SMART GRID TECHNOLOGY

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EE/EEE

JHARKHAND UNIVERSITY OF TECHNOLOGY (JUT)

UNIT-3: DISTRIBUTION GENERATION TECHNOLOGIES

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1. Introduction

Distributed generation and modern power-systems trends are shifting the paradigm from large, centralised generation toward smaller, localised generation near or at the point of consumption. The term *distributed generation (DG)* refers to generation units located close to load (e.g., rooftop solar, small wind, biomass CHP) that may connect to the distribution network rather than the transmission network.
This has important implications for the structure and operation of the grid: increased local flexibility, two-way flows, the need for storage, microgrids, active consumer participation, and addressing intermittency and variability.

The growth of renewables, plus advances in storage and power-electronics, make DG and microgrid concepts viable. At the same time concerns of climate change, emissions, decarbonisation, and cost/risk of large plants are driving interest in DG.

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2. Introduction to Renewable Energy Technologies

Renewable energy technologies (RET) are central to distribution generation. Some key ones:

- Solar photovoltaic (PV) — rooftop, ground-mounted arrays.
- Wind turbines (small wind / urban wind) near load centres.
- Biomass/biogas combined heat & power (CHP) units at local sites.
- Small hydro, geothermal, fuel cell micro-generation.
  These technologies have the characteristics of being local, sometimes variable (wind/solar), lower capacity than central plants, and often modular.

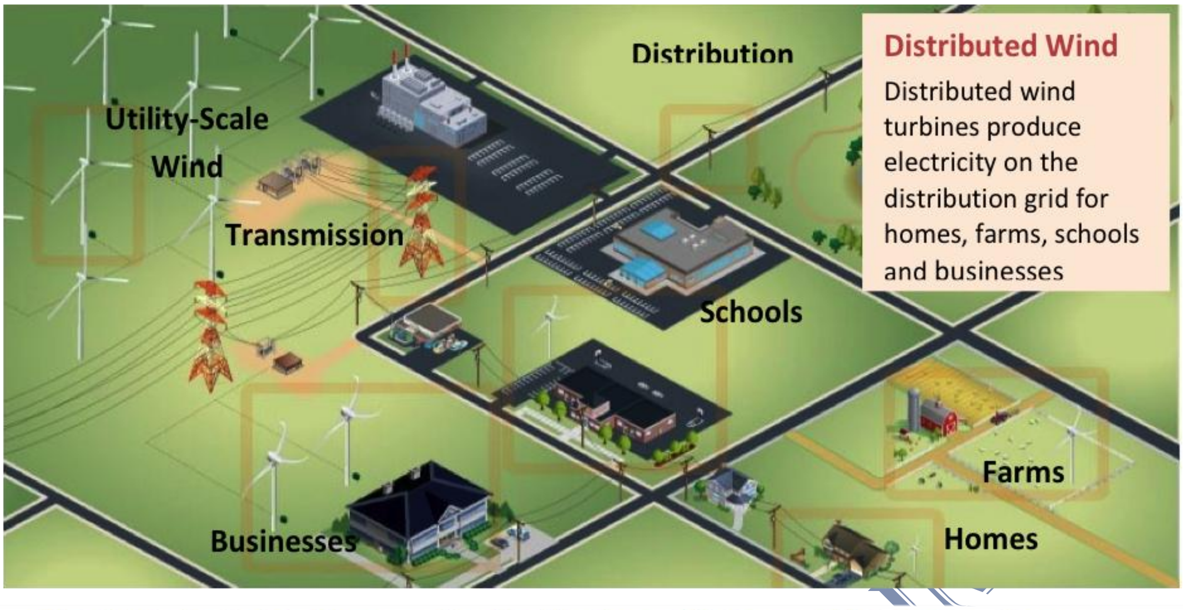
Advantages

- Lower transmission losses (generation near load).
- Reduced carbon emissions.
- Modular deployment; easier to scale incrementally.

