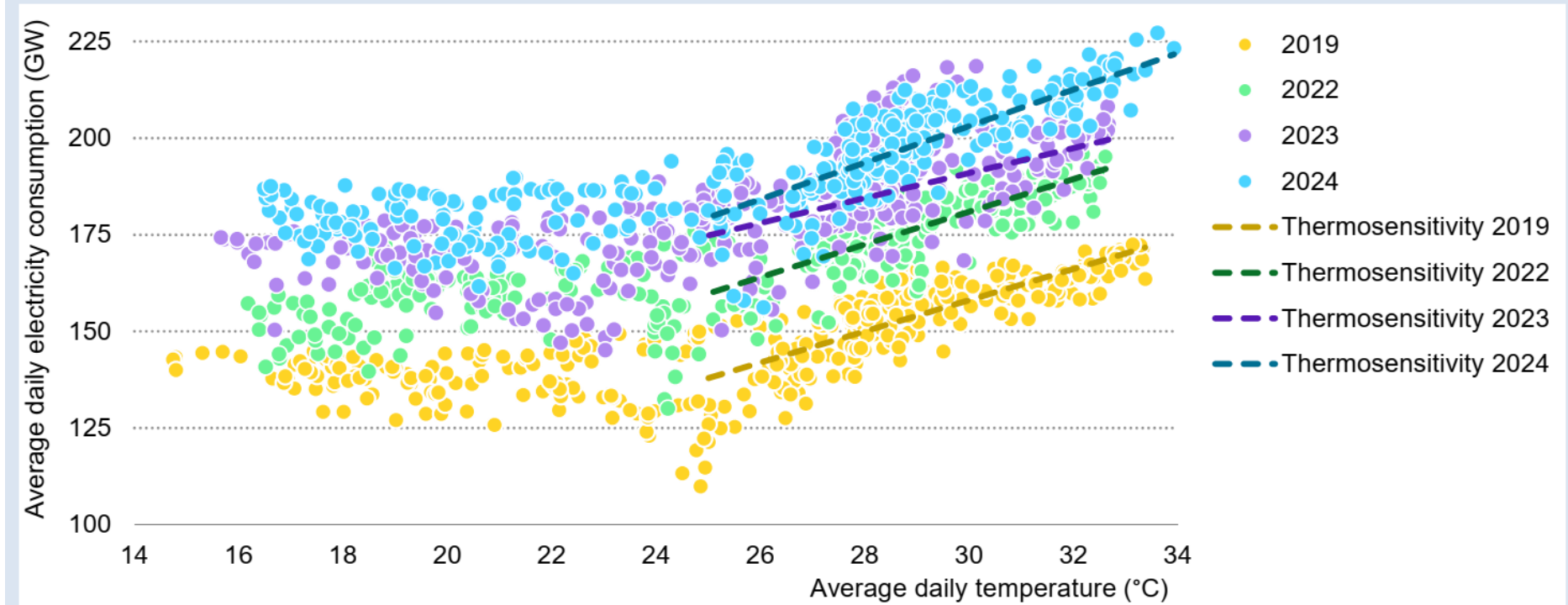
CSIR-National Physical Laboratory, New Delhi, INDIA

Liaison for APMP Energy Efficiency Focus Group (EEFG)

APMP EC Member

CIPM Member

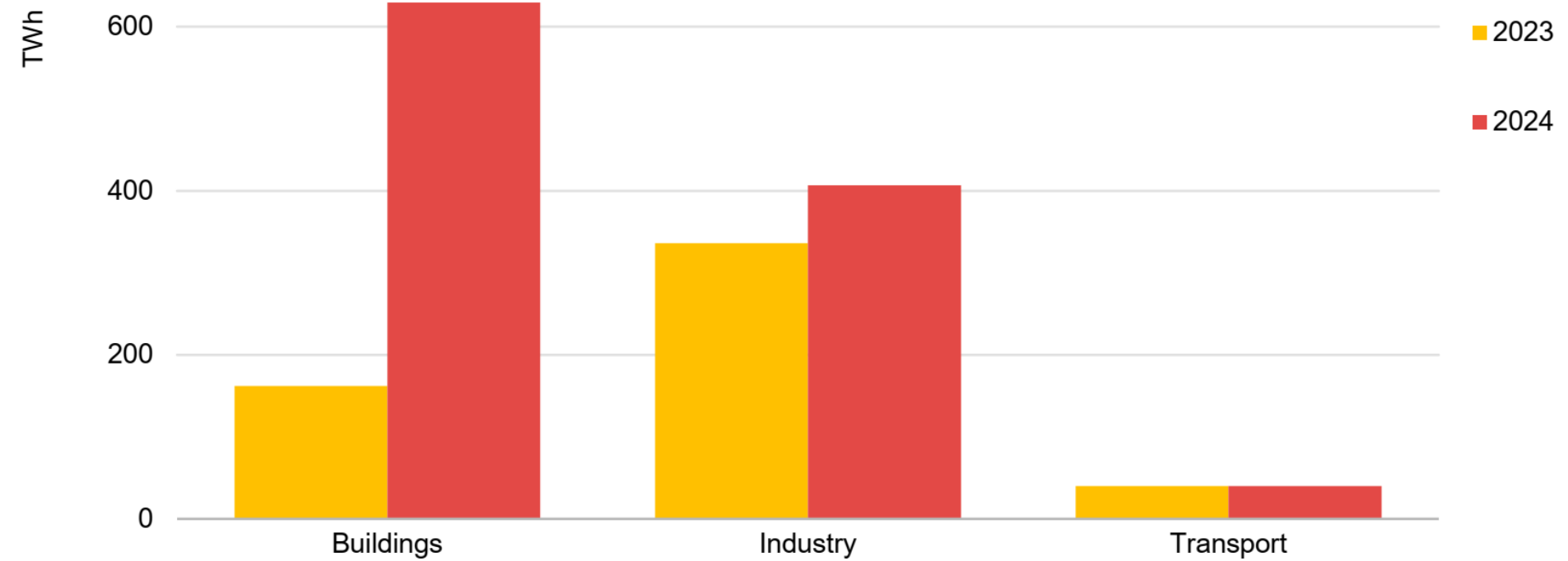
Trends in electricity demand based on temperature in India, 2019-2024



