Smart Grids – a DESIGN need

The intersection of technology, regulatory models, and business models

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My personal SG background…incl. a focus on discoms

- Longtime scholar (Think Tank, Academia (Prof. at Carnegie Mellon Univ.))
- Vice Chair, UN ICT Task Force WG on Low-Cost Connectivity/Enabling Environment (2004-2006)
- Southern California Edison SmartConnect - $1.2B rollout – Technology Advisor Board Member (2005-2008)
- IT Task Force Report (2008) – Lead author
- India Smart Grid Forum – Founding Advisor (2010 – present)
- Govt. of India Smart Grid Task Force – Technical Advisor (2010+)
- India Energy Stack (IES) – Member (2025+)
- *Work closely with a number of distribution companies and regulators, including around smart metering*

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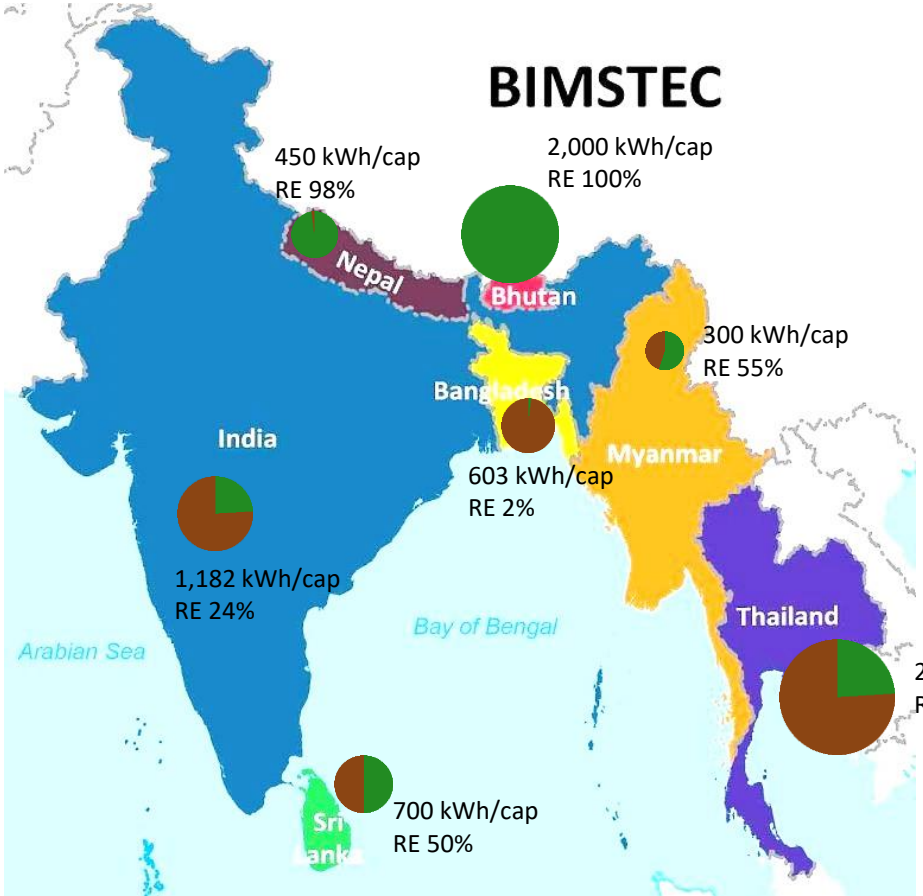
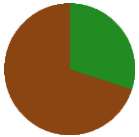
BIMSTEC Electricity Systems: Per-capita *Consumption* and Renewable Share



World



- ~3,600 kWh/person
- RE ~30%

- What are the trends?
  - More growth
  - More Green
- Transformations
  - Decarbonisation
  - Digitalisation
  - Decentralization

Estimates from Our World in Data (2025)

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5 Key Lessons (and a little bit of history/evolution)

1. SG (and the power sector) are evolving; objective functions keep moving
   - "SG are a journey and not a destination"
2. SG operates in an ecosystem
3. Technology is a means to an end

   a) *Some* hardware can be commoditized; "Cheaper" is not the only need
   - "Cheaper, Faster, Better – pick any two" = Tradeoffs

   b) Focus on quality and usability of data, not quantity
4. It's not about standards per se but interoperability
5. If SG is a journey – how do you start, design, and scale? A Roadmap

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Stylized Definition of Smart Grids

- A Smart Grid is a Transformation of the power system based on harnessing digital communications and control
- Utilities will be able to:
  - Know what power is going where, and when
  - Charge “appropriately” for it
  - Control the use of (if not flow) of power

- Although **Advanced Metering Infrastructure (AMI)** is considered to be the **basic building block** for a **Smart Grid,** the Smart Grid is not just **AMI!**
  - ❖ The **Smart Grid** is a much broader set of technologies and solutions

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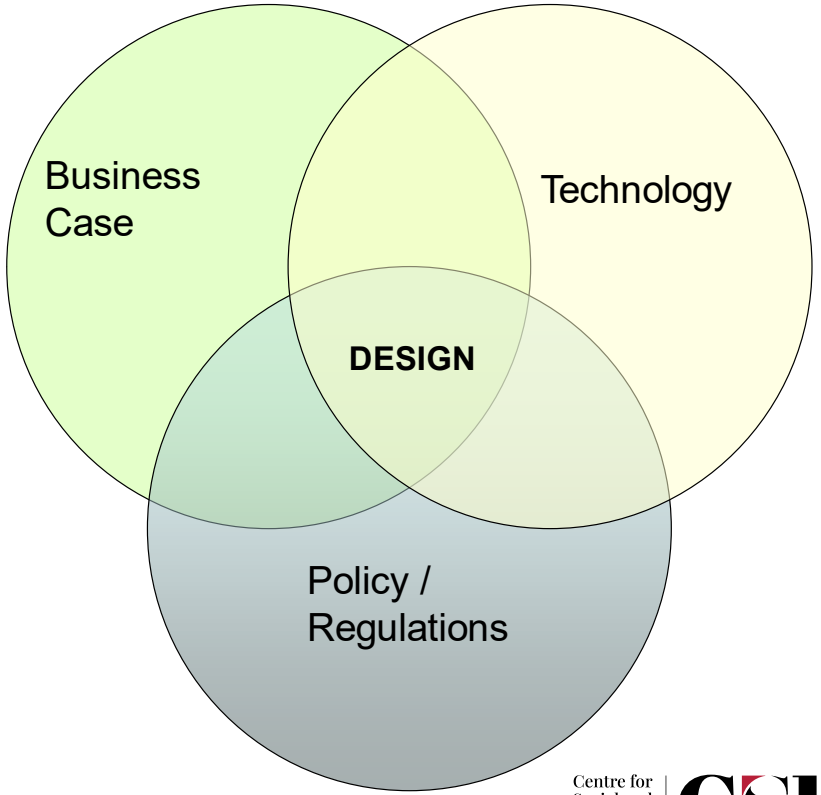
There is no SKU (off-the-shelf purchase) for a smart grid

- It is an ecosystem design with choices
- Your functionality and needs determines the design
  - Do I want real-time meter readings? Push Signals? What time resolution (5 min., hourly, daily, etc.)?
    - All these impact the communications architecture
  - Computing paradigm: SENSE | THINK | ACT
    - Fundamental Q: Where is my intelligence? How much at the edge vs. “cloud”



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(sample) Building blocks for a smart grid

It's not just the WHAT you put in, it's the how/why/where (architecture)

1. Standardization and commoditization
   - Cheaper
2. Customization of how the commodities fit together with iteration / evolution
   - No single answer (forget off-the-shelf)
3. Interoperability ↔ Standards
   - Lowers risk
   - Choices
4. Modularity (won't be equal everywhere)
   - Phased deployment
5. Cost-benefit analysis
   - Helps guide the design – what do I want, why, etc.