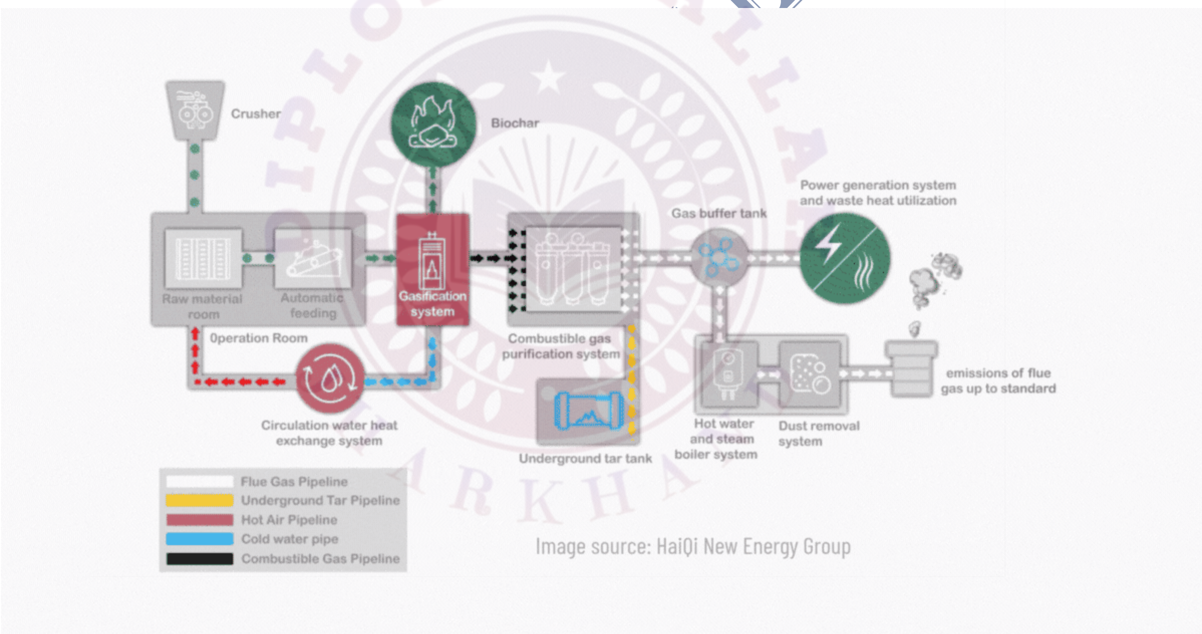
- Can improve resilience and reduce dependency on long lines.

Challenges

- Variability and intermittency (especially solar & wind) → need for storage, forecasting.
- Integration into distribution networks originally designed for one-way flows.
- Grid stability, voltage/frequency control issues when many DG units are connected.
- Cost of small systems, regulatory/market barriers.



Distributed wind turbines on the distribution grid. Source: U.S. Dept. of Energy



3. Microgrids

3.1 Definition & Concept

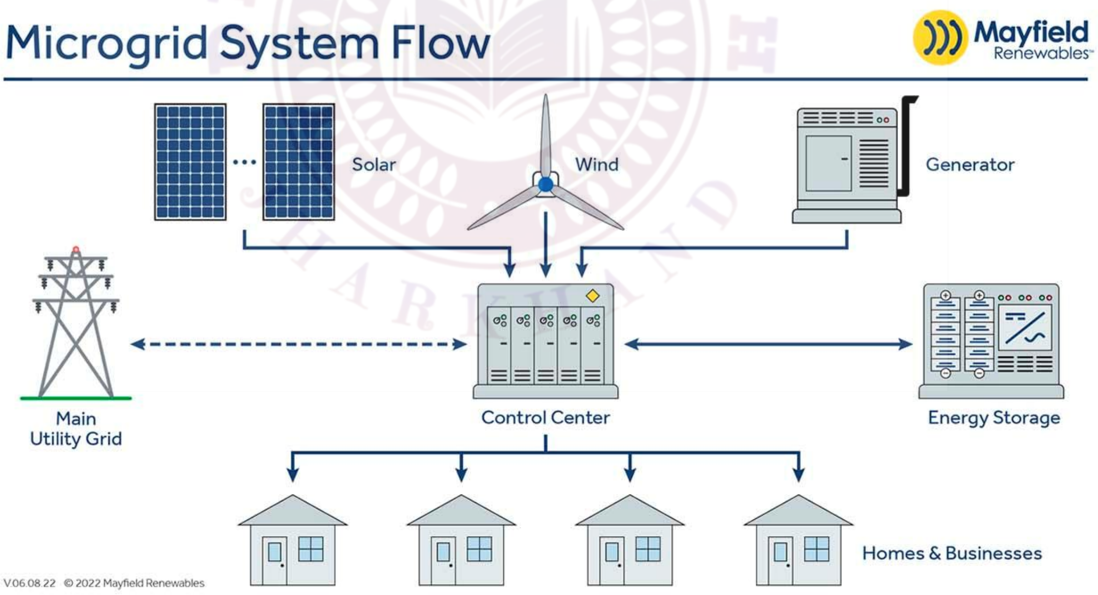
A Microgrid is a localized grid system that can operate connected to the main utility network (grid-connected) or in islanded mode (isolated). It integrates distributed generation, storage, loads, control systems, and can be at the distribution level (e.g., a campus, a neighbourhood, an industrial park).