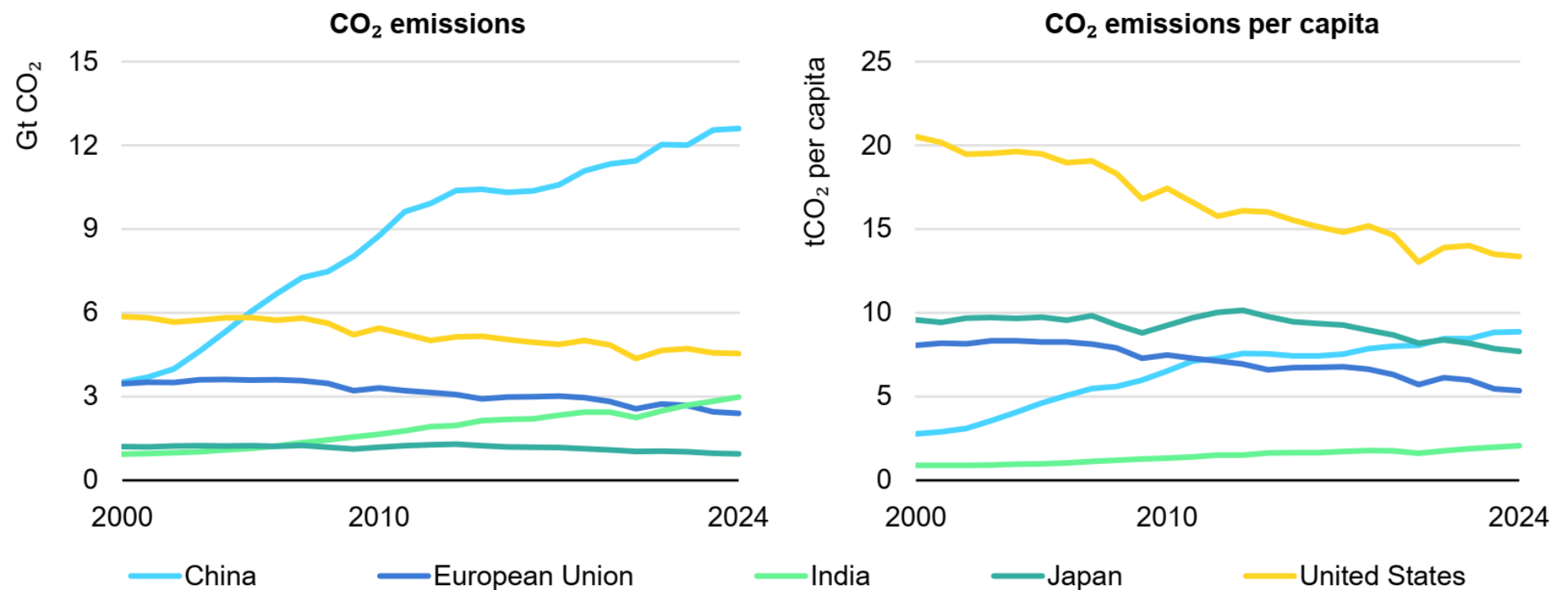
IEA. CC BY 4.0

Heatwaves in May and June : Rise in electricity demand for cooling, placing significant strain on the country's power grid.

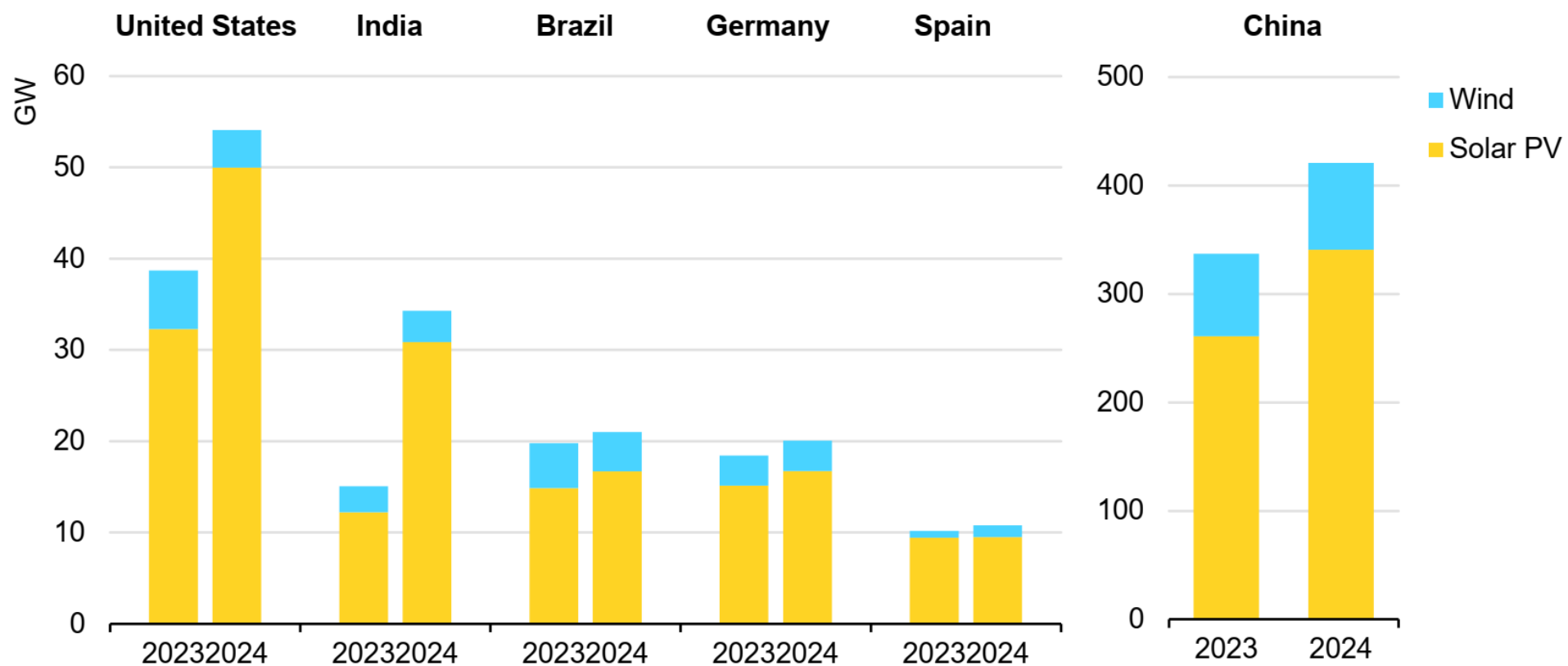
Annual change in electricity consumption by sector