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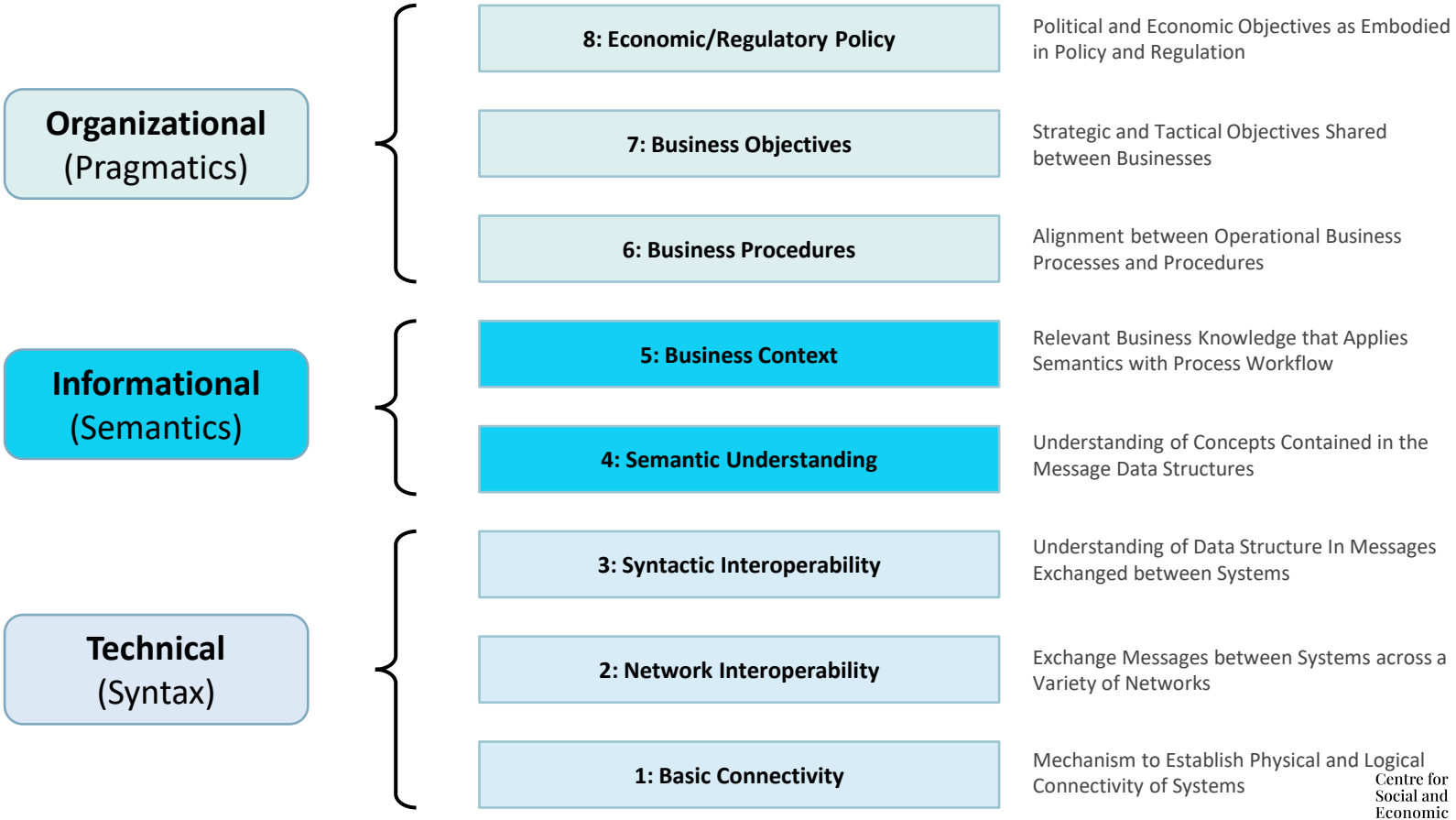
GWAC's 8-Layer Information Exchange and Interoperability Stack (2007)



Source: GridWise Architectural Council (later adopted by NIST, USA)

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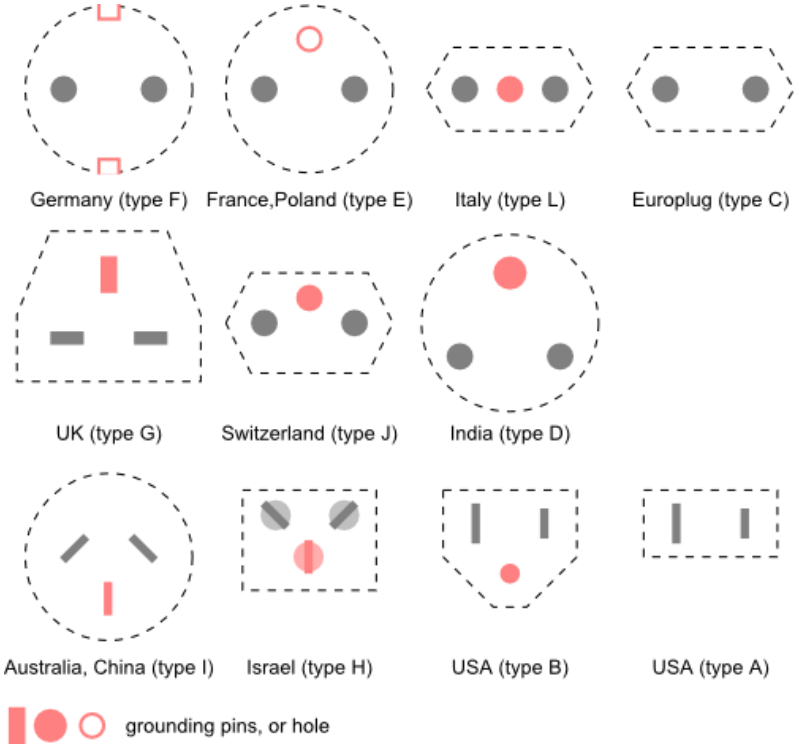
Rhetorical Q: Why do we have (so many) standards?