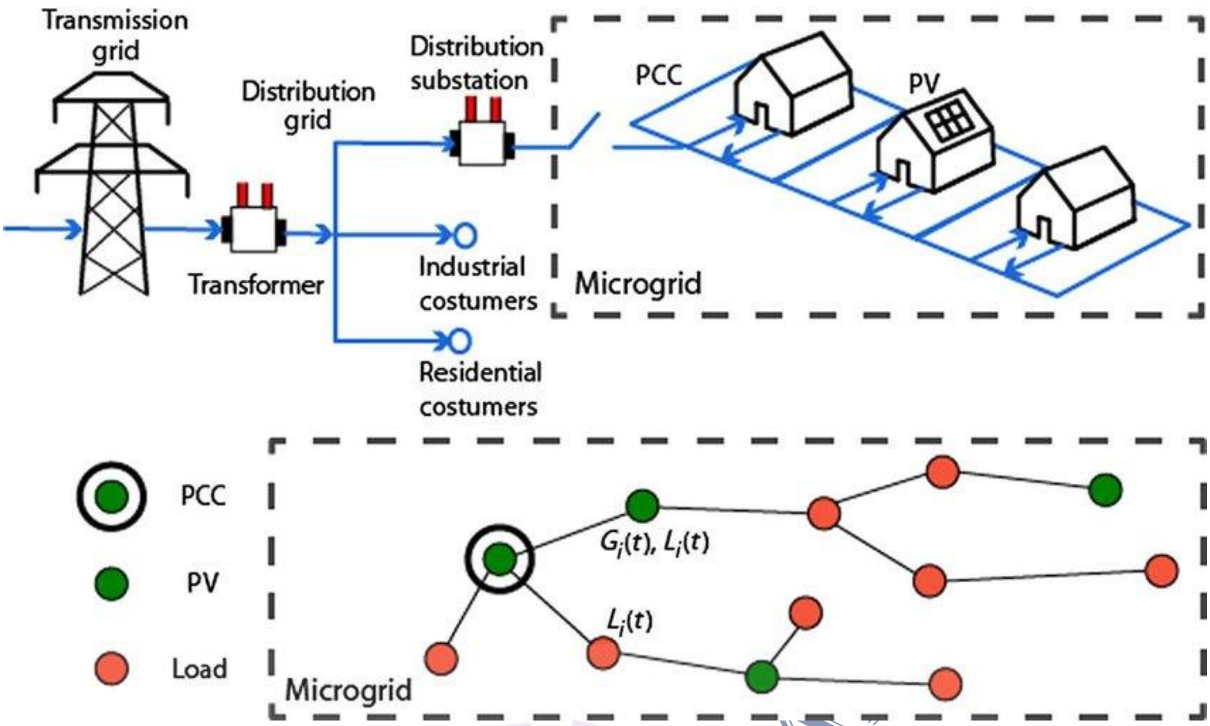
3.2 Features & Benefits

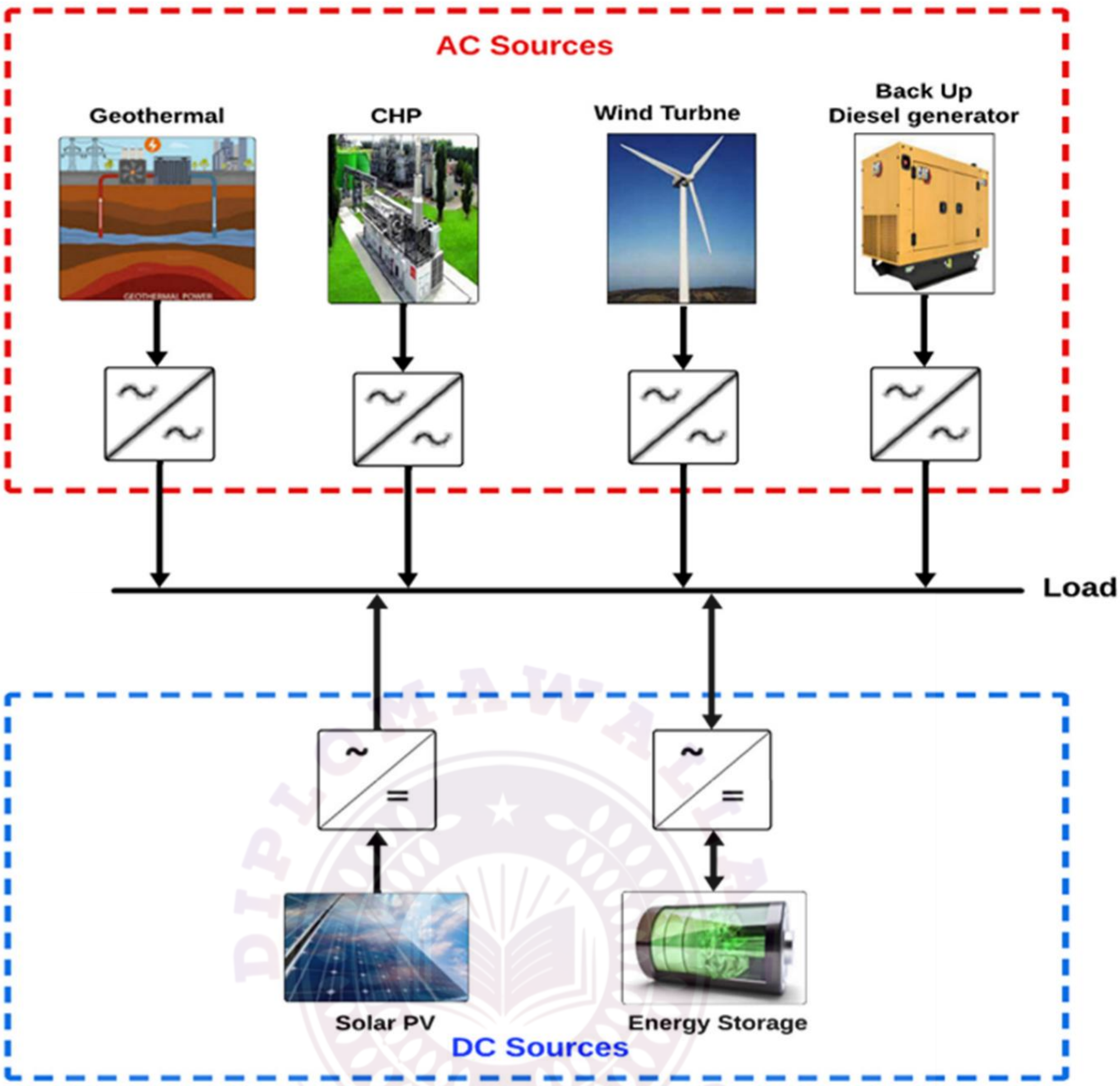
- Localised generation + storage means enhanced reliability/resilience (can operate when main grid fails). (arXiv)
- Flexibility in control: managing local supply/demand, performing load-shedding or prioritising critical loads when islanded.