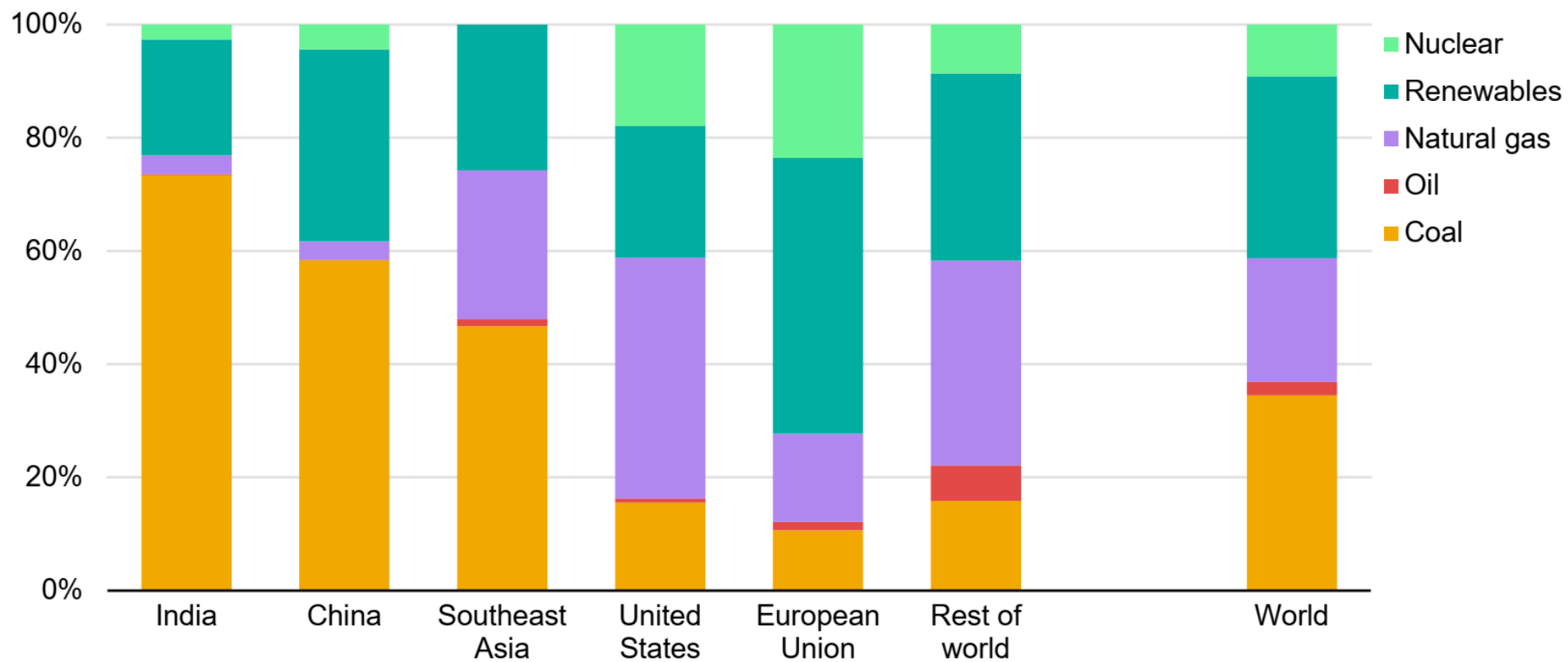
CO₂ total emissions and CO₂ per capita emissions by region, 2000-2024



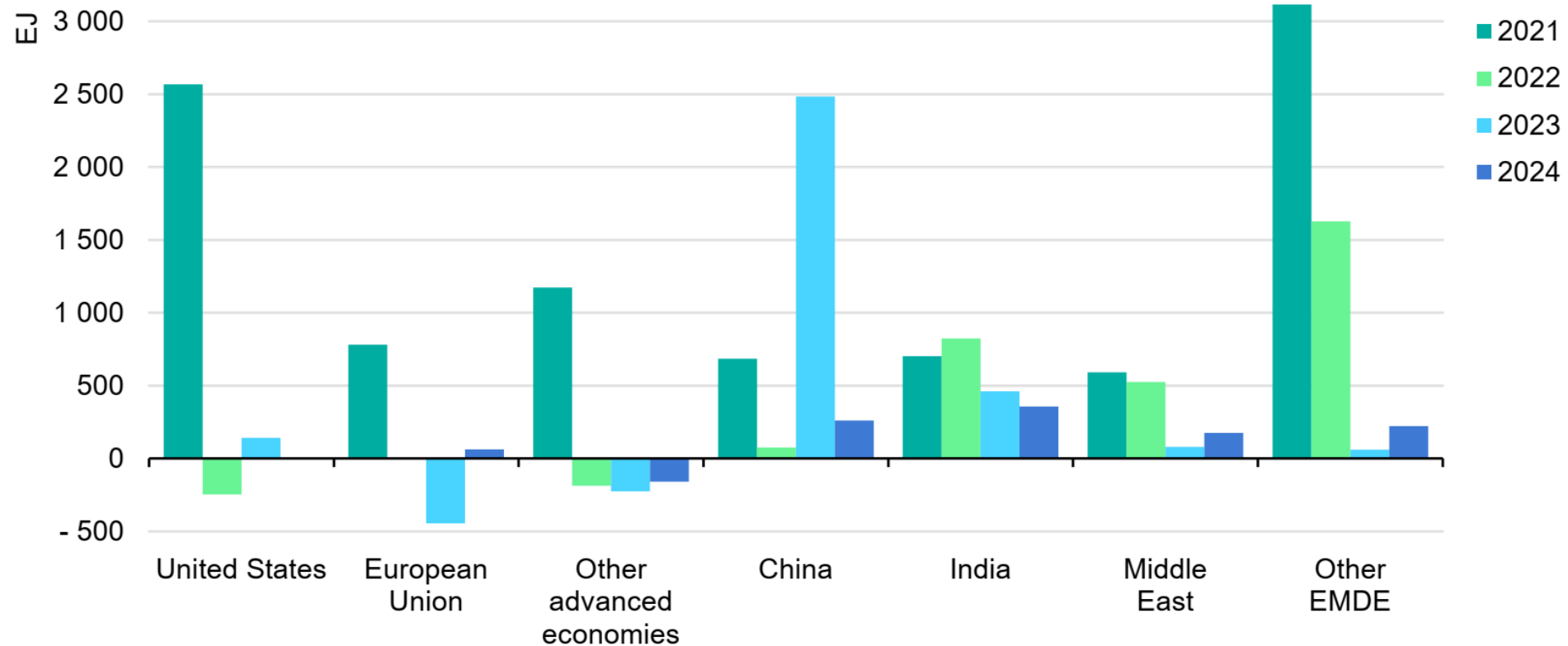
Solar PV and wind net additions in selected markets