Source: Wikitravel.com

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What do perfectly DEFINED standards mean?

1. No ambiguity
2. Testable
3. Will work “as advertised”

- What is the challenge?
  - What are you aiming for?
  - What about alternatives? Better standards?
- How are standards set?
  - Who is the 800-pound gorilla in standards?
  - De-facto standards also can become enshrined

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What does interoperable mean?

- "Following a standard?"
  - Which standard?
  - Who "owns" a standard?
    - Open vs. closed
- What's one of the greatest examples of recent interoperability?

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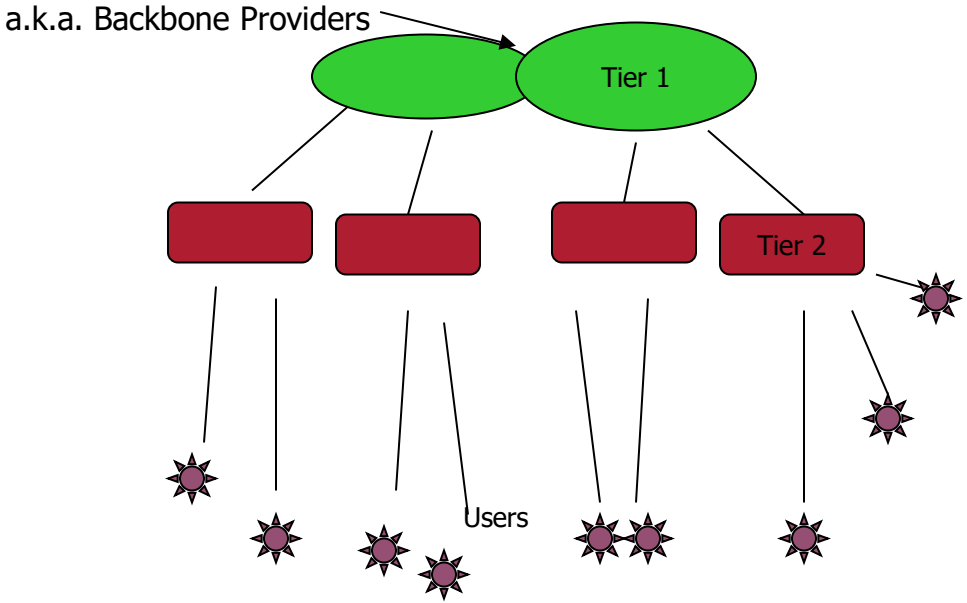
What is the Internet?

- The global (public) network built from hundreds and thousands of internetworking independent networks
- No single entity “runs” the Internet
- Operates on standards
- Built on a modified hierarchical structure



- There are often more layers
- There can be interconnections other than at a backbone

What makes the Internet the Internet?

- Open architecture
  - Standards and protocols allow applications and communications without caring of the underlying infrastructure or system
    - "The Cloud"
  - Anyone can access anything (is public)
- Resiliency (mesh design)
- End-to-end system

- *Layered system of protocols*

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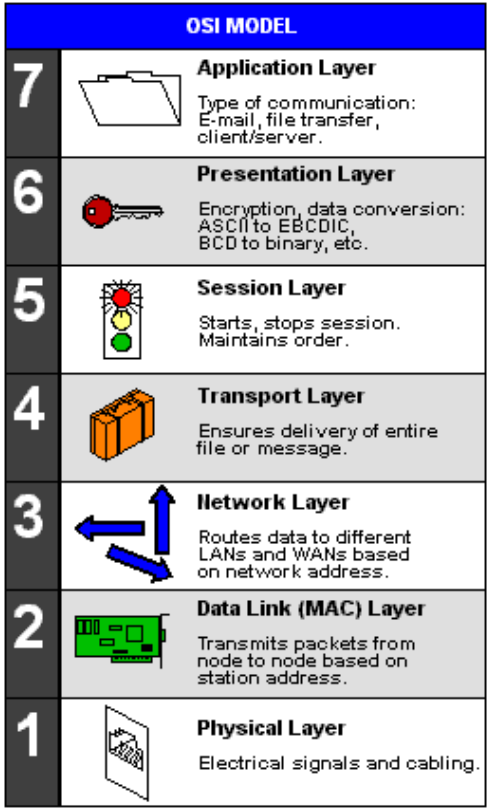
Open Systems Interconnection (OSI) Model



examples

Interface : MESSAGES
User Interacts with these

FTP, Ping, HTTP, etc.

Translation and
encryption : MESSAGES

Remote Procedural Calls (RPCs),
Error Checking : MESSAGES

Reliability,
Error-checking : SEGMENTS
end-to-end validity

TCP, UDP

Software Address,
Routers : DATAGRAMS
establishes routes (extends nodes…)

IPv4, IPv6

Hardware Address, Bridges, Intelligent hubs, NICs, Error Checking : FRAMES
node-to-node validity

Ethernet, ATM

Pins, Wires, Repeaters,
RS-232, Volts, etc : BITS
Deals with the medium

Copper wire, fiber optic, wireless, etc.

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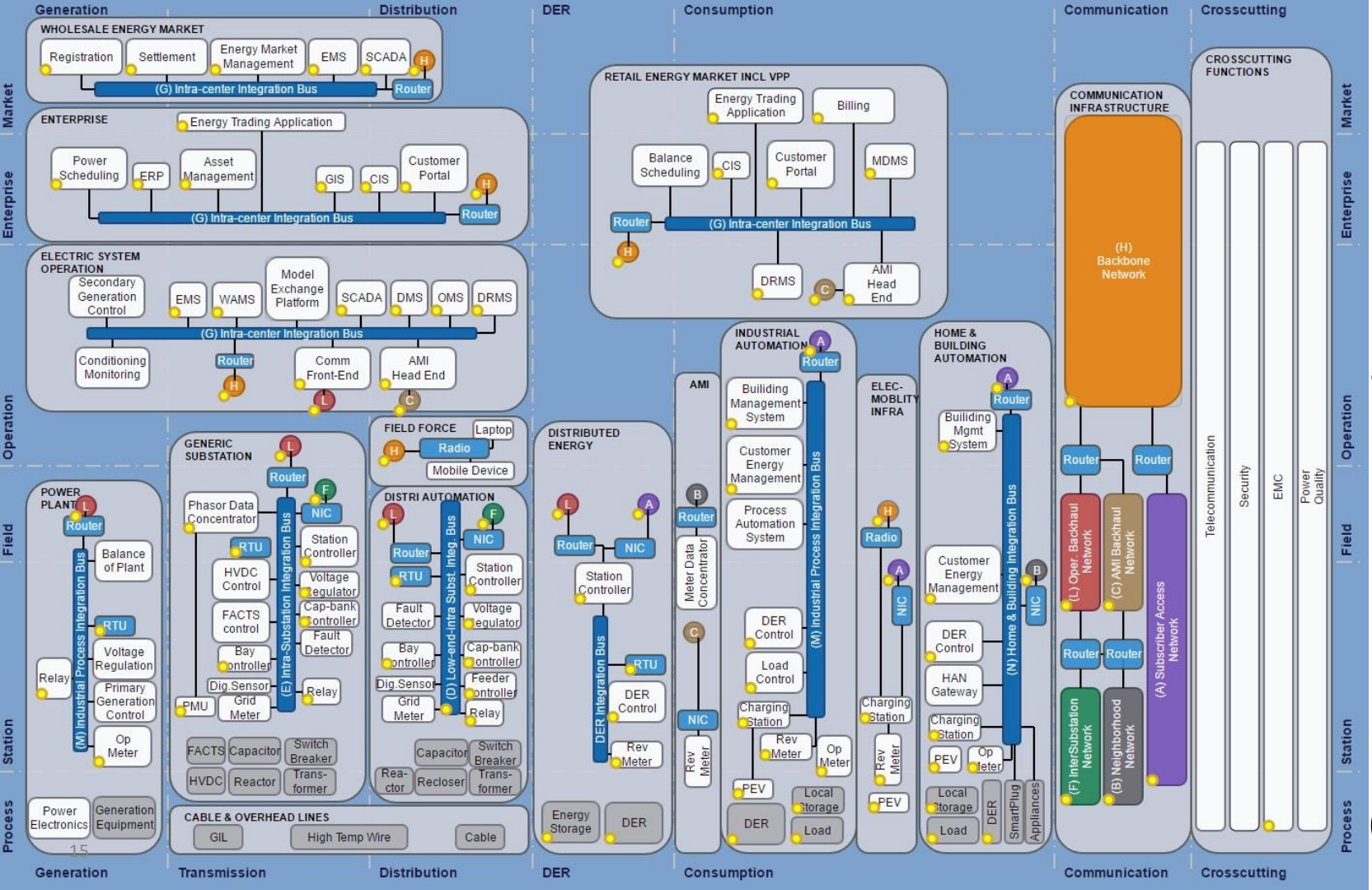

