India Smart Utility Week 2023

Master Class on

Energy Transition to NET ZERO Power Systems

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Action Plan for Decarbonizing the Indian Power Sector

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Background

1997 Kyoto Protocol: mandated emission reduction targets only for developed nations while allowing developing countries with low per-capita emissions

2007 Bali COP: Introduction of Nationally Appropriate Mitigation Actions (NAMA), to engage developing countries in voluntary mitigation effort

2009 - 2010 (Copenhagen & Cancun COP): Comprehensive international system for collective action and major developing countries including India announced voluntary mitigation pledges

2011 Durban COP: ADP launched for evolving a new agreement for post-2020 period

Warsaw & Lima COP : INDC concept for all countries

Gradually countr assume respon

Climate Goals and Initiatives

- **The Paris Agreement** is a **legally binding international treaty on climate change**
  - Adopted by 196 Parties at COP 21 in Paris, on 12th December 2015
  - India is the only country that already met the 2030 target in 2022 – 40% power generation capacity from non-fossil based resources
  - US$ 100 billion fund promised to assist developing countries is yet not in sight!
- **At the COP 26 in Glasgow last year India announced Net Zero by 2070**
- **India's RE target** being enhanced from 175 GW by 2022 to 500 GW by 2030
- IEA's latest estimates: **Indian power system to grow from the present capacity of 406 GW to 823 GW by 2030 and 1584 GW by 2040** - out of 1584 GW, 869 GW is expected to be RE resources; **would require ±85% flexibility!**

Global Installed Generation Capacity in 2020 is 7.78 TW of which 2.98 TW was RE share in 2020

Installed Capacity in 2020 – China: 2200 GW; USA: 1120 GW; India: 390 GW; Japan: 306 GW; Germany: 211 GW; France: 136 GW

Total Power Generation (TWh)	2010: 21520	2020: 26762	2030: 33575	2040: 40553	2050: 46703

Electricity Generated in 2020 (TWh): China: 7787; USA: 4007; India: 1609; Germany: 484

Electrification is the Main Route for Decarbonization

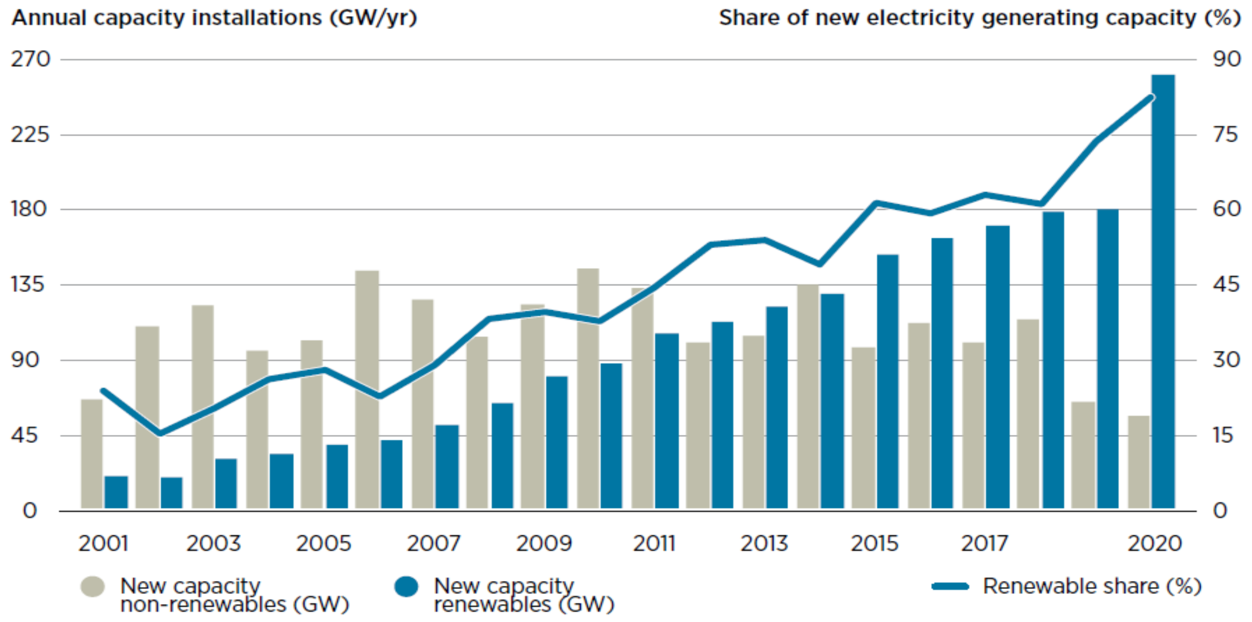
- **Globally accepted decarbonization strategy is to electrifying most of the Human Activities to the extent possible; and decarbonize the electricity sector**
- **Sectors that must undergo Electrification on fast track are :**
    - Transportation
    - Cooking
    - Industry
    - Cooling and Heating
    - Agriculture
- **Power generation needs to decarbonize more quickly**
    - Fossil fuel-based electricity generation is set to cover 45% of additional demand in 2021 and 40% in 2022
    - Carbon emissions from the electricity sector – which fell in both 2019 and 2020 – are forecast to increase by 3.5% in 2021 and by 2.5% in 2022
    - Coal-fired electricity generation is set to increase by almost 5% in 2021 and by a further 3% in 2022
- **Transport sector is the largest consumer of oil**
    - Electrification of transport sector is the top priority for most nations and cities, considering the GHG emission

Decarbonizing the Global Energy Sector by 2050

Annual addition of 630 GW of Solar and 390 GW of Wind by 2030 to give the planet a chance of achieving the emission reductions needed to limit global temperature rise to 1.5°C

- More than twice the record highest levels of Solar addition of 280 GW in 2020
- Almost FIVE TIMES the Wind capacity additions in 2020
- Net Zero energy sector would need 306 million-tons of green hydrogen per year by 2050
- 90% of the energy from RE by 2050 – compared to 20% presently
- Estimated US$ 5 trillion annual investment by 2030 onwards!