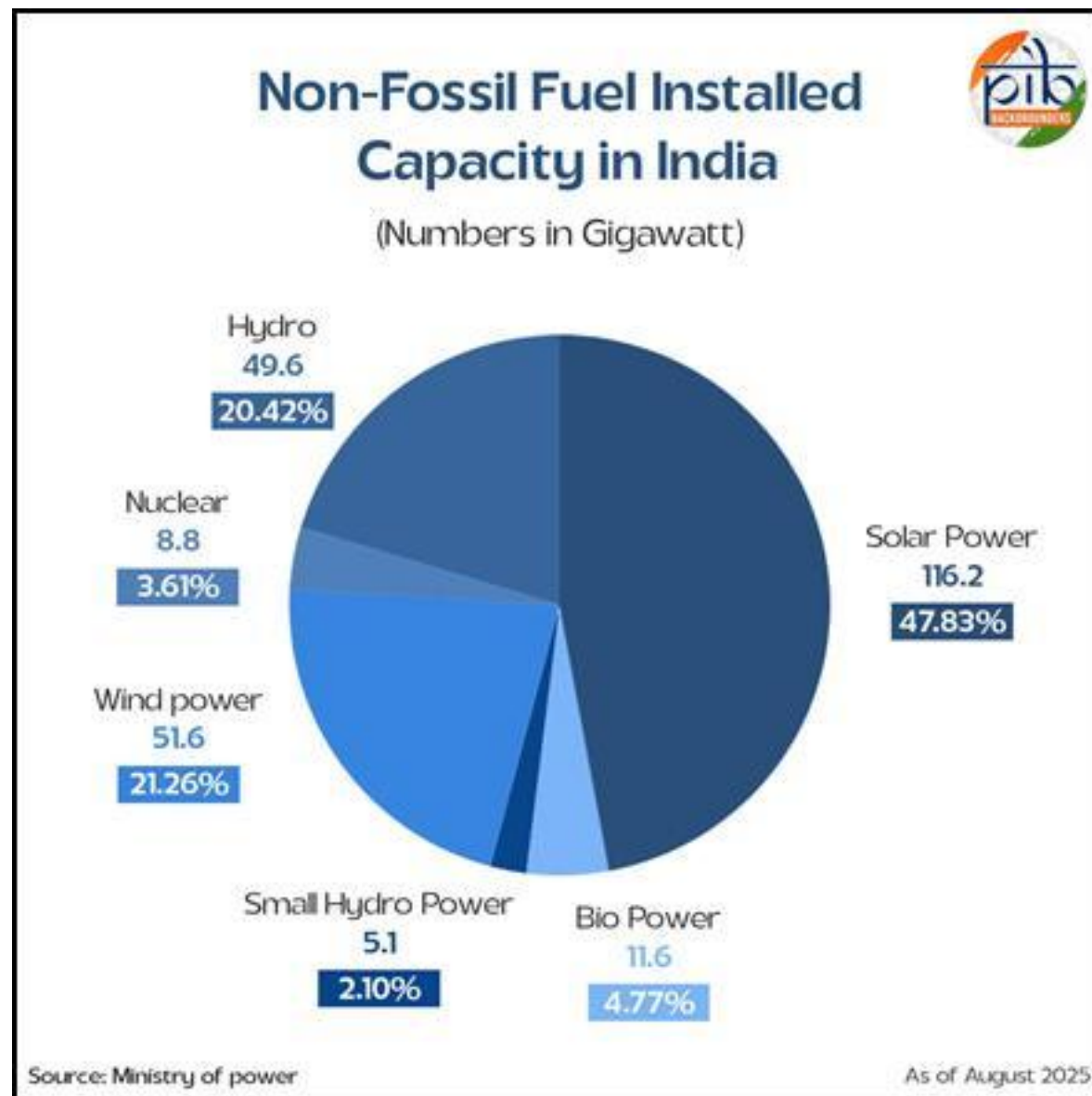


Electricity generation mix for selected regions, 2024



Change in oil demand by region, 2021-2024





By **June 2025**, India has installed **242.8 GW** of non-fossil fuel installed capacity, including **233.99 GW of renewable energy** and **8.8 GW of nuclear power**. This now makes up **50.07% of the country's total power capacity of 484.82 GW**.

Indian Needs...

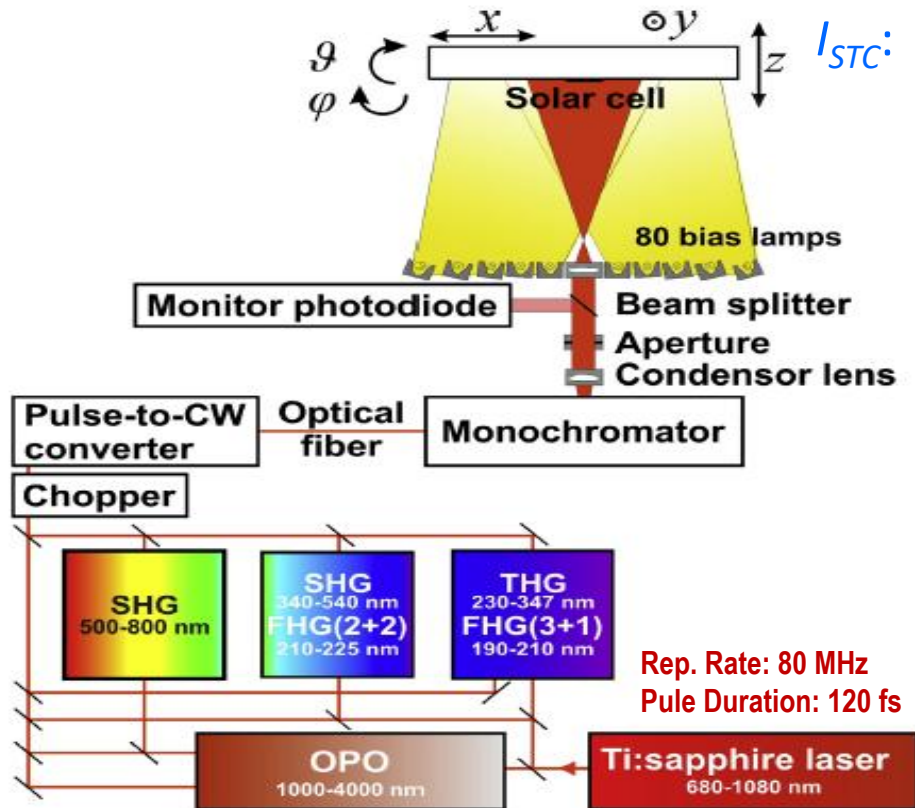
- Metrology for Green energy sources :
 - Solar
 - power grid monitoring
 - batteries
 - ethanol blends
 - hydrogen
- Circular economy : waste recycling