IEC Standards Toolkit

○ = Use Cases

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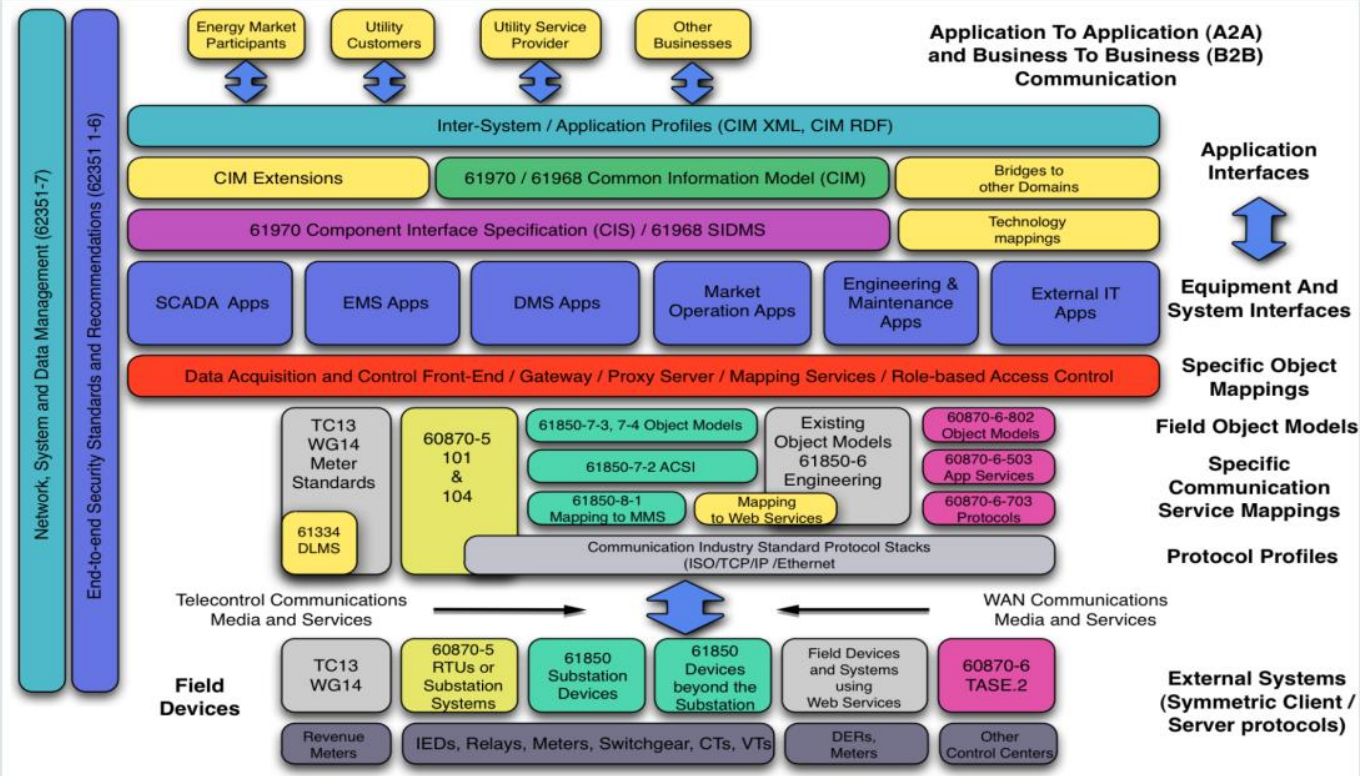
Reference Architecture

- IEC/TR 62357-1 defines the **standards' framework of TC57**
- Provides **basis for implementation strategies and architecture development** for project realizations



IEC TC57 "Power system management and associated information exchange"

