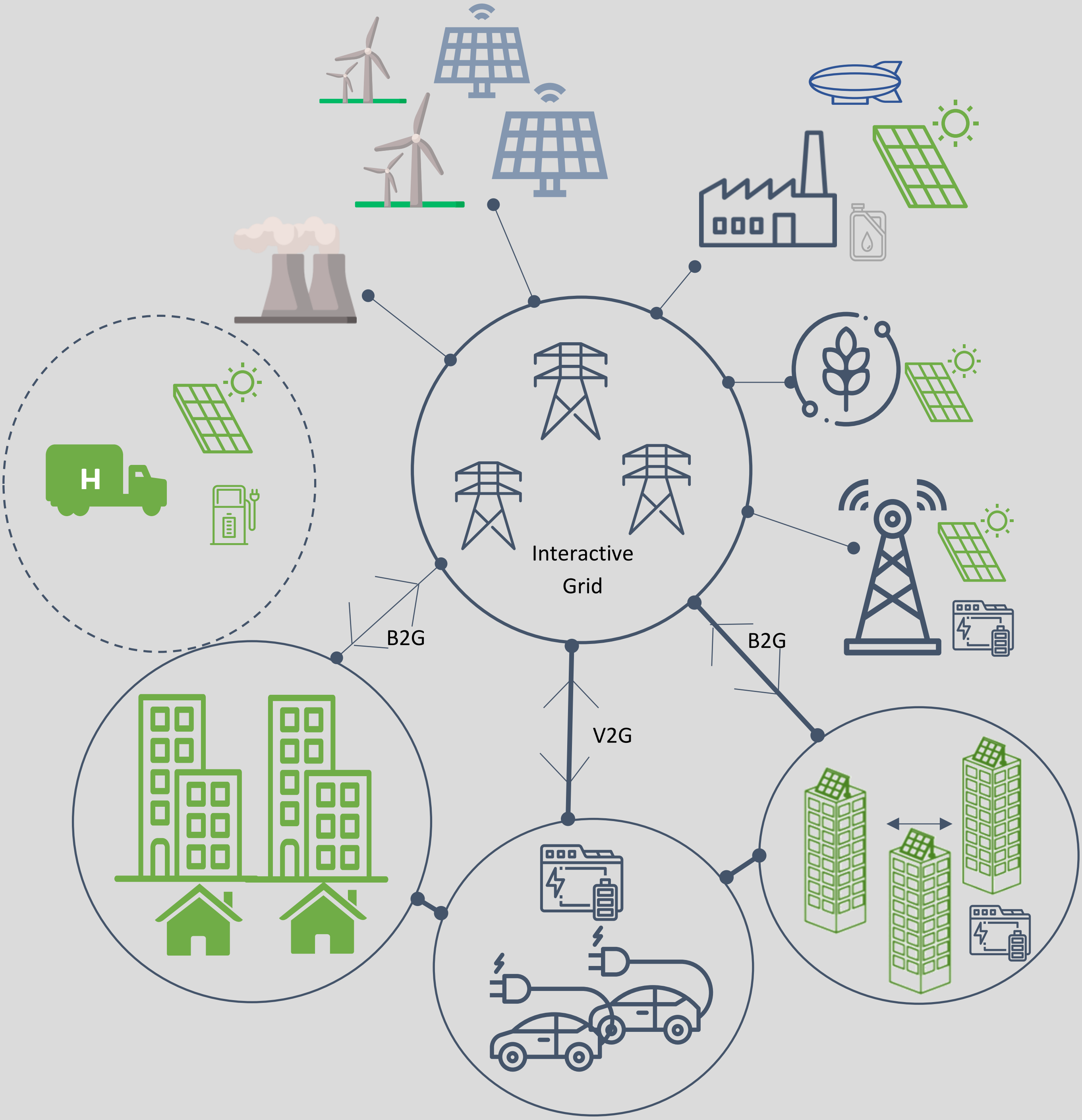

ENVISIONING INDIA'S TRANSITION TOWARDS DISTRIBUTED ENERGY SYSTEMS

This document has been produced for the India Energy Transformations Platform (IETP), an independent, multi-stakeholder group that meets periodically to discuss non-linear, radical and transformative opportunities for deeply decarbonizing India's energy sector by 2050.

It is part of an engagement undertaken by cKinetics Consulting Services Private Limited, with support from Global Centre for Environment and Energy at the Ahmedabad University, on Envisioning India's transition towards distributed energy systems using combinations of renewables, storage and smart control technologies.

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Introduction

As per the IEA, the biggest increase in energy demand over the next 20 years across the globe will happen from India. Between 2016 and 2040, primary energy demand in India will rise by 1005 Mtoe (as compared to 790 in China, 485 in all of Africa and 270 in South America; while Europe and North America will witness a decline in energy demand). Hence, the largest opportunity to reimagine an energy future exists in India.

Given this rising energy demand as also the need for integrating decarbonisation as a core tenet of the country's energy system, India is pursuing a transition towards maximizing renewables. With revised target of 450 GW renewable capacity by 2030, the aim is to go beyond the targets outlined in India's Nationally Determined Contributions (NDCs).
Even as these actions are underway, with the revised global ambition of limiting the temperature rise by 2100 to within 1.5°C, there is a need for transformative and non-linear opportunities that can lead India to a deeply decarbonised energy future in 2050.

Distributed systems supportive of evolving energy landscape

As the energy systems evolve, three (3) megatrends will likely impact energy sector landscape in the future: miniaturization, digitization and convergence.

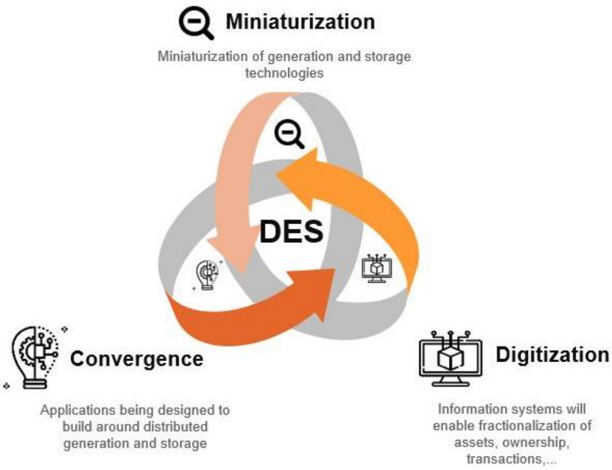


Figure 1: Evolving megatrends

With the development of energy sector, these three mega trends will drive the distributed systems and frame impact across three fronts - supply, demand and interface between the two.

With the ongoing transition, the generation nodes are expected to become smaller and get closer to the application/end user (like distributed green hydrogen production) while at the same time, the energy demand nodes have started becoming a generation source of their own (like solar rooftop in buildings) thus according more independence to energy consumers and enabling their evolution into prosumers – producers of energy.

In order to enhance the demand and supply balance, new smart systems like building to grid (B2G) or vehicle to grid (V2G), virtual power plants, or peer to peer (P2P) would support exchange and trading of energy with grid and/or other consumers; enabled by block-chain based micro-energy trading models.

Thus, Distributed energy systems (DES) can play a significant role in propelling India towards a greener future. It is estimated that out of the target of 450 GW of renewable capacity by 2030, around 50% can be met by rooftop solar alone. This combined with other distributed systems can help India realize its aggressive renewables targets. However, disruptive innovation needed to help India realize the 1.5 scenario cannot come from technologies yet-to-be-invented but by framing mechanisms to maximize uptake of the known solutions – systems which are already commercialized but facing adoption or scale barriers (like solar rooftop, solar water heater or solar pumps) or systems which are 'on the horizon' (in prototyping phase) and requiring technical or economic developments to enable the uptake.

Given the distributed nature of these technologies, it is critical to assess their suitability to the Indian context and to gauge the role that they can play in generation complemented with different storages, to address end-user oriented onsite demands across different sectors like buildings, transport and industry.

About the Report

This study has been undertaken to inform the direction and priorities of the India Energy Transformations Platform (IETP), an independent, multi-stakeholder group that meets periodically to discuss non-linear, radical and transformative opportunities for deeply decarbonizing India's energy sector by 2050.