National Primary Standard Facility for Solar Cell Calibration

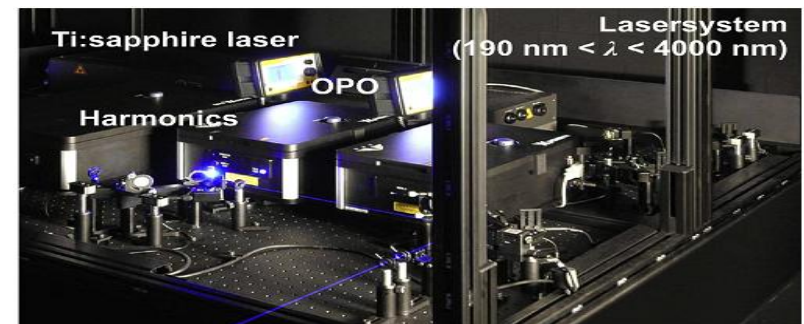
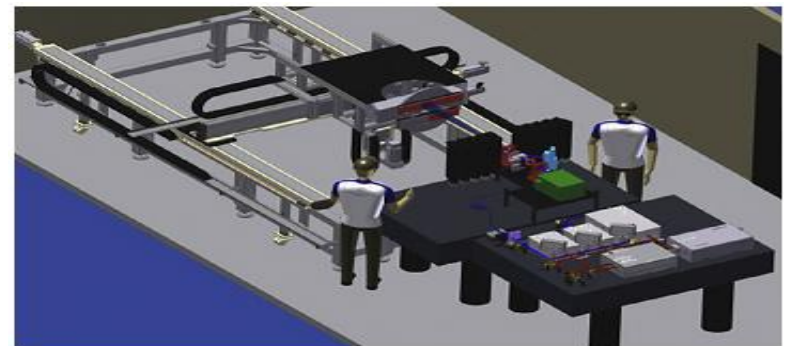
Uncertainty for short circuit current of solar cells

I_{STC} : **0.35%** for 20x20 mm² solar cells ($k = 2$)

0.6% for 156x156 mm² solar cells ($k = 2$)



Schematic of Laser-DSR facility



Complete laser setup with laser beam routed through the SHG (400 nm)

Intercomparison Status

Present status of measurement uncertainty (short-circuit current of solar cells) at other NMIs/WPVS Laboratories

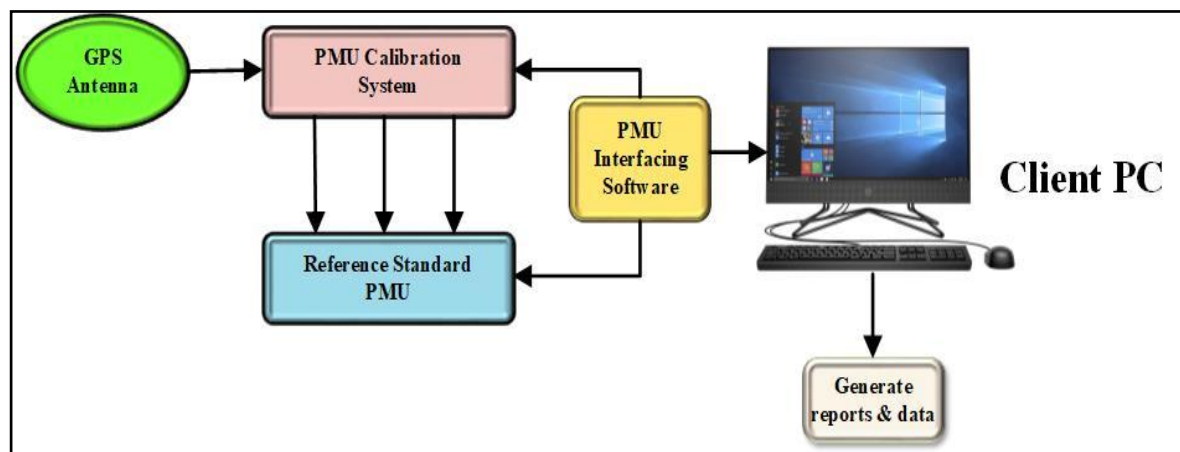
NMI/WPVS Laboratory	TIPS, China	NREL, USA	AIST, Japan	PTB, Germany	CSIR-NPL, India
Uncertainty (I_{STC} @ $k=2$)	0.9 %	± 0.4 %	± 0.6 %	± 0.4 %	0.35 %
Calibration Charges	--	\$3,318	€5000	€3200	\$1400

- CSIR-NPL, India providing the lowest uncertainty among the WPVS (World Photovoltaic Scale) laboratories
- Relatively lower calibration charges of reference solar cells

PMU CALIBRATION SYSTEM

Team: LF, HF Voltage, Current & Microwave Metrology

- The CSIR-NPL PMU calibration system is a fully integrated and automated system traceable to the primary standards at CSIR-NPL.