Current and future smart grid standardization activities

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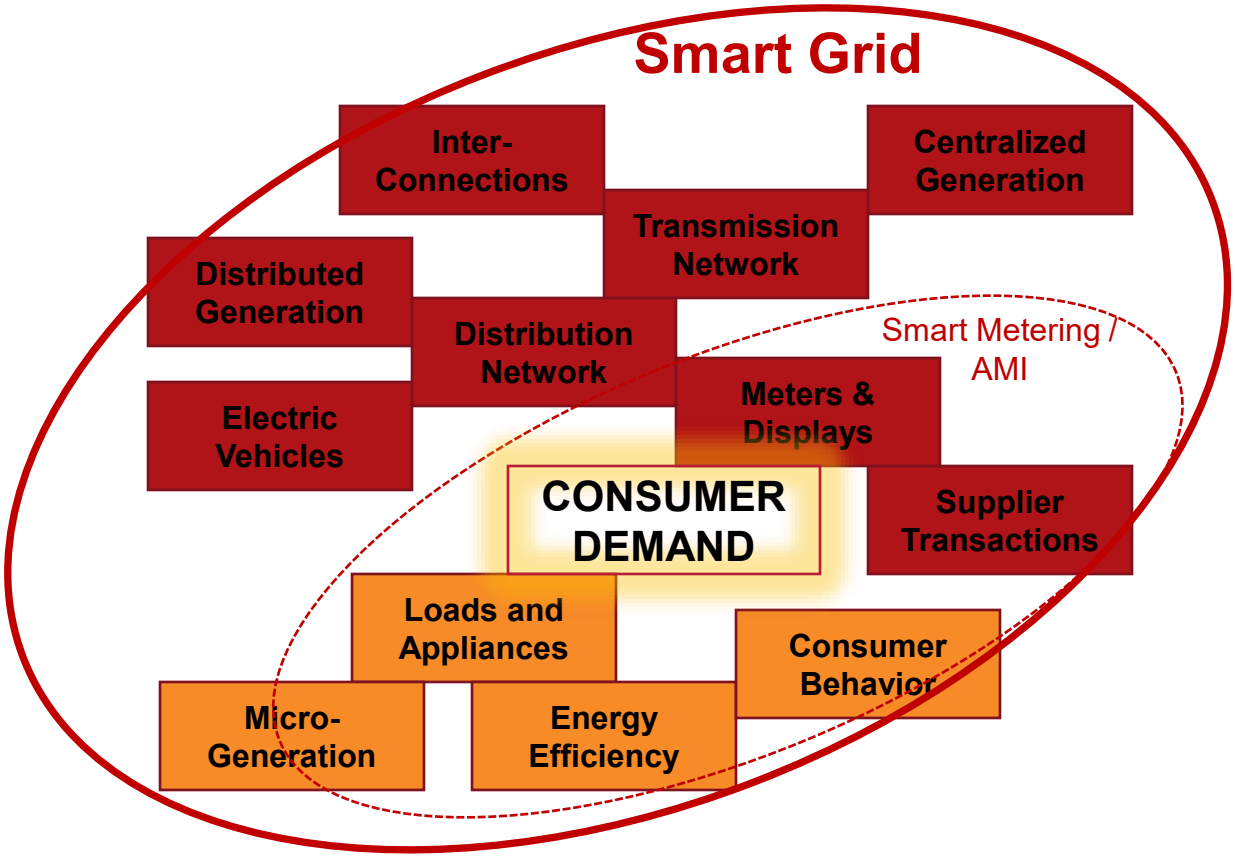
Smart Grid Components



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Standards towards a “Smart Meter”

- Metrology
- Smarts
  - Communications
  - Logic
- Control
  - Connect/disconnect
- Missing standards?
  - Accelerated lifespan (testing)??
  - If we want a 10 or 20 year smart meter (older meters lasted that long!), what are the bottlenecks?
    - Battery
    - Communications ecosystem
      - “The other side”
        - Will 5G be around 10 years from now?

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2 approaches to Smart Metering standards

- Define every step, protocol, etc.
- Then, buyers can pick and choose any vendor for a *fungible* part
- Implications
  - Makes products commodities
    - How does one differentiate?
  - We don't have alternatives
    - Equiv. to the DOCSIS standards in cable modems

- Leave everything as sets of standards (suites) on a pairwise (or similar basis)
  - E.g., Meter to concentrator (DCU)
- Implications
  - More choices
  - Complex!!!

BUT one can also go in-between the two options (have some but limited choices)

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What does this mean for a utility?

- If not everything is a smart thing (e.g., meter), can we do “smart ready”?
- Can I buy this off the shelf?
- Will this stuff last me?
  - Will replacements be available for me 5-10 years down the road?
- Can I change vendors?
  - What if there is a start-up involved? Risks of failing…
- How do I change things or mix-and-match?
- WHERE EXACTLY DO I GET INTEROPERABILITY?
  - Every node?
  - End-points?

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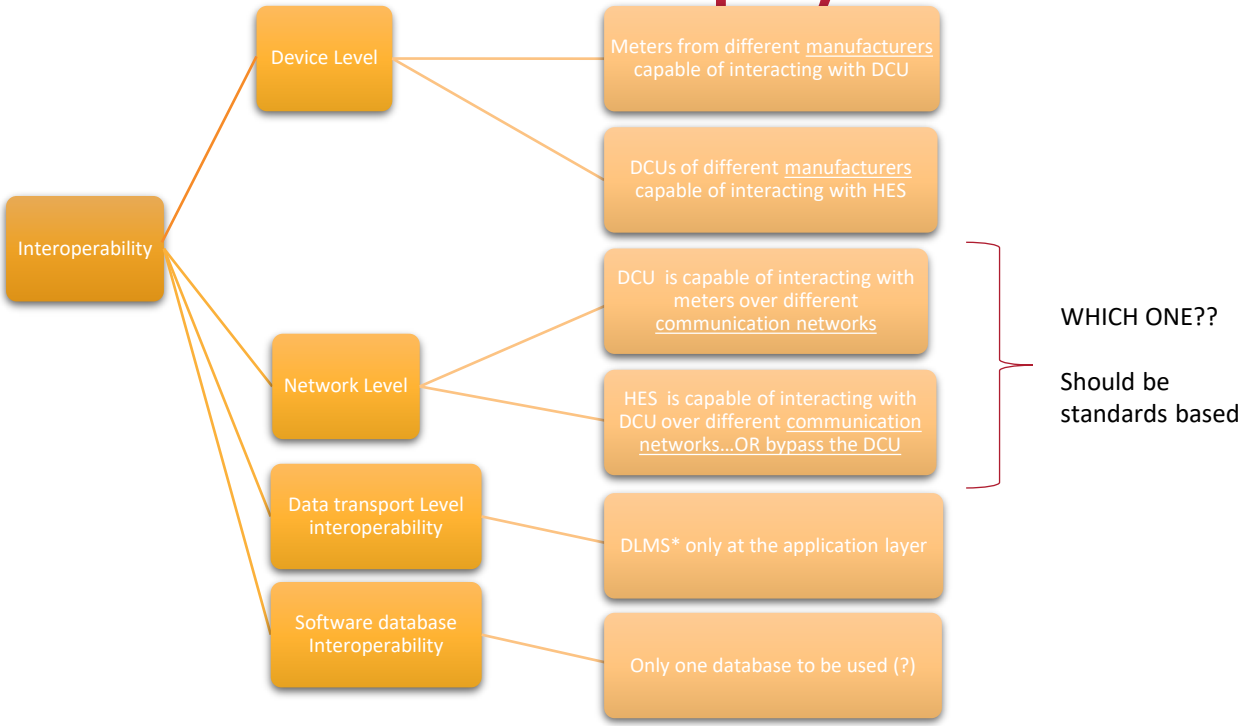
Smart Metering in India Overview (DCU architecture example)



Adapted from: ISGF

* India has formulated IS 15959 Part 2 for smart meters

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Indian Standards on Metering (select)

- IS 13779 – AC Static Watt-Hour Meters: Class 1 and 2 Specification
- IS 15959 – Data Exchange for Electricity Meter Reading, Tariff and Load Control – Companion Specification
- IS 15884 – AC Static Direct Connected Prepayment Meters: Class 1 and 2
- IS 16444 – AC Static Direct Connected Watt-Hour Smart Meters: Class 1 and 2