The study focused at identifying the radical distributed systems (generation, storage and smart control systems) that can play a leading role in India's deep decarbonization pathway over the next three decades. In particular, the study entailed the following components:

1. Evaluate radical technology and policy options on decentralized energy systems (and relevance in India)	2. Understanding nature of demand that could be met with decentralized energy systems	3. Net-benefits of decentralized energy production to the users	4. Estimate the impact potential

The study evaluated various scenarios, barriers for adoption, opportunities and policy frameworks for intensifying penetration of these systems.

- Pursuant to a comprehensive review of the current and emerging technologies on the landscape and application of key criteria influencing uptake of technologies in the Indian context, thirteen (13) technologies which can have a significant impact in the future were identified. These were further refined to align to specific deployment scenarios wherein the impact can be maximized.
- The assessment of suitability and timelines in the Indian context was undertaken both from the perspective of commercial and technical readiness of technologies
- A comprehensive net-benefits mapping for each of the shortlisted technology was undertaken to frame the economic and social rationale for the uptake.
- Recommendations include a snapshot of key transformative policies needed to enable rapid uptake.

Projecting energy needs of 2050 and pathways for addressing the same

Considering the GDP and population growth, India's 2050 demand is estimated[1] to be between 13,000 TWh to 17,000 TWh and is expected to be influenced by:

- *the rise of electrification,* in itself a more efficient way to meet energy needs in many applications leading to a more decarbonized future
- *a marked increase in demand side efficiency,* the result of technological improvements and behavioural changes
- *the growing use of renewables* —a trend resulting in higher energy security due to less dependence on fossil fuels

An overview of the national level demand curve is provided below.

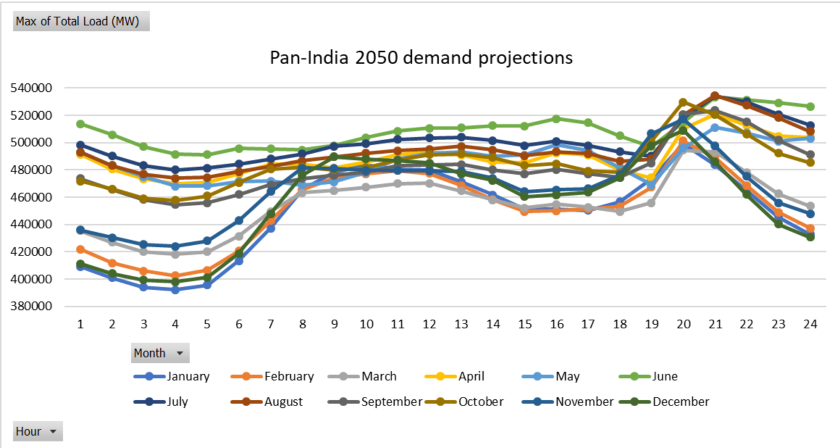


Figure 2. Peak hourly electricity demand profiles at national level

The demand was analysed per the needs and trends across different end-use segments in the five (5) geo-climatic zones in India – Cold, Temperate, Composite, Warm and humid; and Hot and dry. Assessment of the electricity demand curves for each geo-climatic zone on an hourly basis through the year (i.e. an 8,760 profile) indicates the peak and off-peak slots and consequently the potential that distributed renewable resources can meet based on their availability curves throughout the day. 24-hour maximum demand curves across different geo-climatic zones for 2050 are represented overleaf. Annexure 3 provides detailed methodology on demand projections.

[1] cKinetics and GCEE energy model projections

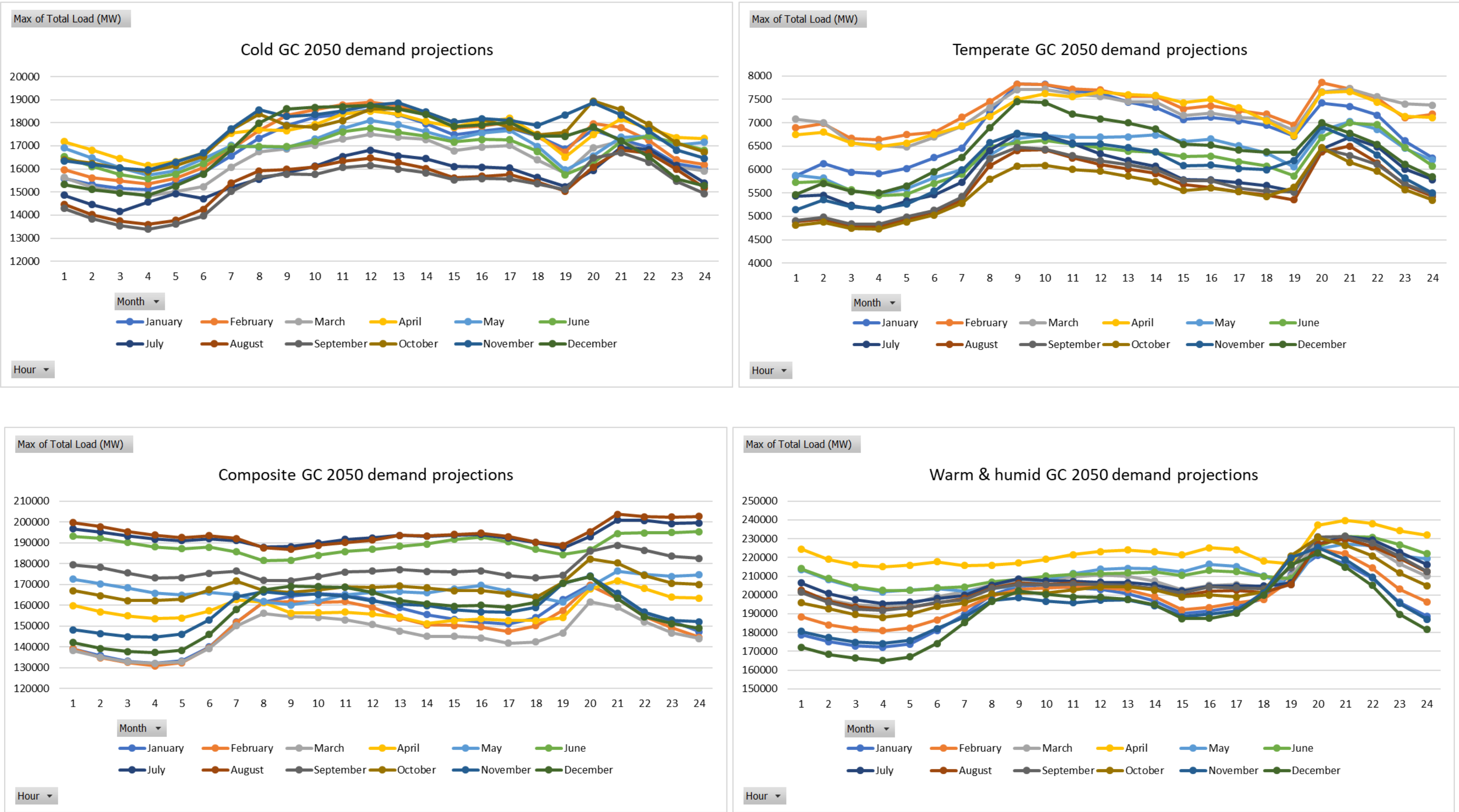


Figure 3. Peak hourly electricity demand profiles for different geo-climatic zones

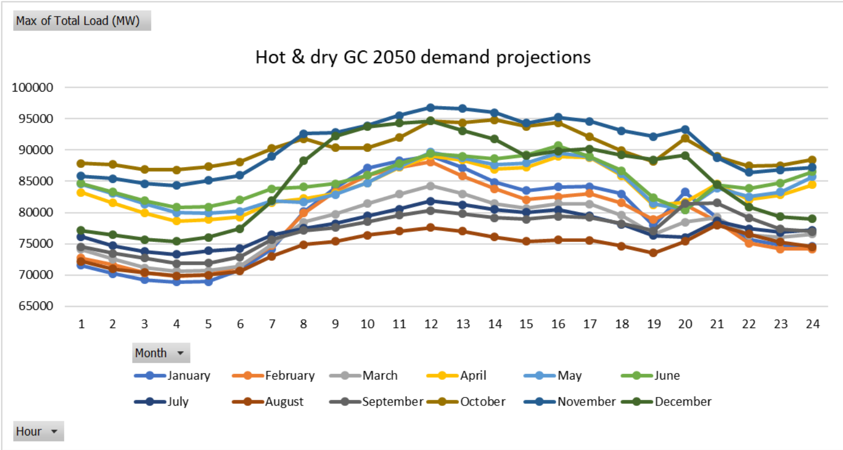


Figure 4. Peak hourly electricity demand profile for hot & cold geo-climatic zone

Role of distributed systems in addressing the demand

In-line with the megatrends touched upon earlier in this report, the distributed systems can play a role on different fronts based on their ability to meet the nature of the demand. Based on a deep-dive of 65 distributed energy systems (including distributed storage settings), thirteen (13) systems are deemed as most suited to the evolving Indian needs and expected to have a significant impact in the future. A synthesis of the same is provided in Figure 5.