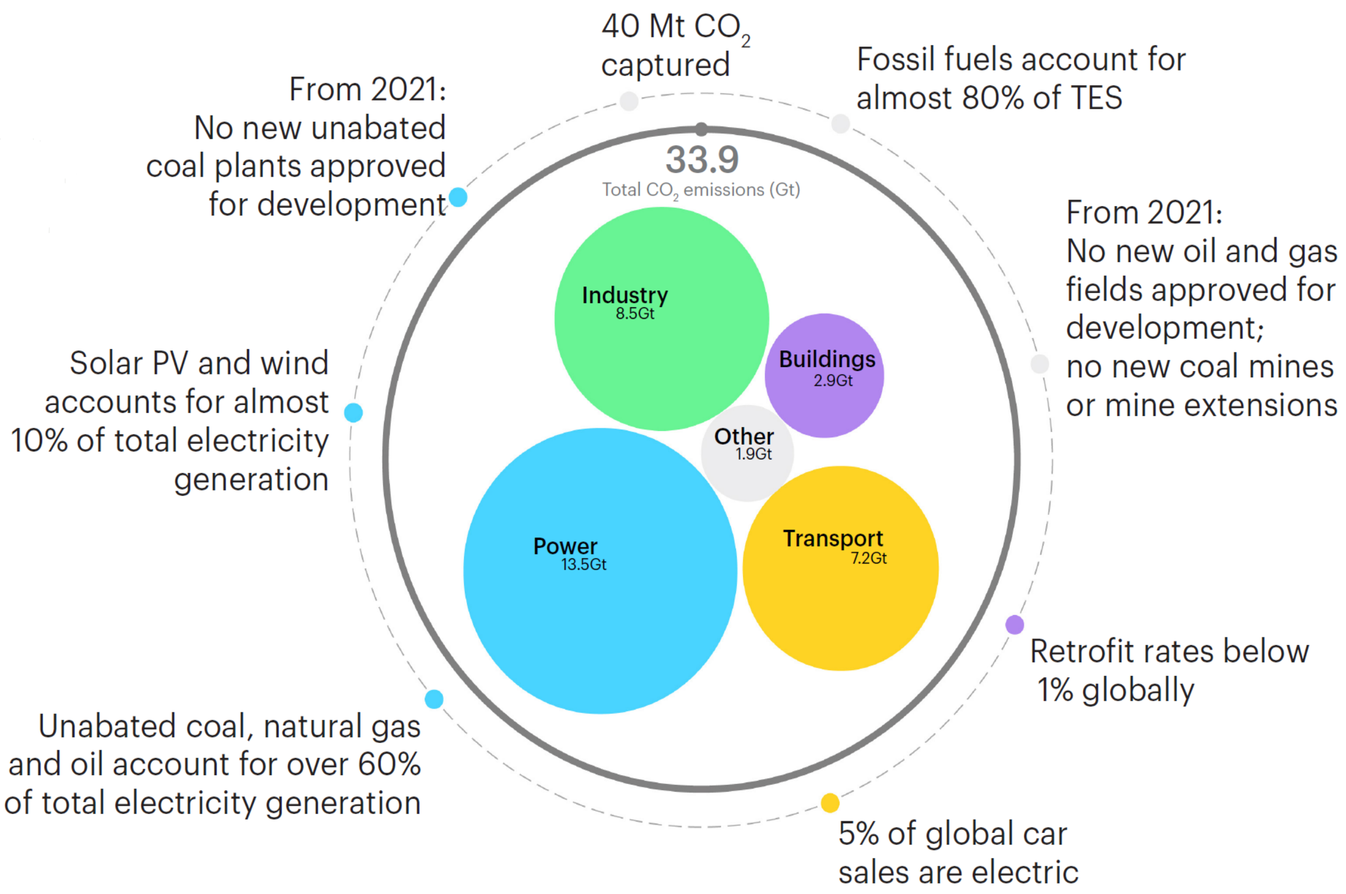
FIGURE S.1 Share of capacity, 2001-2020



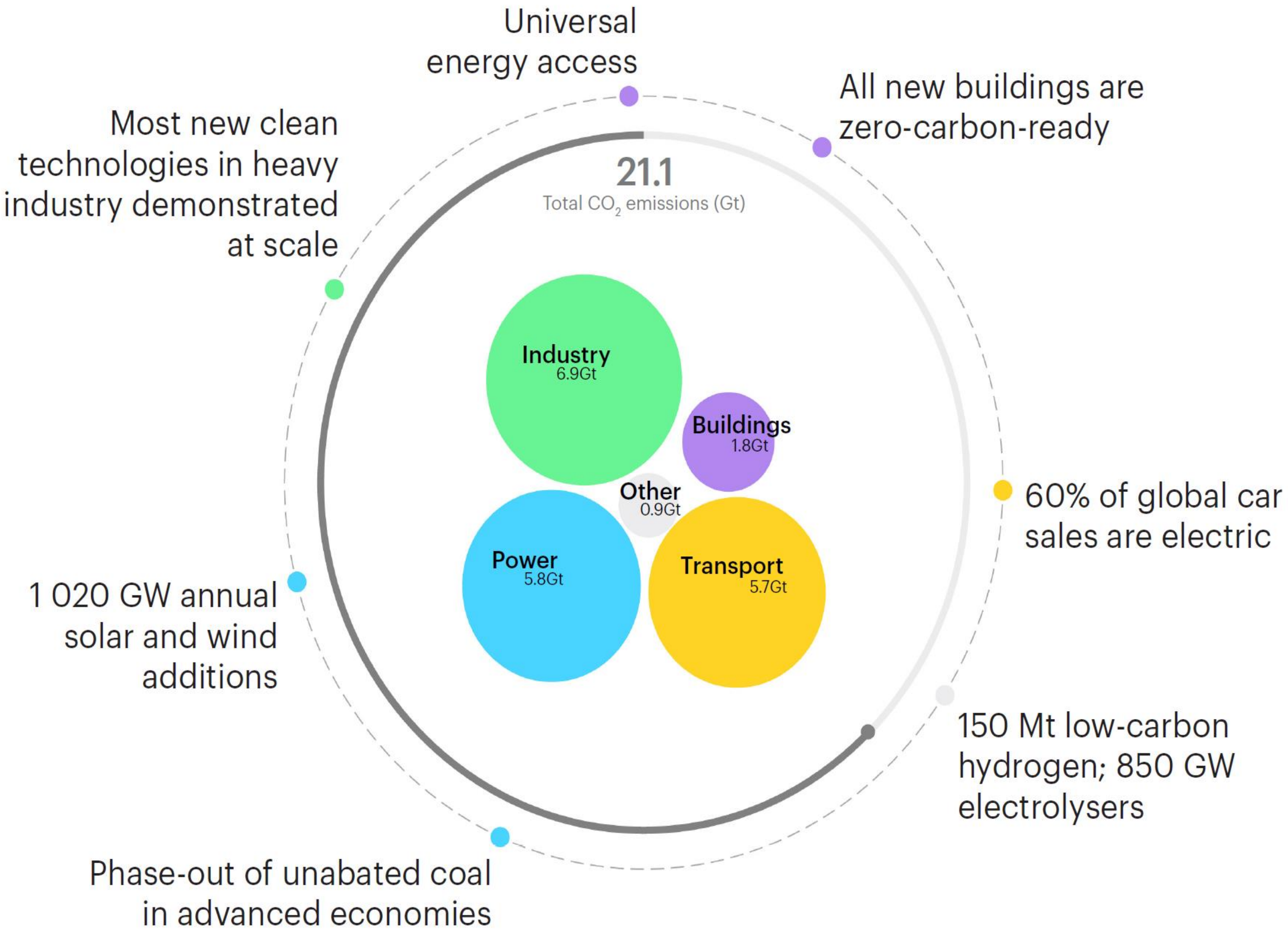
Based on IRENA's renewable energy statistics.