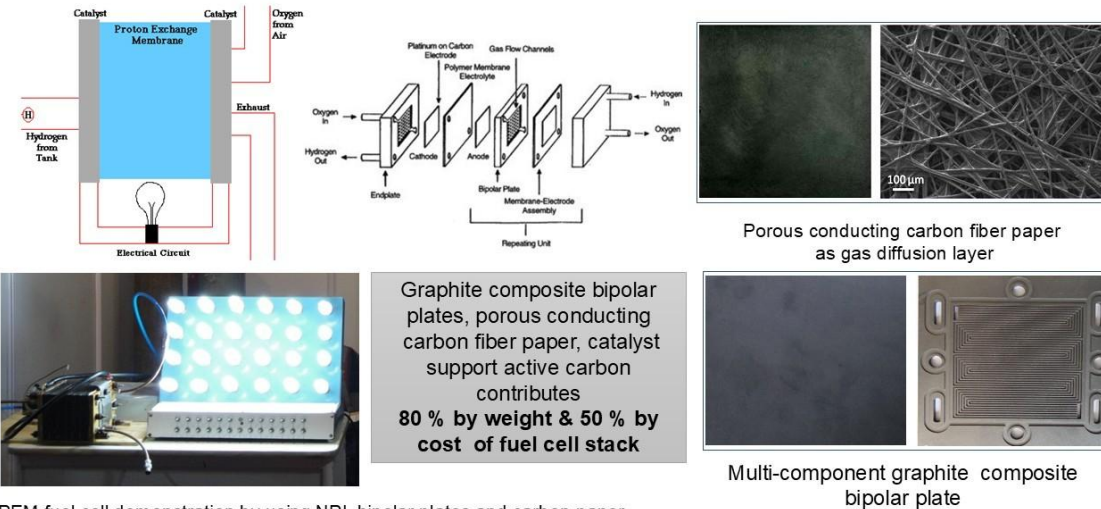
PMU-CAL system calibration setup



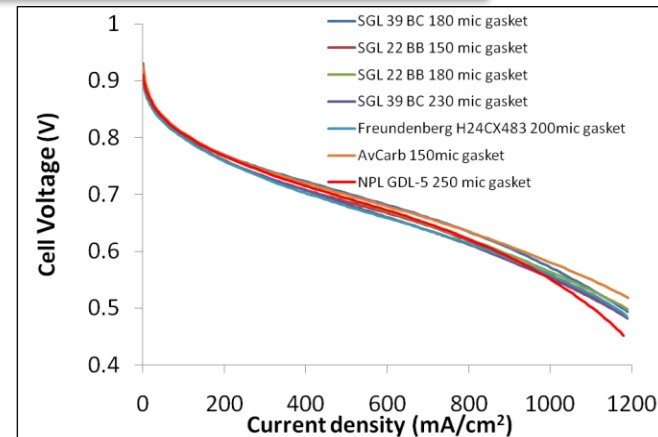
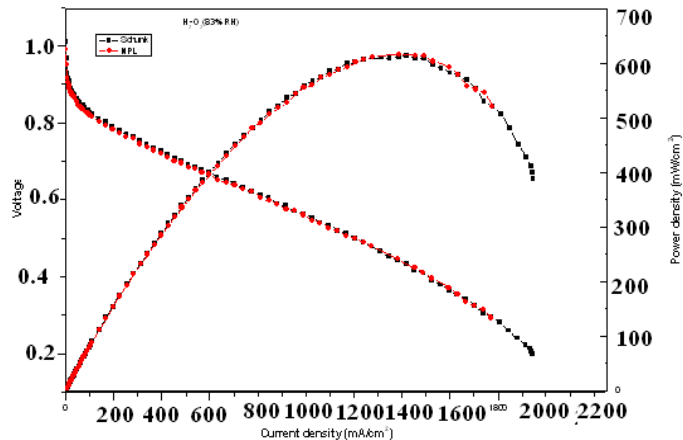
Traceable CSIR-NPL PMU-CAL system

Carbon components for Polymer Electrolyte Membrane Fuel Cell

Demonstration of PEM Fuel made from indigenous Porous conducting carbon paper and graphite composite bipolar plates



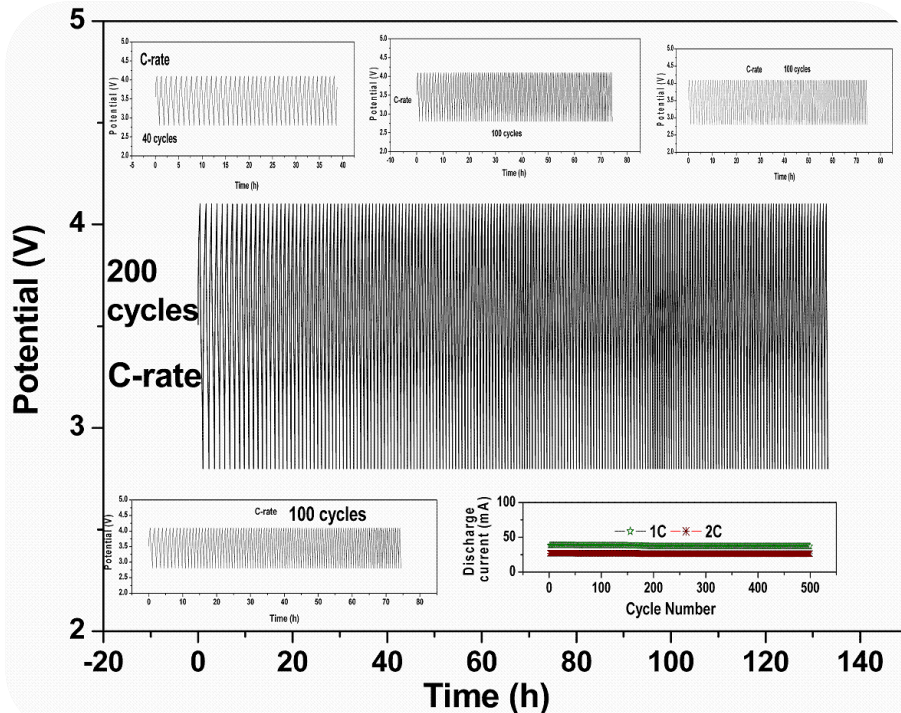
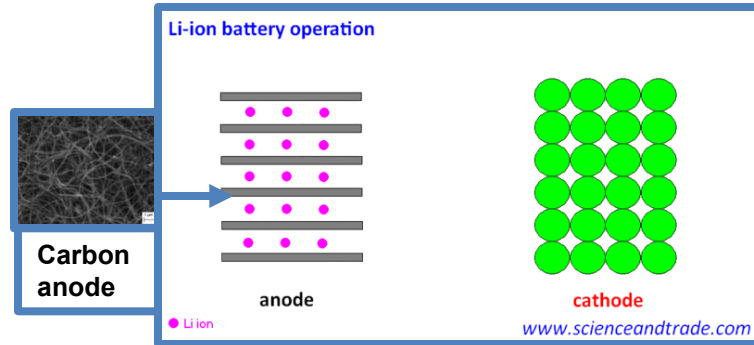
PEM fuel cell demonstration by using NPL bipolar plates and carbon paper



I-V performance of the NPL bipolar plate in comparison with Schunk Germany

I-V performance of the NPL carbon paper vs other commercial papers

Development of carbon based Anode for Li-ion Rechargeable Battery



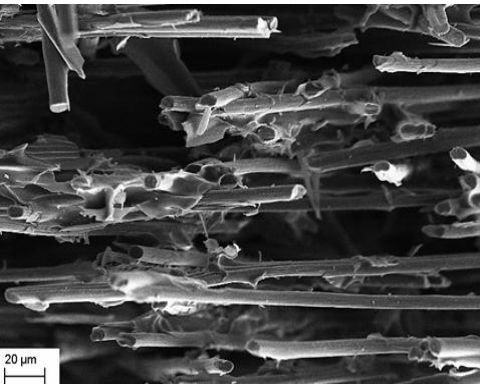
Demonstration of 500 cycles with NPL anode