These systems were mapped for specific deployment scenario in a respective demand sector. Given the nature of deployment, these technologies can be bucketed as:

- **convergence of application and generation** - for systems where energy and consumption nodes converge
- **distributed generation**
- **distributed storage**

Apart from these, there are also systems which provide several societal benefits. Such systems may not contribute as much towards decarbonization but are oriented towards addressing the issues around dimensions like water sustainability, waste management etc.

The following section provides an overview of the shortlisted systems bucketed per the categories described above with specific deployment scenario, impact potential and commercial and technical readiness levels. A detailed narrative for each of these technologies is provided separately in cKinetics report "Envisioning India's transition towards distributed energy systems using combinations of renewables, storage and smart control technologies"

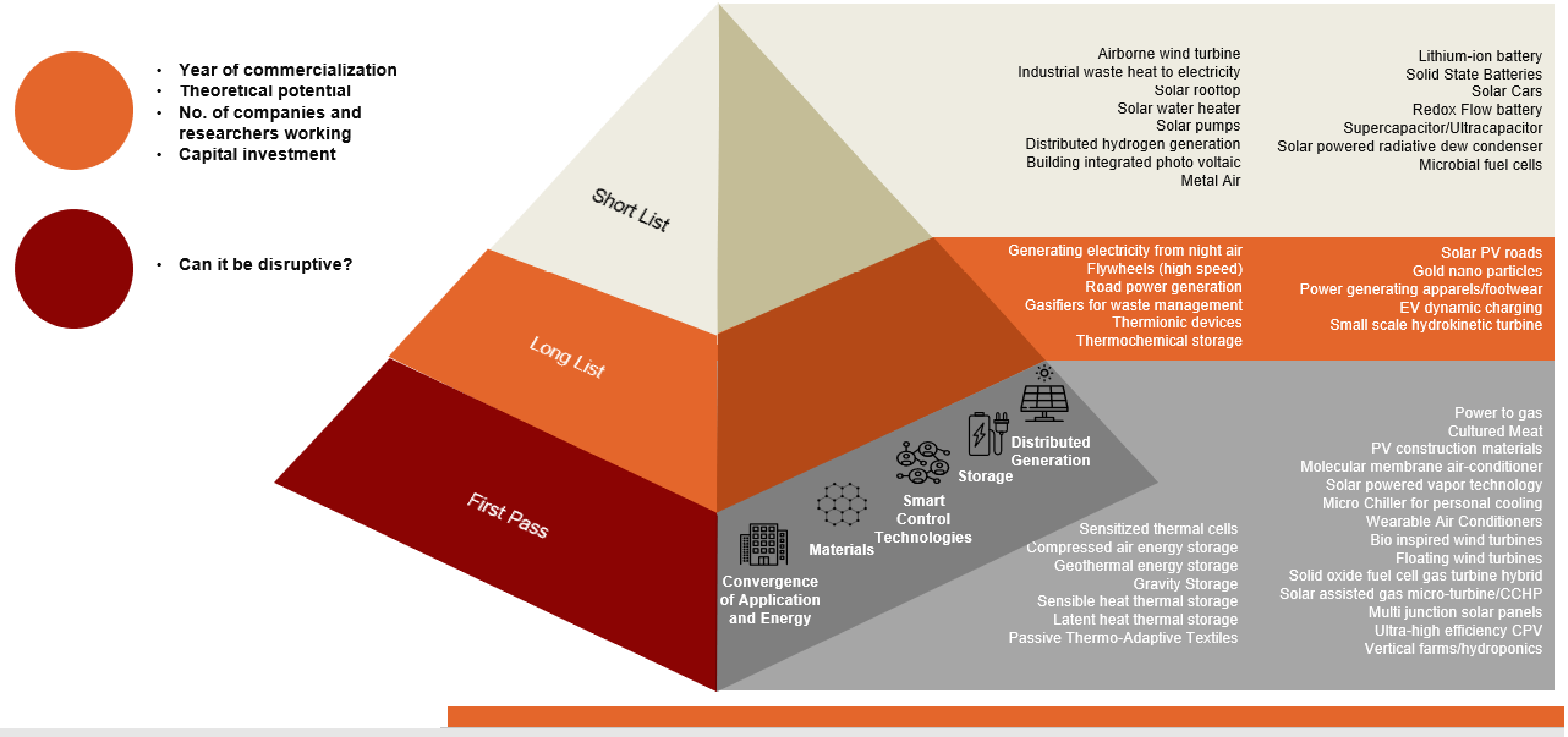
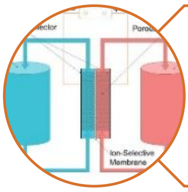


Figure 5. Distributed Energy Systems with deep potential and relevance for India

Distributed storage

By 2050 all personal vehicle will be powered by batteries. Initially Lithium-Ion batteries (TRL-9, CRI-2) would be dominant. By 2035-40 solid state batteries (TRL-4, CRI-1) could become the mainstay. These electric personal vehicles can support upto 4,021 billion passenger kms by 2050



Vanadium redox flow batteries (TRL-8, CRI-2) would find use in stationary charging applications: in telecom towers and EV charging station. Due to longer life of 20+ years, they can support 12% (3.4 million) telecom BTS by 2050

Intracity-public-buses equipped with supercapacitors (TRL-8, CRI-1) can recharge at every bus stop. Super capacitor run for 10+ years without needing replacement. With commercialization in late 2030s, it can support 4.2% of shared mobility energy demand by 2050

Distributed generation

Airborne wind energy systems (TRL-6, CRI-1) leverages consistent and higher-speed winds at altitudes of 500m+. These systems have a capacity utilization factor of 65%+. As the technology matures in the coming decade, it can be expected to replace older captive wind plants (that were set up in the 1990s), and also provide power to industrial townships in wind-swept areas. It is expected that they can meet upto 147 TWh of demand annualy by 2050

With declination in investment costs and increment in efficiencies, systems like Organic Rankine Cycle (TRL-9, CRI-2) or Thermo electric generators (TRL-8, CRI-1) can allow industries to have high penetration of waste heat recovery systems to generate electricity from low-grade heat as well. It is estimated that upto 60 TWh of electricity can be generated from low-grade waste heat recovery annually by 2050

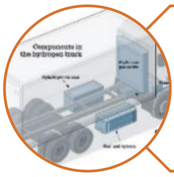
Convergence of application and energy generation

263 GW of roof top solar (TRL-9, CRI-2) capacity can be deployed in residential, commercial and industrial buildings to meet 40% of the building electricity demand. It can meet up to 632 TWh of demand annualy by 2050

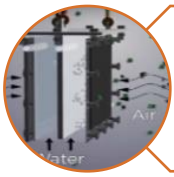
Solar water heaters (TRL-9, CRI-3) can meet 50% of hot water demand in residential and commercial buildings. This translates to upto 49 TWh of demand annualy by 2050

Solar pumps (TRL-9, CRI-2) could power 22% of India's agriculture pumping demand and can have an installed capacity of 120 GW. By 2050, 53 million pumps can be set-up