Over One Terra-Watt (TW)/year of RE addition require Smarter Grids!

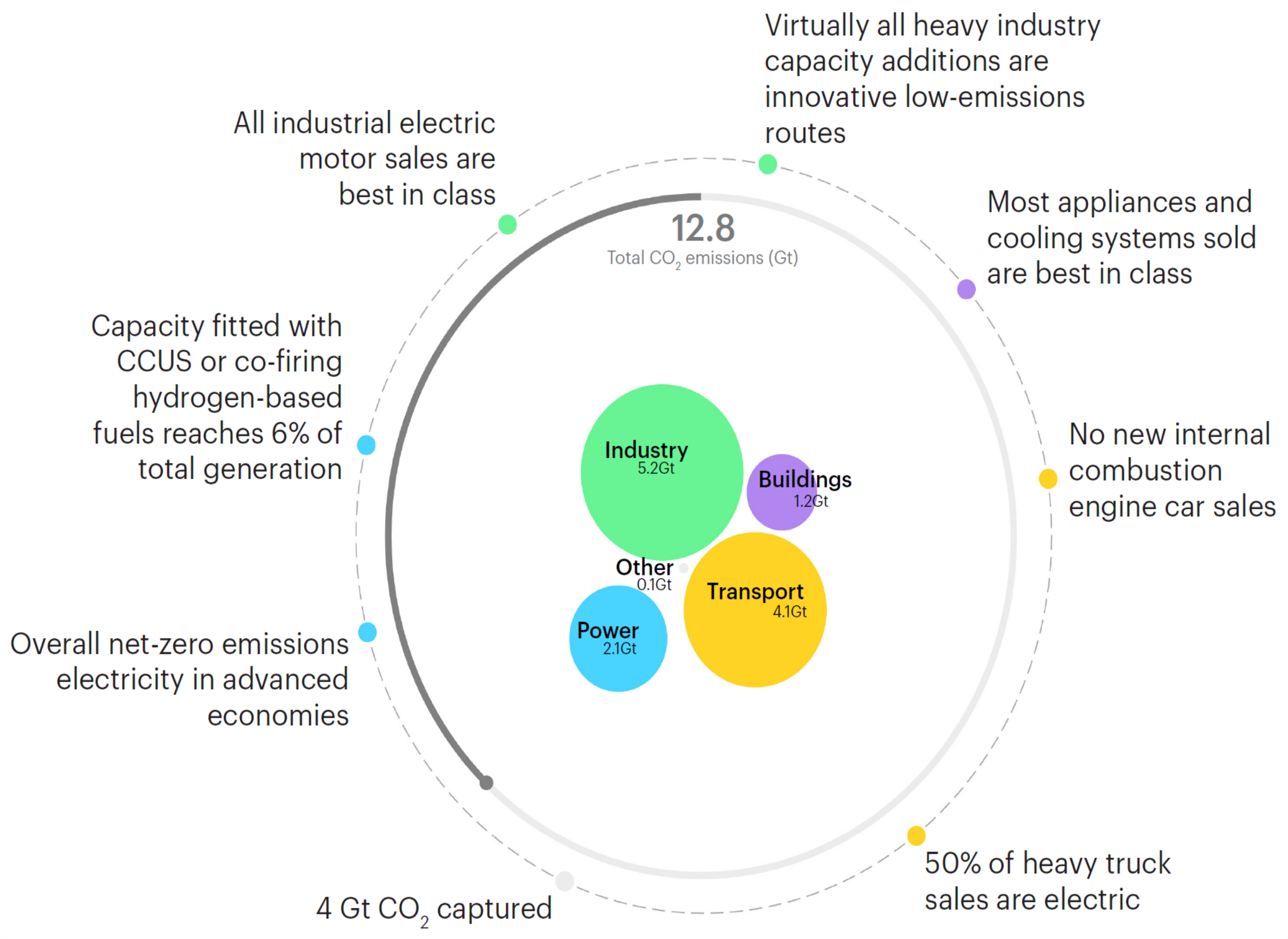
Net Zero by 2050 - IEA Roadmap: Scenario in 2020