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Before we get too fixated on “Standards”

- There is no “one” standard
  - Is a portfolio of standards
- Key is *interoperability* and *layering*
  (just like the Internet)
- Some things should be understood for what they are or aren’t:
  - E.g., ISO (or CMM, SGMM)

  (these signal capabilities, not outputs)



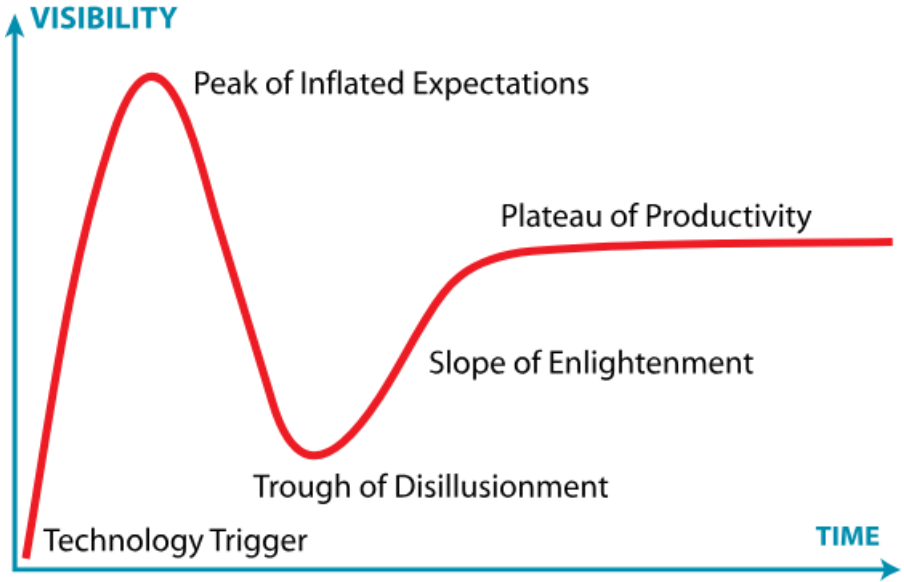
Photo: A. Thatte (used with permission)

Smart Grids have Arrived in India (2010)!

Outlook Business Aug. 7, 2010



Gartner's Hype Cycle



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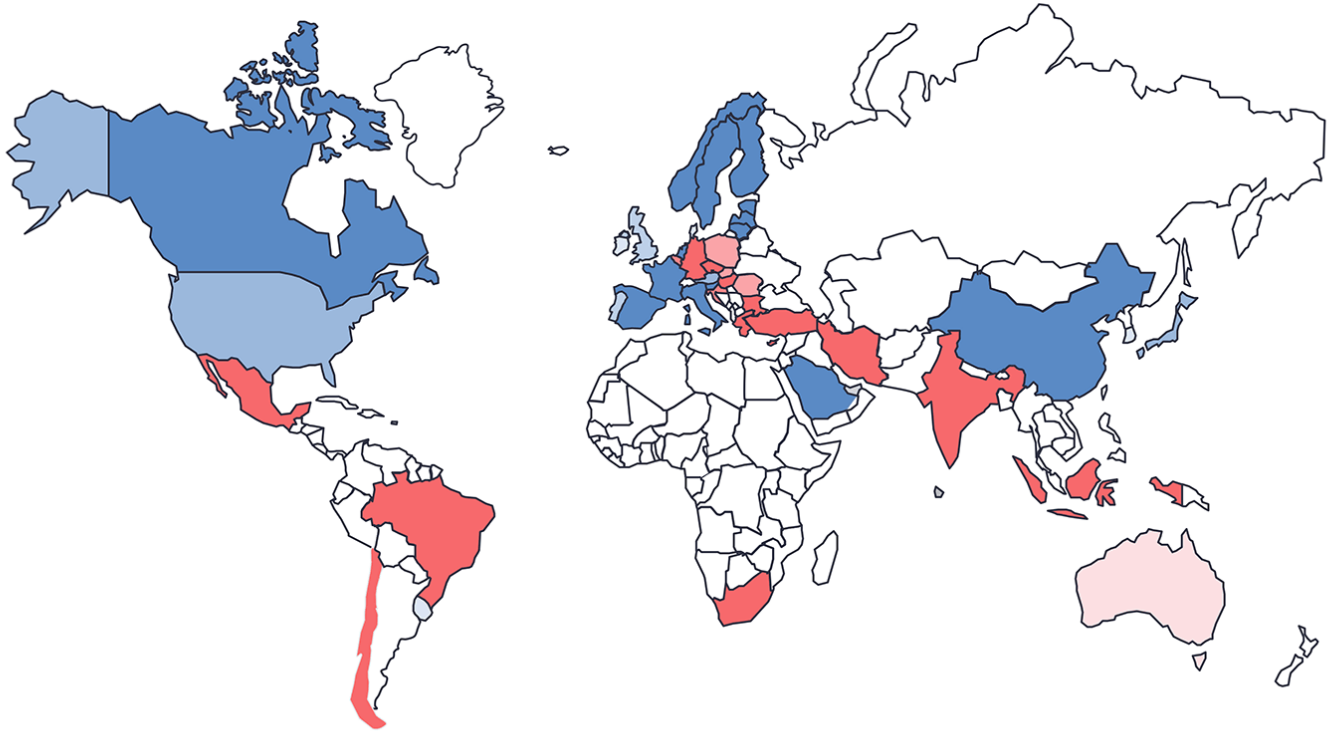
Global smart electricity meter adoption 2024

** Map borders aren't necessarily correct*



* =**Smart meter adoption (as of Q4 2023) =** The share of smart (AMI) electricity meters installed as a share of the total number of metering points that includes residential, commercial, and industrial segments.
Source: IoT Analytics Research 2024 – Global Smart Meter Market Tracker 2020-2030. We welcome the republishing of images but ask for source citation with a link to the original post or company website.