The building stock is expected to grow by five times in 2050 from current capacity. With a likely shift towards verticalization (driven by scarcity of land), mid- and high-rise buildings can have building integrated photo voltaics - BIPV (TRL-9, CRI-2). That can meet 2% of building electricity demand. Some designs can also serve as a building envelope and reduce cooling demand. Overall, BIPV can meet upto 61 TWh of demand annualy by 2050

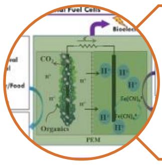


Long haul road-freight consumes nearly 50% of the transportation sector demand. Hydrogen powered Heavy Commercial Vehicles can play a key role in decarbonization. Green hydrogen can be produced on-site at fuelling stations (i.e. distributed) using electrolysers (TRL-9, CRI-2). This hydrogen can be used to power hydrogen-fuel cell vehicles (TRL-6, CRI-1). These vehicles can be introduced in early 2030s and are estimated to move 20% freight by 2050



Recent advancements in Aluminium air batteries (TRL-6, CRI-1) allow for it to be used as a fuel in vehicles. It offers comparative advantage to India in terms of raw material being available in abundance in the country. With an energy density that is 2.5x of diesel, cars can travel up to 1600 km on a single charge. It is likely, that Aluminium-air will start as range extenders for electric vehicles (EVs) to augment lithium ion batteries

Water and waste-water



Microbial fuel cells (TRL-5, CRI-1) can convert waste-treatment-plants from being energy-consumption centres to energy-generation centres in municipalities. Not only would they treat the water, but they woud also generate electricity for the waste-water treatment, as well as some surplus. With commercialization in 2030s, it can support 105 billion LPD of wastewater treatment by 2050

Distributed production of clean drinking water for on-site consumption can be done by harvesting moisture from the air using a radiative dew condenser system (TRL-6, CRI-1) powered by solar energy. Such systems can be extensively used in areas which do not have access to clean drinking water. With commercialization in early 2020s, it can provide 16 Bn litres of clean drinking water annually by 2050

Forging the pathway for maximized uptake

While the snapshot of technologies above indicates the theoretical potential of a system for the illustrated deployment scenario, a TIMES climate model assessment (encompassing 2 alternate approaches – a national carbon budget allocation vs. a global carbon pricing mechanism) for maintaining a 1.5^0 outcome helped gauge the likely uptake of these systems after considering their price competitiveness against competing centralized systems (fossil and non-fossil based). A snapshot of the same as manifested in the future energy demand-supply mix for 2050 is provided overleaf.

The same primarily highlight:

- The carbon budget scenario is more supportive of decoupling of energy and growth. The energy intensity in 2050 for carbon budget scenario is 15% lower than carbon pricing scenario. Also, the per capita energy consumption in 2050 is expected to be 8,406 kWh/capita for carbon budget vs. 9,868 kWh/capita for carbon pricing scenarios. Even with these higher values, it would still be less than the current energy consumption/capita in US and Europe.
- The carbon budget approach helps frame greater demand side efficiencies - for example, in industries, due to limited latitude under the carbon budget approach, the Industrial sector is expected to see a higher transition towards electrification as well as greater deployment of more efficient machinery. For the transport sector, to curtail emissions, the shift towards higher shared mobility adoption in the passenger transport sector is likely to be expedited.
- Higher electrification of energy end-uses: In the carbon budget scenario, 50% of the demand can be supported through electrification while only 42% can be supported under carbon pricing scenario. This paves the way for higher energy security to the country due to less dependence on fossil fuels.