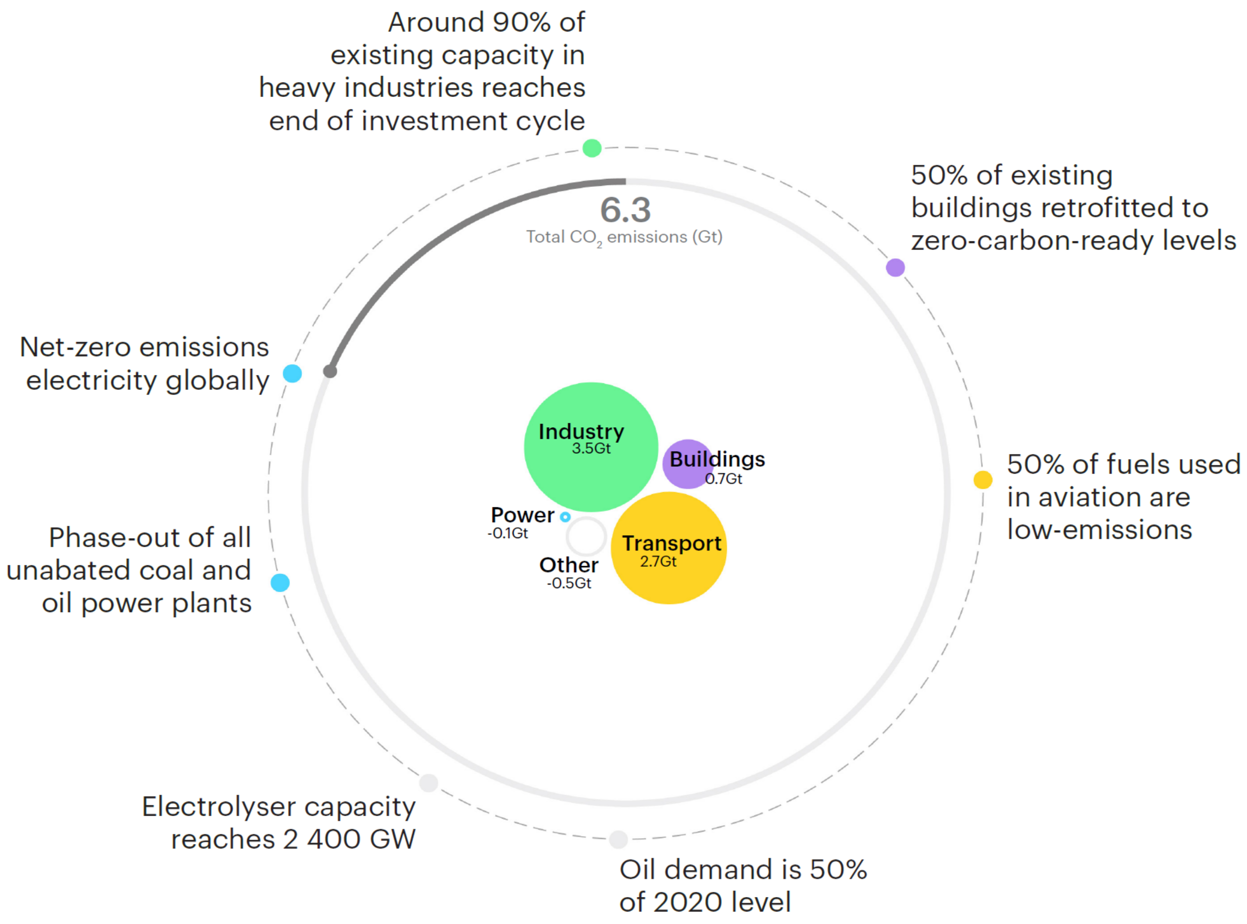
Net Zero by 2050 - IEA Roadmap: Scenario in 2030