https://iot-analytics.com/wp-content/uploads/2024/02/Global-Smart-Electricity-Meter-Adoption-2024-vweb.png
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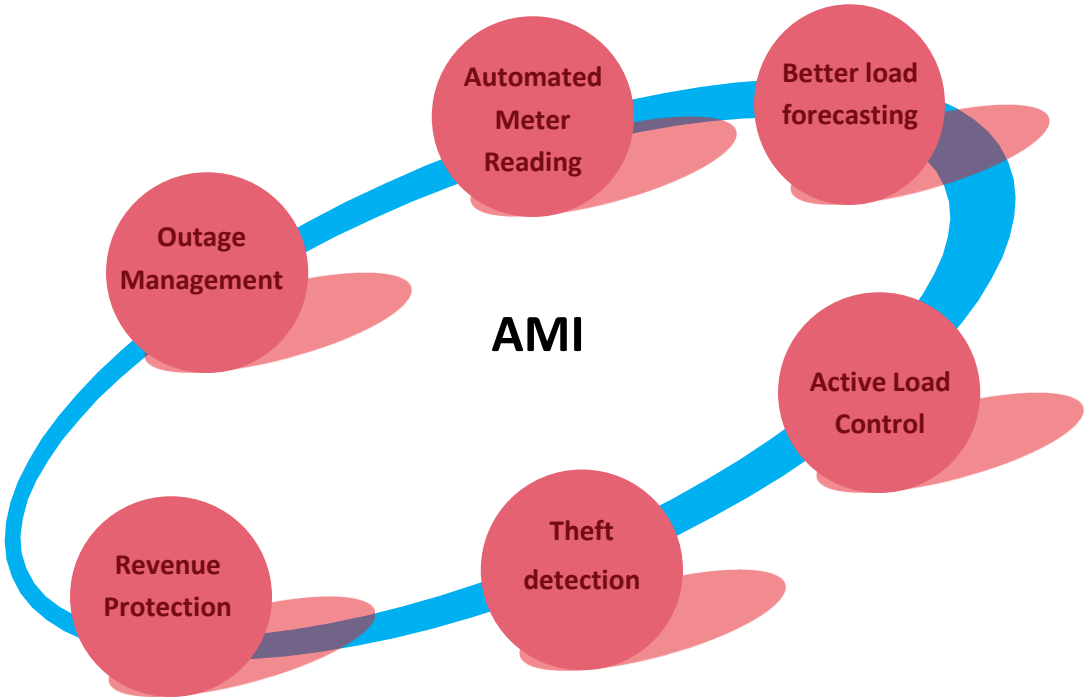
Advanced Metering Infrastructure (AMI) = Basic building block for a Smart Grid



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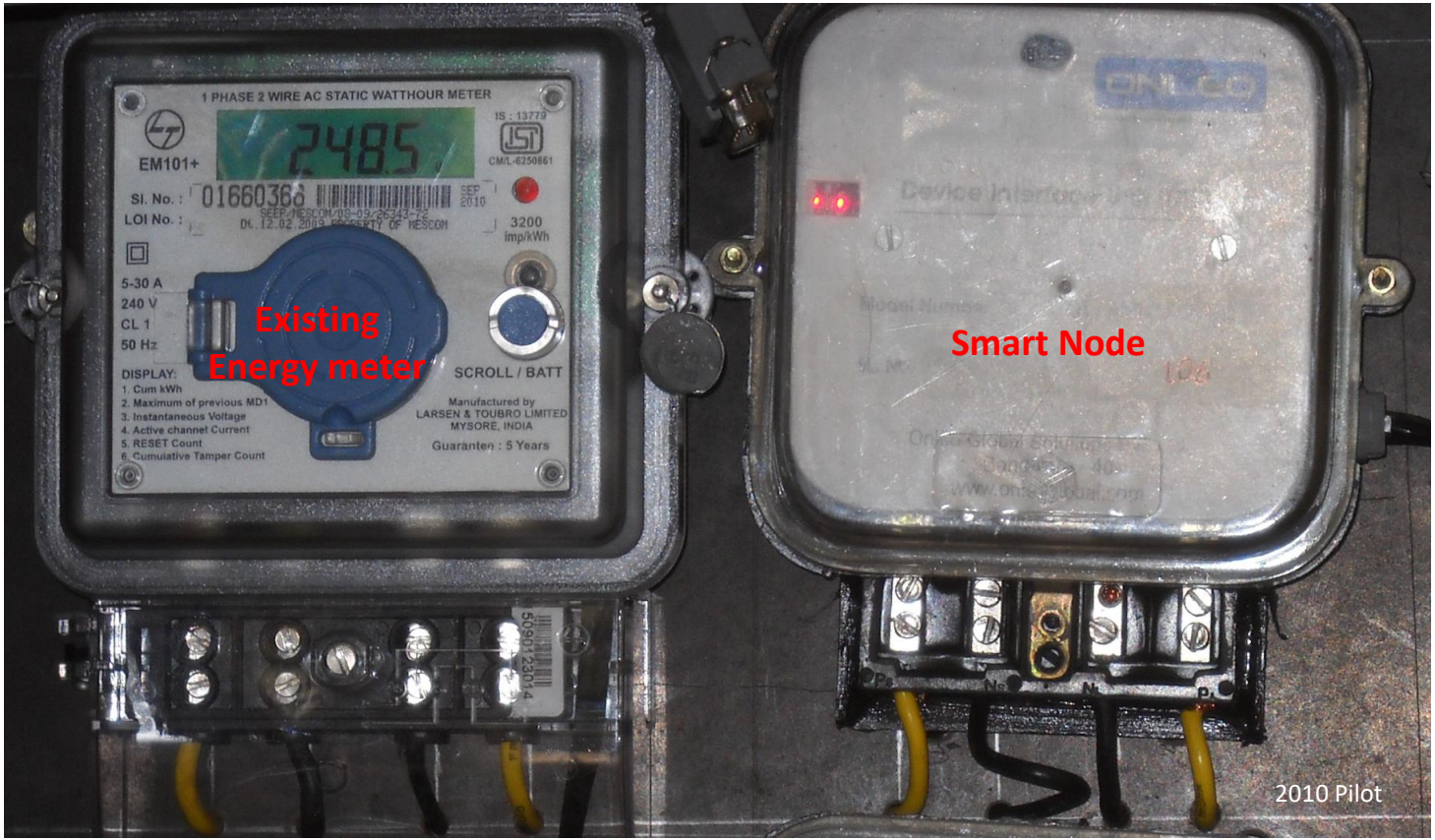
Smart Node plus Digital Meter = Smart Meter



Smart Node = Memory, Logic, Communications, and remote Connect/Disconnect

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Smart Grid Vision and Roadmap [India]

SG Roadmap was approved by Ministry of Power in August 2013 and it was released by the Power Minister on 10th Sept 2013 in a conference of all state power ministers in Delhi

Smart Grid Vision for India

Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders

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What Smart Grids really mean

1. More choices

   Includes renewables

2. Better quality and service

3. Greater resiliency / robustness

4. Increased efficiency and asset utilization

   ($$ savings)