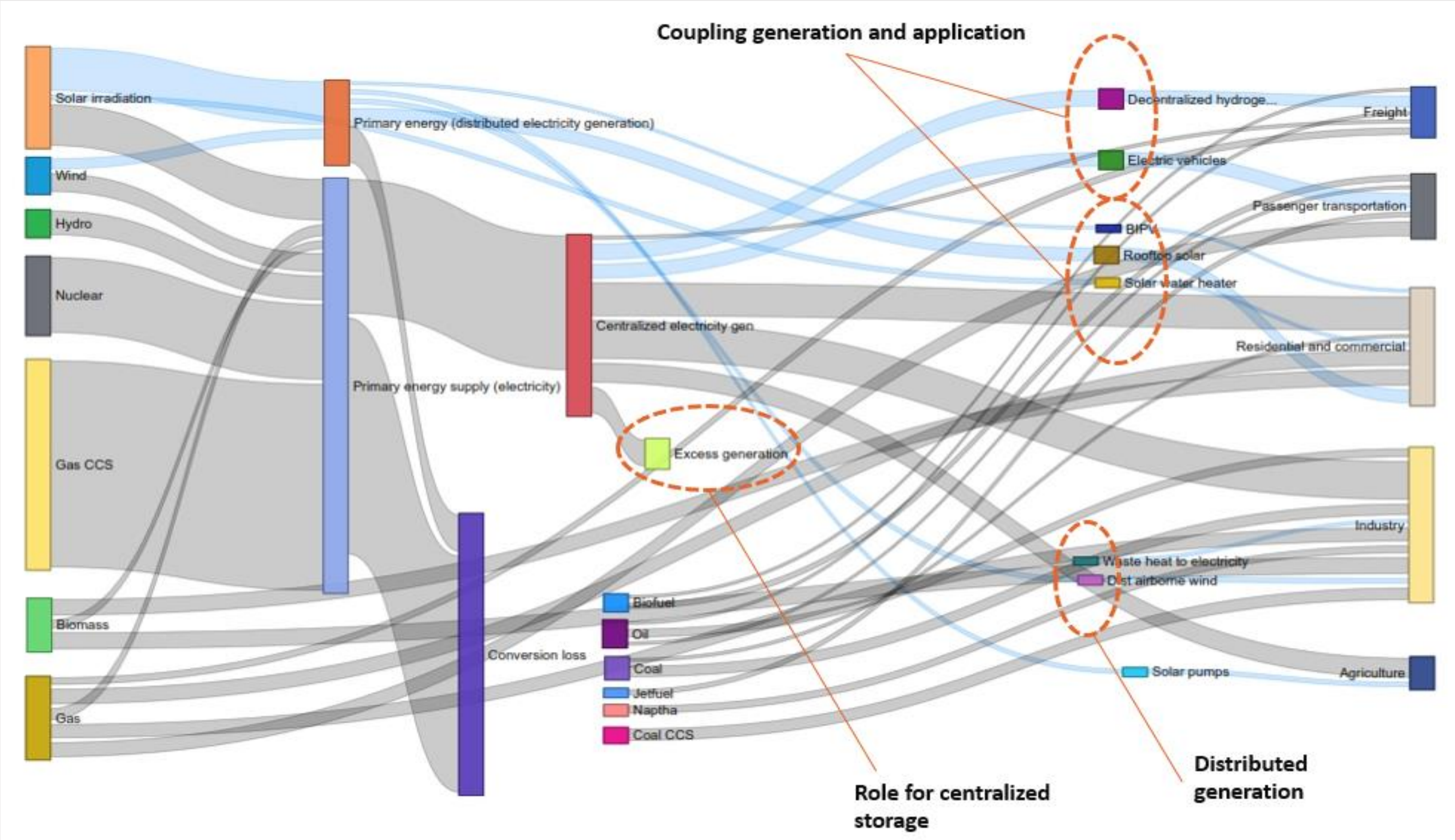


Figure 6. Future energy mix in 2050 – carbon budget approach

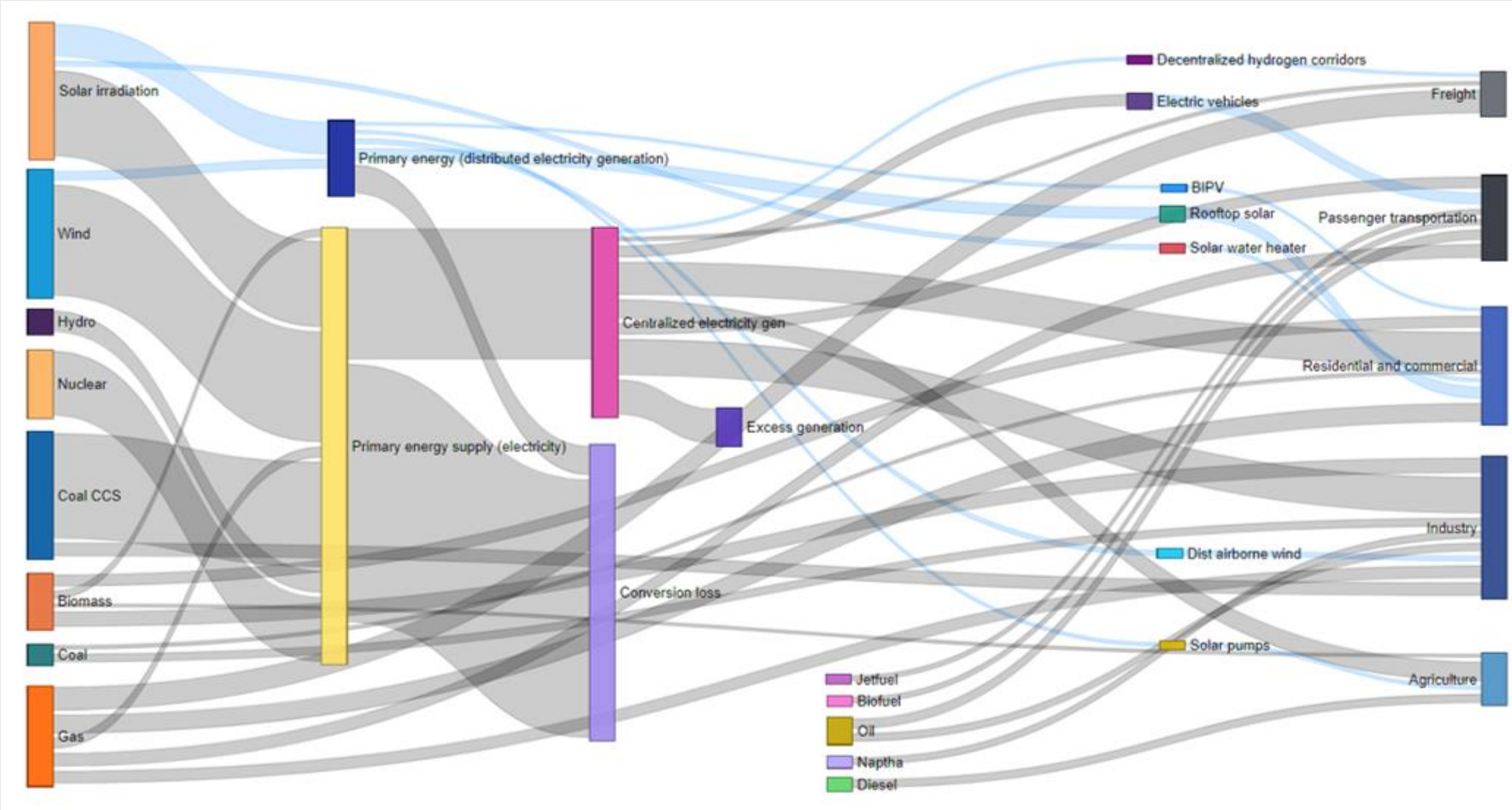


Figure 7. Future energy mix in 2050 – carbon price approach

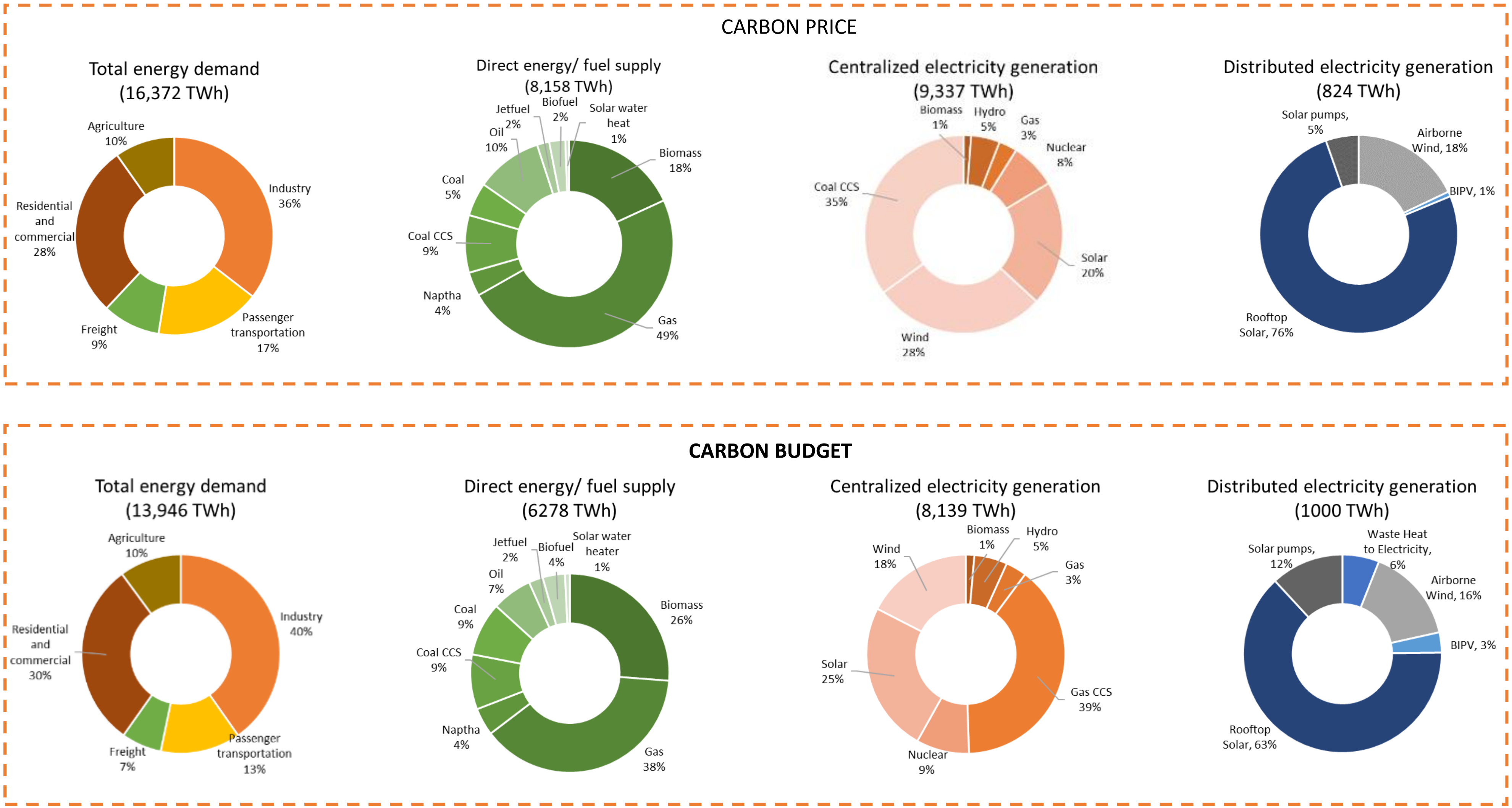


Figure 8. Future demand-supply energy mix in 2050

Illustrative use-cases

Based on the time of the day demand in different energy sectors like commercial, residential, industrial buildings, several illustrative use cases for these technologies are apparent in the Indian context. Figure below illustrates a few contextual settings for the deployment of these technologies and respective potential therein for the recommended generation and storage systems.