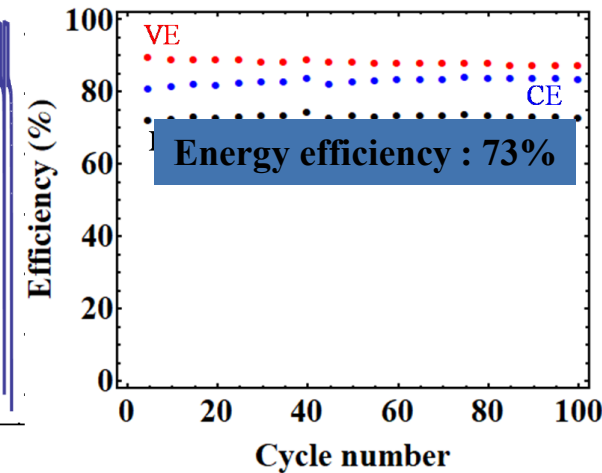
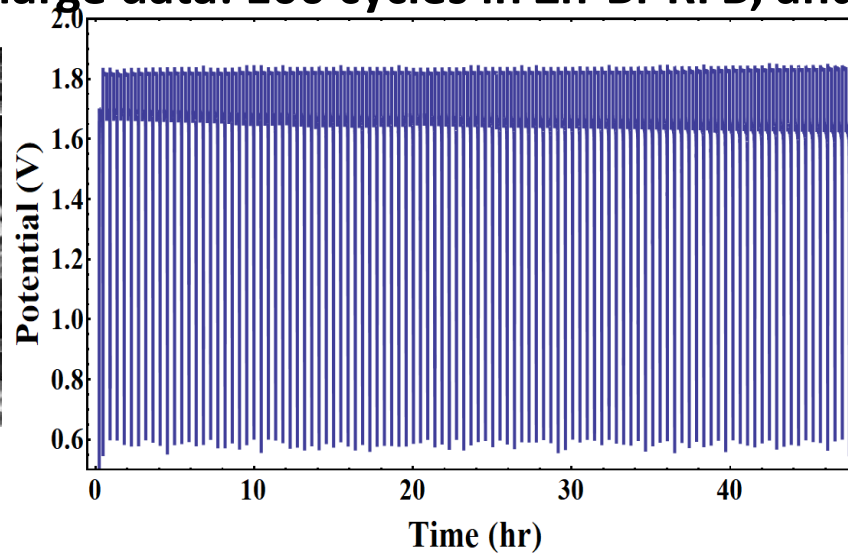
Demonstration of solar lamp with NPL anode & CECRI cathode

Development of Electrode bipolar plate for Redox Flow Battery

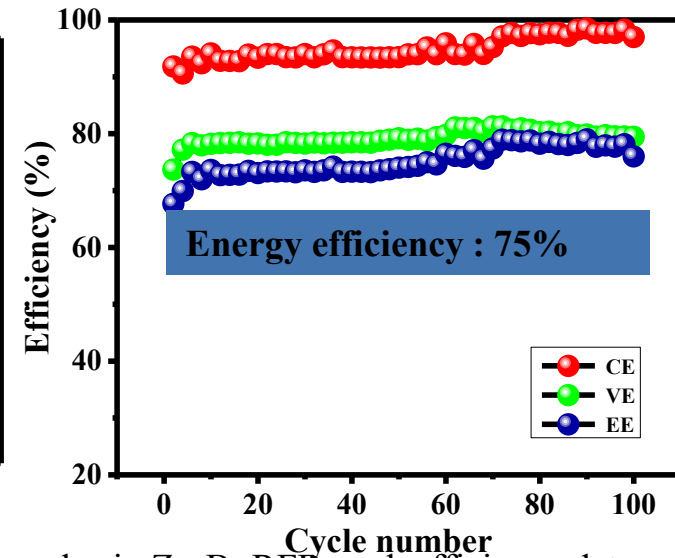
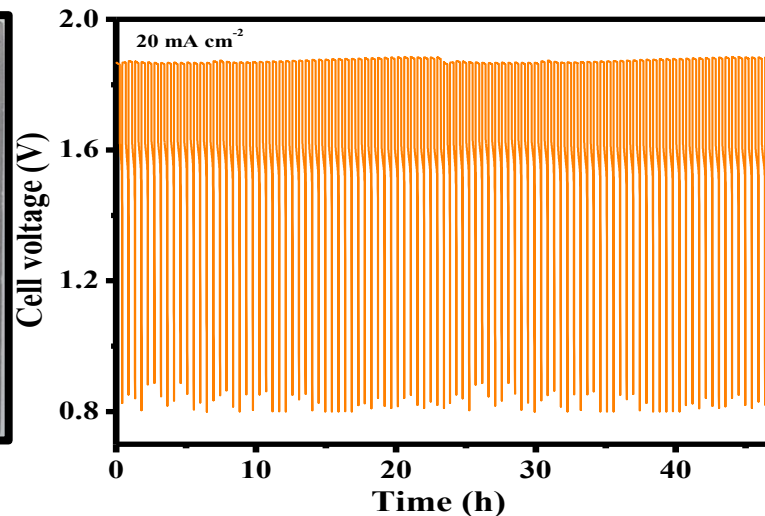
Charge-discharge data: 100 cycles in Zn-Br RFB, and efficiency data



NPL carbon paper electrode



NPL Bipolar plate



GCD data with NPL bipolar plate for 100 cycles in Zn-Br RFB, and efficiency data

Thermoelectric Activity

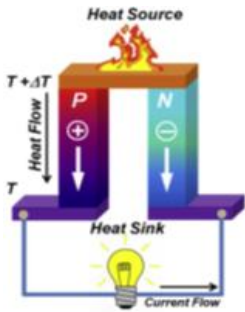
Heat Energy



Electricity

➤ *Works on Seebeck Effect*

➤ *TE device consists of multiple n-type and p-type TE element.*



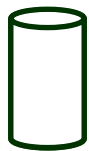
Efficiency of TE device :

$$\eta = \frac{T_h - T_c}{T_h} \frac{\sqrt{1 + ZT} - 1}{\sqrt{1 + ZT} + T_c/T_h}$$

$$ZT = \frac{S^2 \sigma}{\kappa} T$$

S: Seebeck Coefficient, σ :
Electrical Conductivity, κ :
thermal conductivity

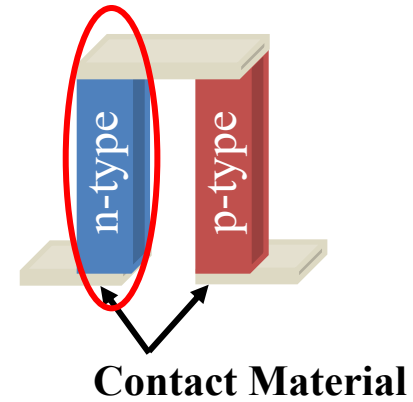
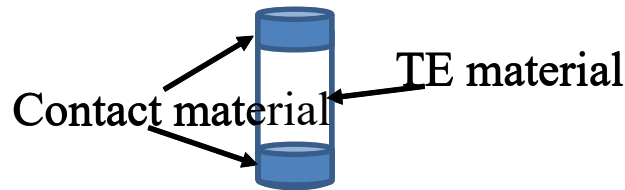
Figure of merit (ZT):



P-type



N-type



- ✓ TE elements are the p & n-type single legs which consist of the thermoelectric material with a proper contact.
- ✓ Device efficiency also depends on an optimum choice of the contact material.
- ✓ Contact resistance should be very low.
- ✓ Coefficient of thermal expansion of the contact material should be matching with that of the TE material.
- ✓ Thermal stability of both the TE material and the contact material should be maintained

Different Type of Thermoelectric Materials

Temperature Range

Low(<450K)