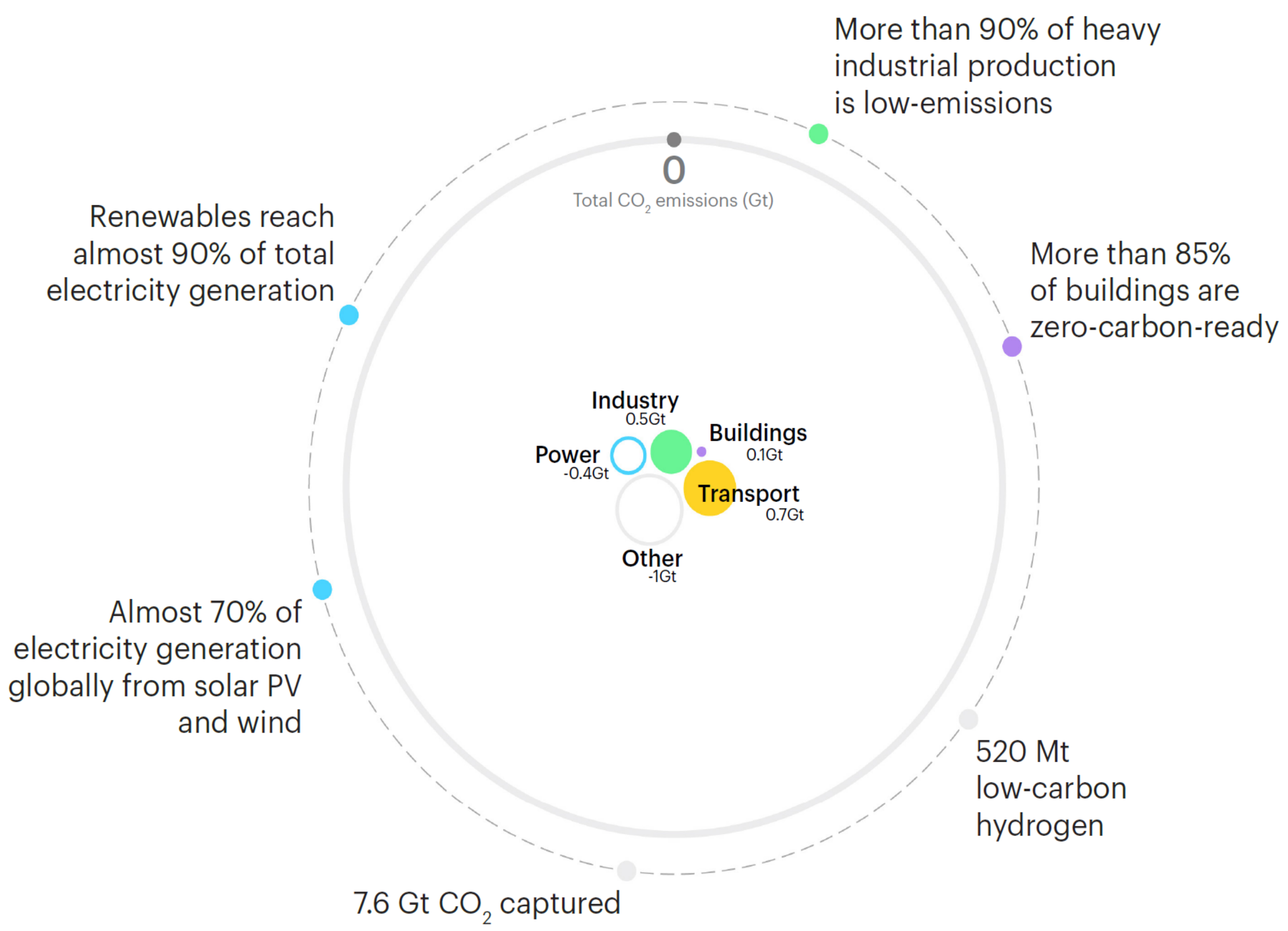
Net Zero by 2050 - IEA Roadmap: Scenario in 2035



Net Zero by 2050 - IEA Roadmap: Scenario in 2040



Net Zero by 2050 - IEA Roadmap: Scenario in 2050



ISGF's Energy Transition Strategy for India

1. Increased RE Supply and RE Use
2. Reduced Use of Coal and Oil
3. Increased Electrification – Mobility, Cooking, Agriculture
4. Increased Use of RE for Mobility
5. Increased Energy Efficiency
6. Dynamic RE Markets and Carbon Markets

Energy Transition Strategy – Approach (1/8)

- Solar PV Revolution
  1. Solar Rooftop PV (RTPV)
  2. Building Integrated PV (BIPV)
  3. Floating Solar PV in all feasible water bodies
  4. Agrovoltaics or installation of ground-mounted solar panels in agricultural fields by raising the height of support structures