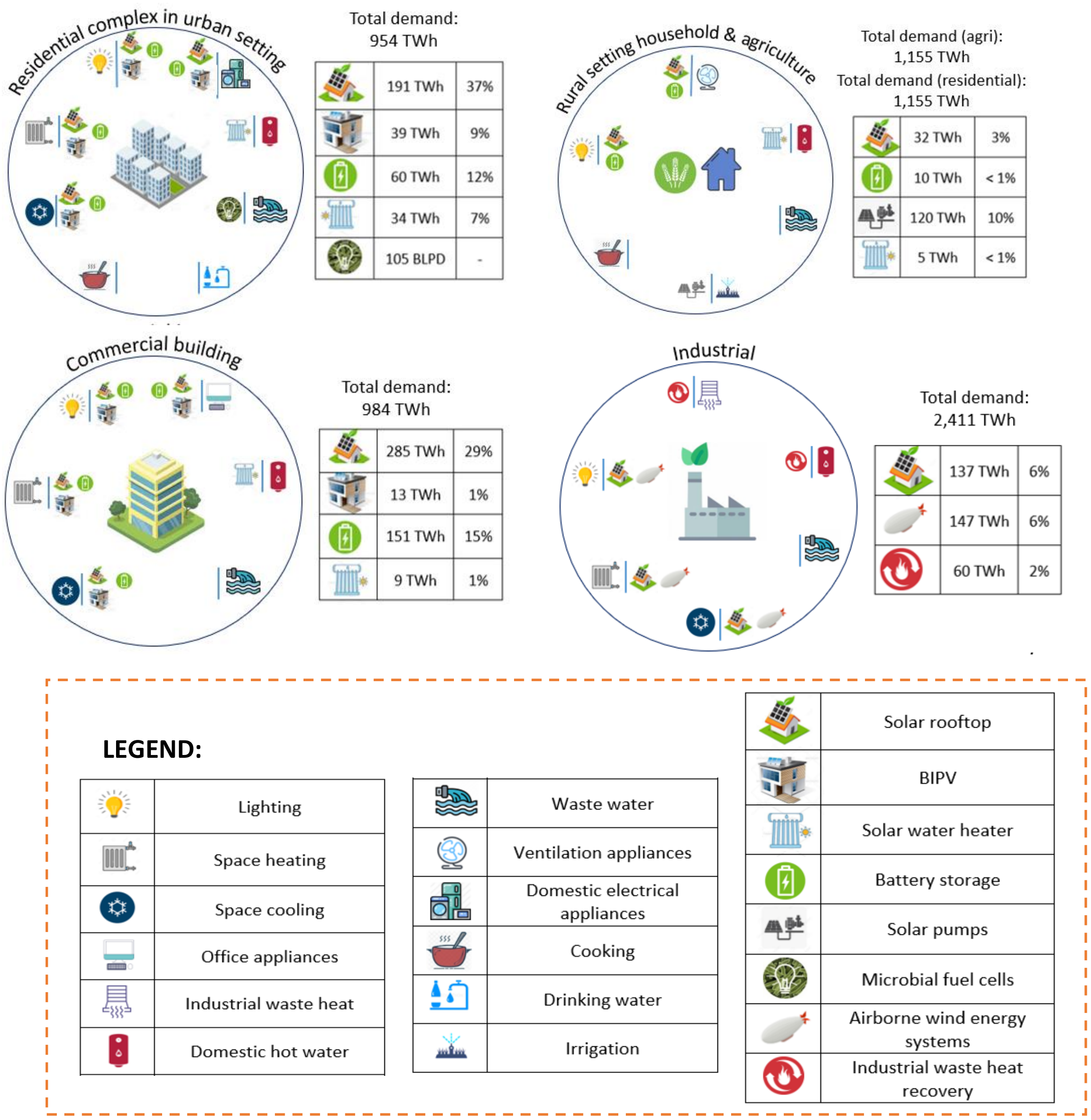


Figure 9. Opportunity for distributed storage

Net benefits allowing for further maximizing distributed energy systems

Along with decarbonization potential of these systems, there are other direct and indirect benefits associated with them, as well as some trade-offs. When considering deployment of these DES, it is worthwhile to assess implications other than direct impact on environment. This dimension further reinforces the uptake of these systems considering the other benefits like energy security, improved health, grid impact and others.

A comprehensive mapping of these benefits for each DES as also any foreseen adverse impacts is represented in the infographic overleaf.

Category	DES Systems	Health benefit	Energy security	Grid impact	Land needs	Lifecycle impact	Water systems	Sector devlpmt	User benefit	Description of co-benefit and trade-off			
Convergence of application and energy generation	Solar rooftop for residential, commercial and industrial buildings									Lower transmission infra cost for utilities. (Avoids capacity of 100 GW of transmission infra)	Does not need land. Rooftop space is estimated to be 2,600 sq. km	Responsible disposal will be required for about 11 million tons of materials that go into the panels	Reductions in energy costs for building operators (1,300 billion INR costs advantage)
	Solar water heaters for personal hot water needs									Avoided electricity/ fuel use (49 TWh)			
	Solar pumps in agriculture									Reduce reliance on oil (diesel) imports (Agri-pumps use 2.4 billion litres of diesel)	Reduced discom losses since they do not have to provide subsidized power (53 billion INR/year)	Irrigation during day light would lead to 10-20% reduction in water use due to better visibility Lack of control may lead to over pumping and deplete scarce water aquifers	Economic benefits to the farmers (579 billion INR in savings)
	Building Integrated Photovoltaics (BIPV) for mid and high rises									Avoided electricity/ fuel use (61 TWh)	Generate power without any land needs (260 sq. km of land equivalent)	Reductions in energy costs for building operators (37 billion INR costs advantage)	
	Distributed hydrogen generation for freight vehicles									Health benefit due to reduced particulates generated by heavy diesel engines (74% of particulates)	Development of a new industry sector (2,100 billion INR for HCVs and 600 billion INR for ~49 GW of Electrolyser)	Easier/ faster to create a distributed infrastructure	Handling hydrogen: Safety issues will require buffer areas
	Aluminium-air batteries as a new fuel for transportation									India has large aluminum reserves; as also a mature industry	Cost to pursuing a policy that is not used elsewhere	Opportunity to create a battery-industry building on indigenous capability	Al-air batteries have a higher range (up to 1500 km) compared to other batteries
Distributed generation	Airborne Wind Energy Systems for captive power and industrial									4-6 times better utilization of land in wind-swept regions	New industry that taps winds at higher altitudes. Potential in India yet to be assessed.		

Category	DES Systems	Health benefit	Energy security	Grid impact	Land needs	Lifecycle impact	Water systems	Sector devlpmt	User benefit	Description of co-benefit and trade-off			
	Low grade industrial waste heat to electricity		✓						✓	Reduced resource demand for the economy	Fuller energy use, i.e. saving in industry (150 billion INR)		
Distributed storage	High energy density Li-ion batteries enabling electric vehicles	✓	✓			✓				Reduced city pollution (Pollution caused by vehicles and redux possible)	Reduction in oil imports/ dependency (Till 2030 India will spend USD 550 b on oil imports)	Safe disposal of LI and SSLI batteries (Recycling 330,000 tons of battery requiring an investment of 100 billion INR)	
	Redox flow batteries for stationary storage application		✓			✓			✓	The lack of availability of vanadium	Infinite life of the vanadium oxide, once imported. Can be reused: long battery life, reduced waste		
	Supercapacitors for electrification of intra-city bus systems	✓		✓		✓			✓	Non-polluting public transport in cities	Uses electricity in the day during solar producing hours. Levelling demand helping make grid more flexible, therefore less investment in generation capacity	Unlike batteries, does not contain harmful chemicals like compounds of lead, lithium, cobalt etc.	Redesign of bus stops and of electricity distribution systems
Societal benefit: Water and waste water	Microbial fuel cells for water treatment centres						✓	✓		Bio-remediation of compounds in waste water streams (105 billion LPD toxic water avoided going into the streams)	India is setting up its waste-water treatment infrastructure. Opportunity to build a new industry	Investments needed in developing this when tech such as anaerobic digesters (which generate gas) exist	Profitability for waste treatment plants (attract private capital to sector)
	Solar powered radiative dew condenser providing on-site clean drinking water						✓	✓	✓	Clean drinking water generated on-site (45 million LPD that does not have to be extracted or transported)	Generates local employment (materials locally sourced and role for water-enterprises)	Especially useful in remote areas with no access to clean water (15 million people)	Risk of water contamination

Policy interventions enabling the uptake

It is clear that policy needs to lead the way for enabling the decarbonization potential that these technologies offer. From amongst the key ones, currently solar rooftop and solar pumping have an evolved policy framework. These need enhancement and state level intensification, particularly for Solar Rooftops, wherein the business frameworks are still not optimized across the ecosystem actors. In case of Lithium ion batteries for EVs, the policies have started emerging however there requires to be a significant thrust and prioritization towards R&D in enabling the move towards solid state batteries as also market framework development to enable V2G mechanisms to flourish.
As for freight, commercial vehicles and captive wind power plants for industries, these are newer technologies and don't figure in the current plans and /or policy mechanisms. Focused policy engagement is needed to enable these to evolve comprehensively over the next decade.