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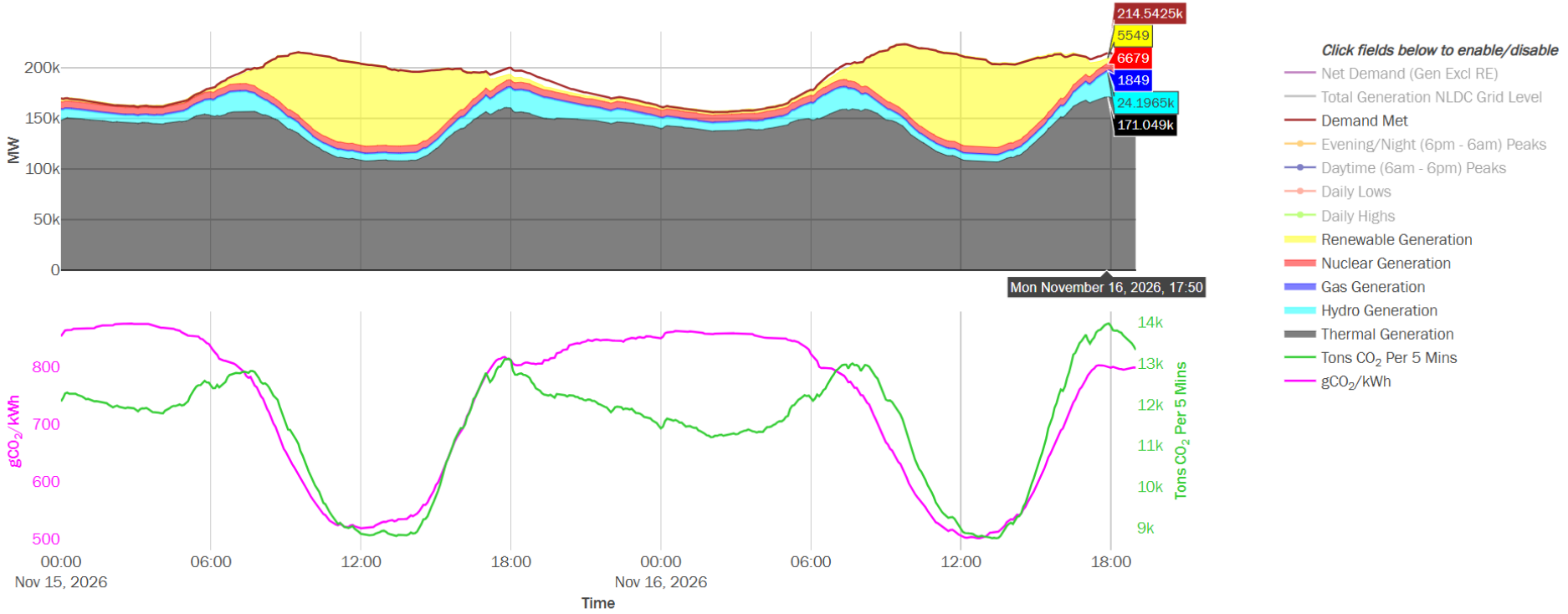
carbontracker.in

FAQs and Instructions | Week of | 16 Nov 2026 | Corrected Generation Data | Submit

CSEP Electricity & Carbon Tracker



Source: Underlying Data from MERIT India

(select) Drivers for Smart Grids

Utilities

- Loss reduction
- Peak load management
- Asset management
- Renewable integration
- Self healing grid

Customers

- Access to power
- Reliability
- Quality Power
- Prosumer (producer-consumer) enablement
- Choices of power purchase

Government

- Satisfied customer
- Reduction in emission intensity
- Financially sound utilities
- Tariff neutral system

Source: India Smart Grid Vision and Roadmap (2013)

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How do consumers (typically) engage?

- Consumption = Supply (incl, outages or not)
- Billing
- Repairs
- New connections or services / upgrades
  - Including rooftop solar

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Consumers want 3 things for in-home smarts to succeed

- Simplicity
  - Plug-and-play
  - Interoperable
- Control
  - Consumers want to choose how they engage
  - They don’t want utilities taking over their appliances
    - And utilities don’t want the liability
- Incentive
  - They need a reason to make an effort or change
    - E.g., ToD or other new pricing schemes
    - OR, the promise of zero load-shedding (in a curtailment model)

Adapted from AHAM

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The Future: Complexity

- "Bapu – if you only knew how much it costs us to keep you in poverty"

  - Sarojini Naidu to Gandhiji

- Analogy: Keeping things simple is very hard (and complex)
  - Big Data / information overload
  - No one wants to stare at an app (or in-home-display) to see power pricing

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How many data points?

- 15 minute readings = over 30,000 readings per consumer
  - That is JUST the static information
  - A systems, networked (flow) analysis is far more complex
- ICT has improved and shall continue to do so
  - Real time and predictive load-flow analysis
    - In transmission, will need Locational Marginal Pricing
    - Edge transactions are even more complex (many, distributed, and poor visibility)
- ToD / ToU pricing is ~inevitable = lots more signals
  - Marginal and average prices vary significantly *per time block*
  - Can start with procurement and limited retail (bulk consumers)

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More data is coming = more challenges

- Who owns the data?
- Who has rights to it?
- Do you trust the cloud?



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Security and Privacy issues will become very important

- Security and health risks are a reason cited for public opposition to smart meters
  - US utilities mostly allow opt-out…for a fee
- Smart Grid data risks
  - At the very least people can know if you're home or not
  - Electricity data has been subpoenaed in divorce cases
  - Police have used it to bust Marijuana growers
  - But there is far more one can know, e.g., wealth
- Hypermetering at the edge (~50 msec) experiment at CMU
  - Can tell if you drink caffeinated vs. decaffeinated coffee

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CyberSecurity is often just paid lip-service

- After-the-fact security is difficult/expensive/disruptive
  - Old joke: The S in IoT stands for security
- Security is a PROCESS, not a black box
- Anyone who says “but we are encrypting” doesn’t understand security
  - Encryption is point to point only
  - Keys CAN and WILL be compromised
    - If it happens to American Express and Citibank, it can happen to anyone
  - How do find out? Recover? Are utilities liable?
  - India now has the Privacy (DPDP) Act – *utilities are NOT prepared*
- Ultimately, from a utility point of view, security is a USABILITY challenge
  - More secure can otherwise become more complex
  - Design Q: How does one associate a Smart Fridge to a Smart Grid securely?

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How do we move forward (esp. get consumers on board)?

- Look for carrots, not just sticks
- Discoms: Set performance standards
  - Fridges are a classic example – State of California set the targets and left it to industry on how to innovate
- Work out *Use Cases* and a Cost-Benefit Analysis
- Innovate
  - Mobiles took off not just due to technology
    - Pre-paid was a big help for developing regions (est. 98% of Indian users)
  - What are the things that consumers want (beyond “cheaper”)?

Smart Meter Cost-benefit analysis challenges

- A “partial” roll-out may never be economic
  - Cannot just put these on a few “bigger consumers” – these are a network, with heavy upfront (fixed) costs
- There are transaction costs
- There are winners and losers, e.g., Time of Day pricing
  - Household usage isn’t solar aligned…
    Do I raise prices for them and lower for industry? POLITICAL ECONOMY

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Key need for utilities and regulators

- Have a published roadmap and timeline
- Do your HOMEWORK (preparedness)
  - Digital asset mapping/consumer indexing
  - Look for interoperability standards for all vendors
    (India is planning an India Energy Stack, just like other DPI projects)
  - SGMM (smart grid maturity model) is one tool
- Build out human capacity at all layers (utilities, regulators, and providers)
- Focus on value proposition, not just cheapest (“L1”)
- Smart Systems need Smart Prices
  - Not as easy as just ToD prices

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The future is already here – it's just not evenly distributed

- William Gibson

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