➤ Chalcogenides
(Bi_2Te_3), (Bi_2Se_3)

Mid(450K-850K)

- Chalcogenides (PbTe)
- Skutterdites ($\text{Co}_4\text{Sb}_{12}$)
- Silicides (MnSi , Mg_2Si , CrSi_2)
- Cu_2Se
- Half-Heusler (ZrNiSn , TiCoSb)

High(>850K)

➤ Silicides
(SiGe)

Thermoelectric Materials Developed at CSIR-NPL

Materials developed	Figure of merit (ZT)	Materials developed	Figure of merit (ZT)
Bi_2Te_3	~ 1	CrSi_2	~ 0.32
Bi_2Se_3	~ 0.7	n-type half-Heusler	~ 1.4
CoSb_3	~ 0.7	P-type half-Heusler	~ 0.8
Mg_2Si	~ 0.7	n-type SnGe	~ 1.5
$\text{MnSi}_{1.73}$	~ 0.8	p-type SnGe	~ 1.2
Cu_2Se	~ 2		

All airlines and aircraft operators will have to offset any growth in CO2 emissions above 2020 levels

**Coal → Syn Gas → MeOH →
SAF**

**1.5 TPD pressurized fluidized
bed gasifier (PFBG)
configuration – CSIR-CIMFR**



**CSIR-IIP pilot plant produces 30 liters/day of
sustainable air fuel**

**World Economic Forum's "Clean Skies for
Tomorrow Coalition Report 2021" : 20 of the 80
private and public-sector organizations that
make up the Clean Skies for Tomorrow Coalition
are from India.**



Green Hydrogen projects and opportunities

Favorable Hydrogen trends – INDIA



Indigenous technologies for electrolyzers, hydrogen storage, and fuel cells.

CSIR's Hydrogen Technology (H2T) Program focuses on various electrolyzer types – Proton/anion exchange electrolysis membrane (PEM/AEM) Solid oxide electrolysis (SOEC)

Advancing hydrogen storage (Type IV cylinders, liquid organic hydrogen carriers),

Indian Oil R&D Centre, Faridabad



Indian Oil Green Hydrogen Project- Integrated Refuelling Station for Buses in Leh (Ladakh)

NTPC- Integrated Hydrogen Refuelling Station at Greater Noida





**First indigenously
manufactured
electrolyser,
commissioned by L&T
electrolysers Ltd,
Hazira-Gujarat**

**Green Hydrogen Project
for Steel : Jindal
Stainless, Hisar,
Haryana**





**India's First Hydrogen Fuel Cell
Ferry by Cochin Shipyard
Limited
Kashi-Prayagraj route for 50
passengers**

**Indian Railways- Pilot Project for Conversion of Old Diesel Locomotives with
Hydrogen Fuel Cells**



**1,200 HP Hydrogen train
To carry 2,638 passengers
Max. speed 140 kmph**

Sonipat-Gohana-Jind route

APMP Activities

- **Directors Workshop in APMP GA 2024 focused on Hydrogen technologies for a sustainable future**
 - AIST, Japan, KRISS, Korea, NIM China; NMIA, Australia; NPL, UK; NPL, India,
- **Activities in the region include**
 - CRMs for hydrogen gas quality
 - standard testing methods for hydrogen fuel cell industry
 - the establishment of flow measurement standards and traceability chain for hydrogen dispensers
 - the development of standard testing device and specifications for measurements of key parameters in water-electrolytic hydrogen production
 - assurance of materials compatibility with liquid and gaseous hydrogen.
 - Verification of high-capacity flowmeters for liquid anhydrous ammonia

The Green Energy Symposium: Metrology Testing and Certification

19 June 2025, Nantou, Chinese Taipei

- Empower APEC Economies through advanced metrology, testing and Certification supporting Hydrogen energy, Solar PVs, Batteries, Smart grids and Carbon-free technologies.
- CMS/ITRI, APMP EEFG, APEC EGNRET, National Taiwan University, TÜV SÜD, EURAMET Energy, NMIs etc.

Key impact areas

- **Metrology for Energy: Ensuring performance, Safety, and Trust in emerging energy systems**
- Stakeholder collaboration: 117 participants from 46 institutions across the fields of measurement field, industry, academia, and government.
- **Regional Resilience: Accelerating measurement capabilities for energy transition and climate goals.**
- Supports APEC Energy Efficiency, Sustainability, and Standards Cooperation
- Foster technical capacity & regional harmonization



International workshop "Measurement for Sustainable Energy"

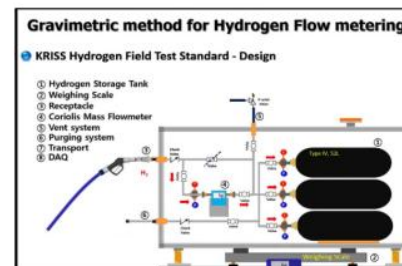
- The APMP Energy Efficiency Focus Group, in collaboration with the DEC FG Task Force and National Institute of Metrology Thailand, conducted a two-day workshop "**Measurement for Sustainable Energy**" in conjunction with the ASEAN Sustainable Energy Week.
- APMP participants, along with 123 external attendees (87 Online and 36 Onsite) from government, industry and academia took part in the EEFG Seminar.
- The presentation topics covered by the vice president of Gunkul Engineering Public Company Limited and APEC Expert Group on EGNRET including 5 energy topics from NMIs in APMP, EURAMET and a University.
- Workshop Part II took place at National Institute of Metrology Thailand, Pathumthani. It focused on the information exchange and strengthening regional cooperation between NMI and their governments.



Workshop "Measurement Supporting Hydrogen Economy"

5 November 2024, New Delhi, India

- The APMP Energy Efficiency Focus Group conducted an online workshop titled "**Measurement Supporting Hydrogen Economy**" on 5 November 2024 (>100 participants).
- Key presentations were given by hydrogen industry leaders BOC by Linde (Australia) and TOKICO (Japan) along with national metrology institutes KRISS, NMIA, NMIJ, and NIMT. The discussions focused on measurement challenges for safety, quality assurance, and measurement infrastructure for the hydrogen economy.
- "Metrology Supporting Energy Sector" workshops at APMP 2024 in New Delhi were highly productive, covering measurement challenges in EV, Smart grids, PV solar, batteries, H₂ gas flow, and thermometry. The workshop promoted collaborative efforts to support energy efficiency and clean energy transitions.



APMP-EEFG



Summary

- India has an ambitious target of having 50% of total energy by renewable sources by 2030.
- Though target achieved, the energy requirements doubled for 2030, needing more installations.
- Metrology needs are there for solar, green hydrogen, power grid monitoring, biofuels, waste recycling,....
- Energy Efficiency Focus Group (EEFG) of APMP is looking at various aspects including inter- and intra- RMO collaborations