Some specific policy interventions include[2]:

1. Policy certainty, consistency (across states) and comprehensive market mechanisms on power injected back into the grid from distributed sources is key to enabling scale
    - Policy frameworks to be intensified to reiterate the coupling of demand and supply leveraging DES
        - Provisions for maximization of onsite generation to be mandatory, e.g. under National Building Code for solar rooftop, solar water heater and BIPV
        - DES definition to include Waste heat to electricity as source that can feed into the grid
        - Bi-directional (such as V2G) charging standards should be developed
        - B2G, V2G, Virtual Power Plants and P2P guidelines to support exchange and trading of energy with grid and/or other consumers in the same discom area; enabled by block-chain based micro-energy trading models
    - Market mechanism enhancements leveraging smart systems and tariff innovations
        - Guidelines from FoR/ CERC detailing principles for net billing mechanisms to ensure DISCOM support.
        - Framing discom owned rooftop implementation schemes for low cost housing and peri-urban/rural areas
        - Formulating compensation tariff structures that primarily are built around opt-out default tariff rather than an opt-in tariff (allowing consumers to be in control if their vehicles are used or not)

2. Investment in development and uptake of 'On the Horizon' technologies
    - Initiatives in R&D ecosystem/ technology transfer
        - Developing standard wind pattern models for high altitude
        - Initiating focused R&D efforts or strategic technology partnerships for developing:
        - Indigenous AWES
        - Domestic production of electrolyzers to support hydrogen based heavy freight vehicles (target price of $150 /kW or less)
        - Metal-air battery design
        - Explore collaboration for research and manufacturing capability of solid-state batteries

[2] Deployment-case linked policy enablers are provided in cKinetics report "Envisioning India's transition towards distributed energy systems using combinations of renewables, storage and smart control technologies"

- Enabling market readiness
  - Standard product design/ modularization will make it easier to scale the adoption of low-grade waste heat recovery. This is especially true of TEG, a modular system.
  - Integration of supercapacitors installed buses and bus stops with charging capabilities under Smart Cities Mission
  - A segment specific carbon pricing mechanism (similar to the approach in California) to catalyze the uptake of distributed hydrogen

3. DES prioritization based on coupling of sustainability dimensions with energy security considerations
   - Intensification of codes and regulations
     - E-waste policy to be enhanced for recycling of solar panels (after end of their service life) and battery systems for EVs
     - Mandating PSUs to craft global JVs to access key raw materials
     - Formalization of a code for certification and testing of materials used for BIPV would be required
   - Infrastructure ecosystem
     - Fostering better ground water management practices thus avoiding depletion of aquifers due to excessive use of solar pumps
     - Development and enforcement of safety standards to mitigate risks associated with handling and storage of hydrogen

The suggested policy interventions are based on maximizing the uptake of existing technologies like solar rooftop and solar pumps as also ensuring upcoming technologies with significant opportunity specific to India can be prioritized in the country's low carbon planning in the days ahead.

These policy actions are also deemed necessary for framing country's energy security in terms of access to core raw materials needed for a certain key technology, market mechanisms that can help deliver on the potential and R&D efforts to ensure requisite indigenization amongst others.

Conclusion

India needs to adopt a multi-pronged strategy for framing the appropriate mix of conventional and radical distributed renewable energy resources along with a focus on energy efficiency to reduce energy demand and enhance domestic supply in order to achieve its overall developmental ambitions in the energy space. In this context, the penetration of business-as-usual DES, currently projected to meet 5% of the demand in 2050 per IESS, can be increased by around 2-3x thus bringing the potential to meet up to 10-15 per cent of the demand.

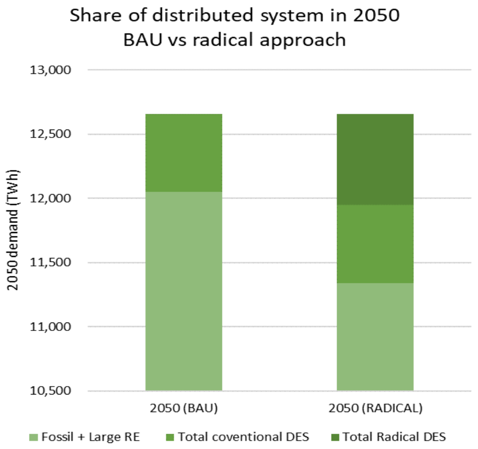


Figure 10: Radical potential of identified DES to meet the supply in 2050[3]

Core to enabling this, particularly with a view to reduce imports and create energy accessibility, are the following:

1. Meeting energy security targets: Two technologies that can play a role in meeting India's energy security targets include airborne wind turbines wherein it would be possible for India to gain a technological edge and aluminum-air batteries, for which the raw material is abundantly available in India as compared to Lithium-ion batteries.
2. Heavy fossil fuels like gas/coal would continue to be part of the energy mix in 2050. Carbon Capture and Sequestration (CCS) technologies would be coupled with these deployments. A robust transport and disposition infrastructure would be needed by 2050 to dispose 3,000 to 4,000 mT CO_2.
3. Focused programs and policies from the aspect of net-benefits would support technologies which are not able to see a natural uptake. An overview of benefits that are likely to be realized with the appropriate scale of deployment of these technologies is indicated below.

Benefit	Quantum of the benefit
Carbon mitigation	1,065 mt of CO_2 mitigated per year
Resource Savings	Around 1,100,000 hectares of land use avoided Reduce reliance on oil (diesel) imports (Agri-pumps use 2.4 billion litres of diesel)
Jobs	Incremental 3 million jobs potential over the entire value chain
End user benefits	Reductions in energy costs for building operators (~ INR 1,300 billion) Industry – WHR (~ INR 150 billion) Economic benefits to the farmers (INR 579 billion) Health benefit due to 74% reduced particulates generated by heavy diesel engines
Utilities	Infrastructure level: Avoided capacity for 100 GW of transmission infra) Reduced discom losses (INR 53 billion INR/year)

[3] BAU refers to IESS Heroic scenario

ANNEXURE-1: LIST OF TECHNOLOGIES REVIEWED

Category	Distributed energy technologies
Convergence of application and generation	Gasifiers for waste management (creating energy from trash)
	Gold nano particles: solar energy to water
	Road power generation/Solar PV roads
	Power generating apparels/footwear
	Production of proteins via fermentation of engineered microbes
	Vertical Farms/Hydroponics/Micro farms
	Solar powered non-compressor vapor technology
	Solar acoustic refrigeration System
	Molecular membrane dehumidifier/air-conditioner
	Production of steel from molten oxide electrolysis
	Super strong, Low-Cost Wood for Lightweight Vehicles
	Using recycled CO2 to improve the manufacturing process
	Synthetic Methylotrophy to Liquid Fuel (Methanol to liquid fuel), CCS
	PV construction materials (concrete)
Distributed generation	Micro hydrokinetic turbine
	Generating electricity from night air
	Directly converting heat to electricity using thermionic devices
	EV dynamic charging
	Multi junction solar panels
	Near shore tidal energy harvesting
	Bio inspired wind turbines
	De-coupled solid oxide fuel cell gas turbine hybrid (dFC-GT)
	Solar assisted gas micro-turbine (bio solar CCHP)
	Micro-scale Ultra-high Efficiency CPV/Diffuse Hybrid Arrays Using Transfer Printing
	Power to gas/liquid
	Active Aerodynamic Load Control for Wind Turbines
	50 MW Segmented Ultralight Morphing Rotors for Wind Energy
	Floating wind turbines
Distributed storage	Thermochemical/Electrothermal energy storage system
	Flywheels (high speed)
	Gravity Storage/gravtricity
	Compressed air energy storage
	Geo mechanical pumped storage
	Geothermal energy storage via horizontal drilling
	Adaptive SOFC for Ultra High Efficiency Systems
	Sentisized thermal cells (STC's)
	Sensible heat thermal storage
	Latent heat thermal storage (PCM's)
	Superconducting magnetic energy storage (SMES)
	Scalable Thermochemical Option for Renewable Energy Storage (STORES)
	Wearable Air Conditioners/ Micro Chiller for personal cooling