- **Solar RTPV and BIPV** may be mandated for certain types of buildings
- **Floating Solar PV Plants**: Deployment of PV panels on the surface of water bodies which is a viable alternative to ground base solar plants
  - **Benefits of Floating Solar Plants**
    - Address land acquisition issues
    - Cooling Effect- increased power generation
    - Less waster evaporation and algae bloom in water bodies
    - Relatively easy to maintain
- **Agrovoltaics** consists of using the same area of land to cultivate as well as install solar PV panels
  - PV Panel support structure height may be increased according to the crops in each farm – only marginally expensive; Solar panels can also be installed on greenhouse roofs
  - Vegetables, fruit bearing trees and medicinal plants can be grown below the solar panels that increase farmers income, besides rent for the land from the solar developer

Energy Transition Strategy – Approach (2/8)

- Distributed Energy Storage Systems (ESS)
  1. Battery Energy Storage Systems (BESS) at solar and wind farms
  2. Solarization of Irrigation Pump (IP) sets with BESS
  3. Diesel Generator (DG) set replacement with BESS
  4. District Cooling Systems (DCS) with Thermal Energy Storage

- **Replacement of DG sets with BESS** is the fastest and cheapest route to build flexibility for the Indian grid
  - Over 70 GW of large-size DG sets in India
  - Diesel at INR 95/liter, DG set will cost INR 29.07/kWh
  - BESS can supply at INR 15.40/kWh (bought from grid at 9:00/kWh)
- More than half the electricity consumption in a building is for space cooling
  - Instead of each building having their centralized air-conditioning plant (or room-ACs)
  - **District Cooling Systems (DCS)** are successfully implemented around the world (including GIFT City in Gujarat, India)
- *ISGF White Papers (www.indiasmartgrid.org)*
  - ***(i) DG Replacement with Lithium-Ion Batteries in Commercial Buildings***
  - ***(ii) Sustainable Air Conditioning with District Cooling Systems (DCS)***

Energy Transition Strategy – Approach (3/8)

- **Comprehensive planning and re-design of the electrical network for the evolving "green grid of the 21st century"**

Both transmission and distribution grids follow the same architecture today; but in the era of distributed RE resources connected to the medium voltage and low voltage grids, the distribution grids require a different architecture. Grid reliability is threatened by increasingly erratic and severe weather events and changing customer behavior of adding renewables and other non-wire alternatives both on grid and behind- the-meter. The recent advances in operational technologies (OT) and information technologies (IT) such as advanced automation systems, smart inverters, cloud computing, mobile computing, machine learning, big data analytics that have potential for efficient grid management at a lower cost

- Present architecture of transmission and distribution grids is based on the concepts of: ***"one-way flow of electricity***" and "***electricity cannot be stored"***
- Features of the evolving Green Grid are (1) different System Operators controlling different segments of the power system; (2) different sources of active/reactive power supply ranging from transmission-located to rooftop solar-based; (3) the ability to dispatch sources of power supply versus 'must take' when available; (4) new cost models for power whether tariff-based or market-based
- The new approach is to have two different architectural constructs – a **data bus** and a **control bus**.
  - ***Data Bus responsible for carrying all non-operational models of information necessary to drive utility decisions***
  - ***Control Bus responsible for carrying all operational data and control actions taken at the local level, centralized level, or other levels in between where that exist***
- The two Buses are isolated by one or more security mechanisms ensuring that information transported by either of them or their actions are not compromised

Energy Transition Strategy – Approach (4/8)

- EV-Grid integration
- Vehicle-to-Grid (V2G) technologies
- Virtual Power Plants (VPPs)
- Promotion of RE for EV charging
- Dynamic RE Markets
  - Peer-to-Peer (P2P) Trading of Green Energy on Blockchain Platforms
- Carbon Markets

EV-Grid Integration

- Both EVs and RTPV are connected to the low-voltage (LV) grid
- **V2G:** Grid connected EVs can mitigate the variability of RTPV generation during the day as well as store surplus generation in the EV batteries and pump back to the grid during peak hours
- **VPP:** Large number of EVs connected to the grid can be aggregated as virtual power plants (VPP)
- **Promotion of RE for EV charging** through innovative business models to decarbonize the transport sector
- **Peer-to-Peer (P2P) Trading:** Prosumers with Solar RTPV can sell their surplus electricity to others who wish to buy GREEN ELECTRICITY – this can be done efficiently on blockchain platforms
  - ***ISGF implemented three pilot projects (Lucknow, Delhi and Kolkata) on P2P trading of solar RTPV energy on blockchain***

Energy Transition Strategy – Approach (5/8)

- **Ancillary services**
- **Demand Side Management (DSM)**
- **Demand Response – Business Models**
- **Time of Use (ToU) Tariff Mechanism**
- **Smart and Grid Interactive Appliances**

- **Promotion of all potential forms of Ancillary Services** including energy storage, EVs, etc through appropriate business models
- **Demand Side Management (DSM**) through incentives and penalties to flatten the load curve
- Time of Use (ToU) Tariffs are real-time pricing for electricity based on supply-demand scenario in real-time
  - Price signals are communicated to the participating customers 15/30 mins in advance about a higher or lower price for following hour(s) and customers adjust their interruptible loads accordingly
  - ***ISGF prepared a ToU Tariif Framework for Gujarat in 2020 and now doing a Pilot Project in Lucknow, UP***
- **Demand Response (DR):** Active control of loads at customer premises by the utility/DR Aggregator – can disconnect the loads when required
- **Smart Appliances:** All electrical equipment and appliances should be made smart and grid interactive; Ban production and sale of inefficient equipment and appliances in a phased manner

Energy Transition Strategy – Approach (6/8)

- **Promotion of Electric cooking**
- **Incentives for cooking during surplus generation of RE**

With Smart Plugs (available at Rs 1000) connected to Home WiFi, appliances can be remotely controlled

- Globally about **4 million people die prematurely** from diseases caused by household air pollution, **primarily from cooking with firewood, charcoal and biomass**
  - As of 2019, 63% rural and 18% urban households in India use firewood, dung cakes or biomass for cooking
  - According to a study, the average PM2.5 in rural India is in the rage of 22 to 112 μg/m³, but the indoor PM2.5 concentration ranges from 106 to 512 μg/m³
- **Promotion of Electric Cooking:** Need of the hour as almost all households in the country are electrified and we have surplus electricity generation capacity
- In FY 2019, 1500 million LPG cylinders were distributed in India which is not sustainable – neither financially, nor from the energy efficiency stand point
- **To meet NDC targets, India must reduce emissions from the kitchens**
- *ISGF White Paper on Electric Cooking – www.indiasmartgrid.org*

Energy Transition Strategy – Approach (7/8)

- Smart Microgrids
- Green Hydrogen Generation

- **Smart "grid-connected" microgrids:** Large building and campuses to be made Grid-interactive with islanding features to provide flexibility to the main grid
    - Buildings and Campuses with RTPV, BESS (instead of DG sets for standby power), and EVs with V2G capability
    - Microgrids can buy (green) electricity from the grid at the cheapest rates and store it in the BESS and EVs and use it during peak hours or even sell it back to the grid at higher prices
- **National Hydrogen Mission:** Envisages to set up green hydrogen generation facilities – electrolyzers run on RE
    - **GW-scale electrolyzers could offer flexibility to the grid** – can be a load that can give load relief when needed
    - Hydrogen can be stored and Fuel Cell based generation respources can be integrating with the electricity grid - Power to gas (P2G) and gas to power (G2P) technologies maturing fast

Energy Transition Strategy – Approach (8/8)

- Retrofitting of Thermal Power Plants
- Retirement of Coal Plants
- Abandon ALL New Thermal Plants – under construction and planning stages
- Instead of FGD, invest in ESS

- **Thermal power plants may be retrofitted as flexible power plants** - To address the variability of solar and wind energy and to avoid curtailment of the RE generation
- **Retirement of Coal based Power Plants**
  - Out of 210 GW of thermal plants in operation today, about 50 GW are older than 35 years and another 50 GW are between 25 and 35 years old
  - Need comprehensive plan for retirement of thermal power plants each year
  - Find efficient and commercially viable alternatives for substituting the energy from the de-commissioned plants
- **Abandon All New Coal based Power Plants**
  - 39 GW under construction, another 25 GW under different stages of approval – these must be abandoned
- **FGD Funds to be utilized for ESS**
  - CERC mandated all thermal plants to install Flue Gas Desulphurization (FGD) units; nobody has done it so far
  - Now that we are talking about retiring coal plants no point in spending billions on FGD – that can be invested for creating ESS

New Technologies to Support Energy Transition Goals

- **Several New Technologies presently in the labs are expected to be commercialized by end of this decade**

1. Nuclear Renaissance – SMR and other technologies
2. Solid State Batteries
3. Solid State Transformers (SST)
4. Higher Efficiency Solar Cells
5. Wave Energy Systems
6. Grid Interactive Buildings and Vehicles
7. Synthetic Inertia
8. Digital Technologies – AL.ML, Robotics, VR, AR, MR
9. Energy Positive Buildings and Campuses
10. Higher Efficiency Electrolyzers – without rare earth materials
11. Higher Efficiency Wind Turbines – offshore, floating, multiple turbines

New Technologies

This groundbreaking motionless wind turbine from Aeromine Technology is 50% more efficient than regular turbines

Wind turbines can be coupled with rooftop solar and integrate with a building's existing electrical system to generate up to 100 percent of a building's onsite energy needs while minimizing the need for energy storage