ANNEXURE-2: GLOBAL EXPERTS CONSULTED

Expert	Organization
Dr. Ammi Amarnath	EPRI
Dr. Dolf Gielen	IRENA
Dr. Cecilia Tam	OECD
Mr. David Palchak	NREL
Dr. George Crabtree	Joint Center for Energy Storage Research (JCESR)
Ms. Randi Kristiansen	IEA
Ms. Zoe Hungerford	IEA
Mr. Tarun Khanna	IEA
Mr. Enrique Gutierrez	IEA
Dr. Damodaran M. Vasudevan	IIM Bangalore
Dr. Andrew Martin	KTH Royal Institute of Technology
Dr. Wolfgang Eichhammer	Fraunhofer
Dr. Praveen Kumar	IIT Guwahati
Dr. K. P. Rajeev	IIT, Kanpur
Dr. Abdus Samad	IIT, Madras
Mr. Pierluigi Bonomo	SUPSI
Dr. Mahadeva Srinivasan	Ex-BARC
Dr. Purnima Jalihal	NIOT
Dr. Akshay Singhal	Log9 Materials
Dr. Mike Giulianini	Redflow batteries
Mr. Marcus Fendt	The mobility house
Mr. Charlie Blair	Gravitricity
Dr. Vishal Mittal	Delectrik
Dr. Jason Holt	Baruch Ventures
Dr. Roland Schmehl	Delft University; Kite Power research group
Mr. Thomas Hårklau	Kitemill
Mr. Rod Read	Windswept and interesting limited
Mr. Alexandre Viviers	Sia Partners

ANNEXURE-3: METHODOLOGY

Methodology for shortlisting technologies:

Step 1: Screening for capacity to be disruptive, while being distributed

Based on the initial list, technologies were shortlisted for long list based on their distributed and disruptive nature. The criteria applied towards the technologies as first screening filter are as follows:

Distributed	Disruptive
•The dynamics (area, type, utilized for other resources, specially designated to the technology etc.) of land utilized towards implementation of the technology. •The extent of physical area of an application where the technology can be utilized. •Proximity of generation/storage and utilization. •Storage technologies which are used towards localized balancing.	•**Deployment:** If the technology innovation (for a core technology that can typically only be centrally deployed) enables it to be now deployed in a distributed mode. •**Yield enhancement:** If there is a significant enhancement in the yield – say 3x the normal enhancement - by virtue of advanced performance characteristics. •**Extraordinary ability to unlock latent potential:** If a technology can enable/unlock an untapped potential at scale.

Any of the technologies qualifying against these criteria were considered for further analysis.

Step 2: Applying Technology Readiness Level and Commercial Readiness Index4 + framing deployment scenarios to assess likelihood of commercialization before 2050

The Technology Readiness Level (TRL) is a methodology for gauging the maturity of the technology. The TRL levels varies from a scale of 1 to 9; 1 being the basic research level and 9 being the operational level readiness of the technology.

The Commercial Readiness Index (CRI) is a framework developed by the Australian Renewable Energy Agency (ARENA) to complement the TRL methodology and further define the commercial maturity of the technology. Following table indicates TRL description for technologies.

TRL	Description
1	**Technology research**: Basic principles observed and reported
2	**Technology concept**: Concept and/or application formulated
3	**Proof of concept**: Concept proven for a specific application
4	**Technology demonstration**: Technology characteristics demonstration in a laboratory environment
5	**Conceptual design and prototype demonstration**: Demonstration of technology in an operational/deployment setting
6	**Preliminary design and prototype validation of the technology**: Validation of the technology performance against set parameters in an operational/deployment setting
7	**Detailed design and assembly level build**: Detailed design finalized based on validation results along-with component assembly with production capability
8	**System build and test**: Assembly and integration of the technology (product) with sub-components and operational in the deployment setting
9	**System Operational**: Functionality and operations of the technology well established and proven at a small commercial scale for a specific duration
10	**Well proven operations:** Technology has proven in commercial scale settings

[4] Arena 2014 & Straub 2015

CRI	Description
1	Technically and commercially untested and unproven.
2	Commercial trials of the technology on a small scale
3	Commercial scale-up of the technologies
4	Multiple commercial application of the technology
5	Market competition/market acceptance driven by widespread of the technology
6	Readily financial support of the technology by banks

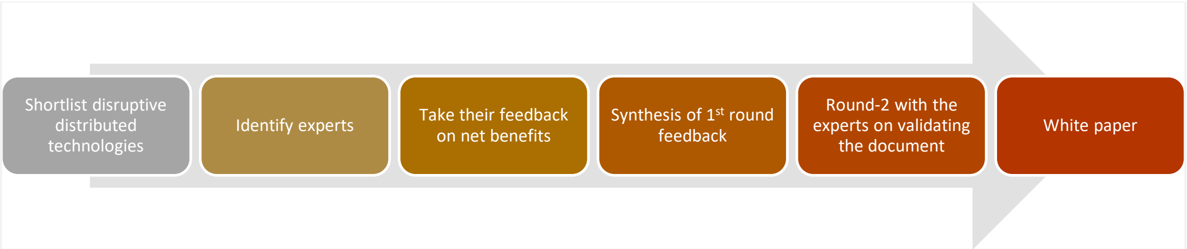
Mapping year of commercialization in India for technologies

The TRL and CRI were arrived at based on expert interviews and the research carried out. The TRL for a technology was considered as global standing while CRI was considered in Indian context. The idea behind this approach was the fact that once a technology has moved up the ladder from TRL 1 to 8, it can be bought outright and be introduced in the Indian market. It would rather be interesting for a technology which is at same TRL both at Indian and global level. Over there one can assume that India can not only have a leading R&D edge but also be exporter of the technology.

Methodology for demand Projections:

- Two primary databases were used – State wise aggregate 8760 demand and state wise sectoral aggregate demand for 2015.
- Using the time of the day (TOD) demand for different sectors and the type of state (industrialized, agriculture – based, urbanized), ratio of load was allocated for every sector to come up with sectoral level 8760 demand numbers for 2015 at a national level.
- The states were then divided into five (5) different geo climatic (GC) zones by referring to the India's climate zone map by National Buildings Code.
- For more than 2 GCs in a state, the demand was divided on the basis of:
    - Population mixes of the districts.
    - If it was agriculture-based economy, then district wise agriculture production in the state was considered.
    - If it was industry-based economy, then district wise industries in the state was considered.
- The 2015 national demand was hence forth divided into sectoral demands for every geo climatic zone at an 8760 level.
- For projecting the demand to 2050, growth rates were assigned to every state and then projected out over a period of time, which were also validated to the IESS demand over the years.
- The 8760 numbers were projected on a similar growth rate for every geo climatic zone and corresponding demand curves were generated for the same.

Methodology for assessing net-benefits:



An adapted Delphi method that engaged 5 experts was used to assess net-benefits. Experts shared their inputs, which were categorized into the following areas:

1. **Grid impact**: Reduces transmission infrastructure cost and help avoid discom losses
2. **Energy security**: Allows reduction in reliance on oil imports
3. **Land needs**: Does not need additional land or can achieve better utilization of current land
4. **Water systems**: Better utilization of natural water resources
5. **User benefit**: Economic benefits to the end user
6. **Sector development**: Development of new industry thus strengthening national economy and job aspects
7. **Health benefits**: Leading to reduction in city pollution

Experts engaged

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- Dr Ajay Mathur, The Energy & Resources Institute (TERI)
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- Padu Padmanabhan, International consultant, Energy & Water productivity
- Dr. Steven Fawkes, Energy Pro
- Danny Kennedy, New Energy Nexus