Aeromine Technology's New Wind Turbine

THANK YOU

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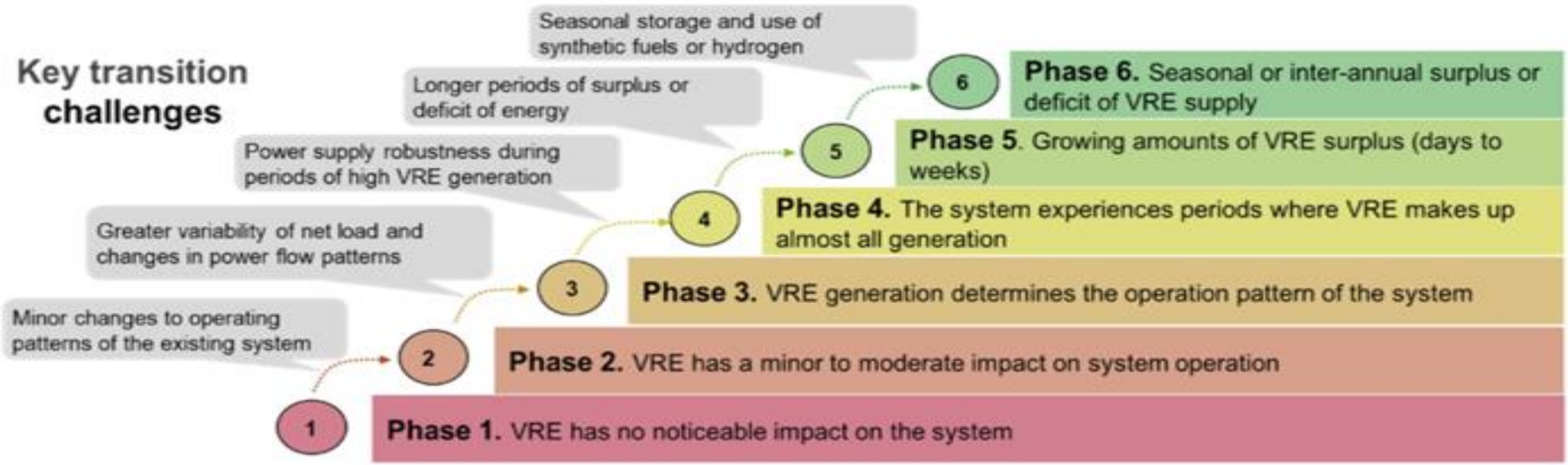
Different Phases of VRE Integration

Phases of system integration of renewables



Source: IEA, Status of Power System Transformation 2019.

Flexibility at Different Timescales and Phases

Flexibility at different timescales and phases

Flexibility type	Ultrashort-term flexibility	Very short-term flexibility	Short-term flexibility	Medium-term flexibility	Long-term flexibility
Timescale	Sub-seconds to seconds	Seconds to minutes	Minutes to days	Days to weeks	Months to years
Issue	Ensure system stability (voltage, transient and frequency stability) at high shares of non-synchronous generation	Short-term frequency control at high shares of variable generation	Meeting more frequent, rapid and less predictable changes in the supply/demand balance	Addressing longer periods of surplus or deficit of variable generation	Balancing seasonal and inter-annual availability of variable generation
Most relevant integration phase and example regions	Phase 4 Several VRE-rich states by 2025	Phase 3 Gujarat, Karnataka, Tamil Nadu in 2021	Phase 2 India as a whole, Maharasthra in 2021 Gujarat, Karnataka, Tamil Nadu in 2021	Phase 4	Phase 5 Phase 6

Source: IEA, Maharashtra Power System Transformation Workshop Report.

Flexibility Resources For Different Timescales

Flexibility Timescale / Flexibility Resource	Ultra Short Term (sub-seconds to seconds)	Very Short Term (seconds to minutes)	Short Term (minutes to hours)	Medium Term (hours to days)	Long Term (days to months)	Very Long Term (months to years)
State-of-the-art VRE	Controller to Enable Synthetic Inertia; Very Fast Frequency Response	Synthetic Inertial Response; Automatic Generation Control (AGC)	Downward/ Upward Reserves; AGC; Economic Dispatch (ED) including VRE	ED tools; Unit Commitment (UC) Tools; VRE Forecasting Systems	UC Tools; VRE Forecasting Systems	VRE Forecasting Systems; Power System Planning Tools
Demand-side Resources	Power electronics to enable Demand Response	Demand-side Options including Electric Water Heaters, EV Chargers, large Water Pumps, Electric Furnaces etc	ACs with Cold Storage and Heat Pumps; Equipment listed under Very-Short-Term Flexibility	Smart Meters for Time-Dependent Retail Pricing	Demand Forecasting Systems	Demand Forecasting Systems; Power-to-Gas (P2G)
Storage	Super Capacitor; Flywheels; Battery Storage; PSH Modern variable speed units	Battery Storage	Battery Storage; CAES; Pumped Storage Hydro (PSH)	PSH	PSH	PSH; Hydrogen Production; Ammonia or other P2G
Conventional Plants	Mechanical Inertia; Generation Shedding Schemes	Speed Droop Control; AGC	Cycling; Ramping; AGC	Cycling; Quick-Start; Medium-Start	Changes in Power Plant Operation Criteria	Retrofit Plants; Flexible Power Plants; Existing Generators as Reserve
Grid Infrastructure	Synchronous Condensers and other FACTS Devices	Special Protection Scheme (SPS); Network Protection Relays	Intra-regional Power Transfers; Cross-Border Transmission Lines	Inter-nodal Power Transfers; Cross-Border Transmission Lines	Control and Communication Systems to Enable Dynamic Line Ratings (DLR), WAMS, Static VAR Compensator	Transmission Lines/ Transmission Reinforcement

Few Definitions

- **Inertia:** Kinetic energy of the massive rotating machines works like a shock absorber to keep grid frequency from dropping too fast when demand exceeds supply or rising too fast when supply exceeds demand. Without this stabilizing force, power grids could face a greater risk of frequency excursions that could force generators offline or cause cascading outages. The rise of renewables presents challenges — and possible solutions. The total system inertia comprises the combined inertia of most of the spinning generation and load connected to the power system . Low levels of rotational inertia in a power system, caused in particular by high shares of inverter-connected renewable energy sources which normally do not provide any rotational inertia, have implications on the grid's frequency dynamics.

- **Droop Control**: Droop speed control is a control mode used for AC electrical power generators, whereby the power output of a generator reduces as the line frequency increases. It is commonly used as the speed control mode of the governor of a prime mover driving a synchronous generator connected to an electrical grid