- Integration of DERs (distributed energy resources) and storage in a coordinated way; better grid support for renewables.
- Potential for peer-to-peer trading, local markets, improved efficiency.

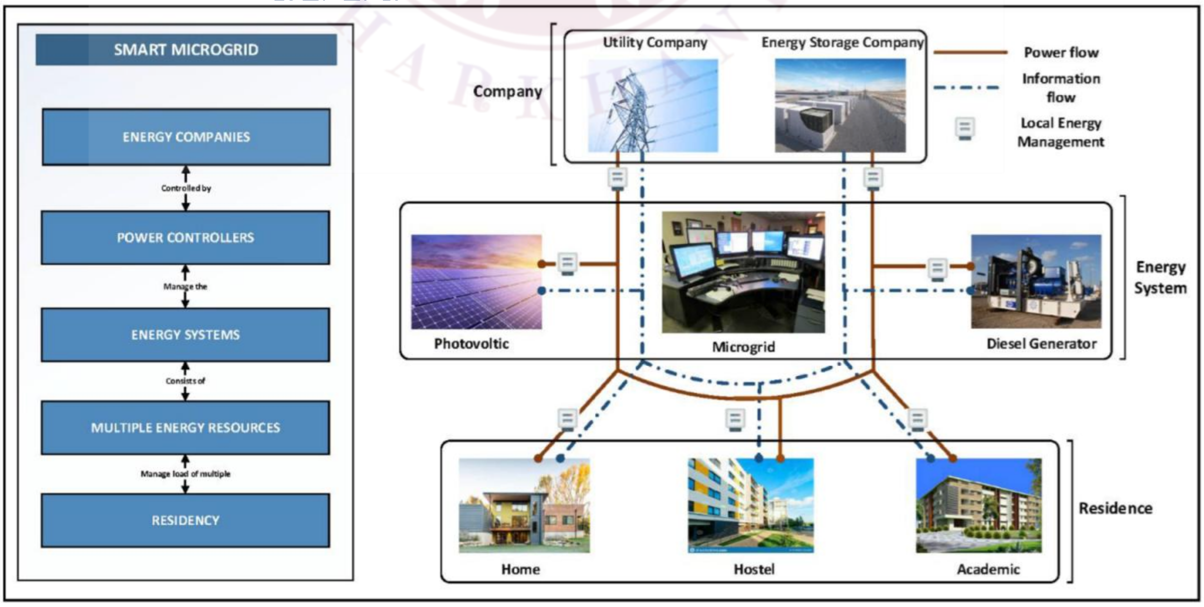
3.3 Key Technical Aspects

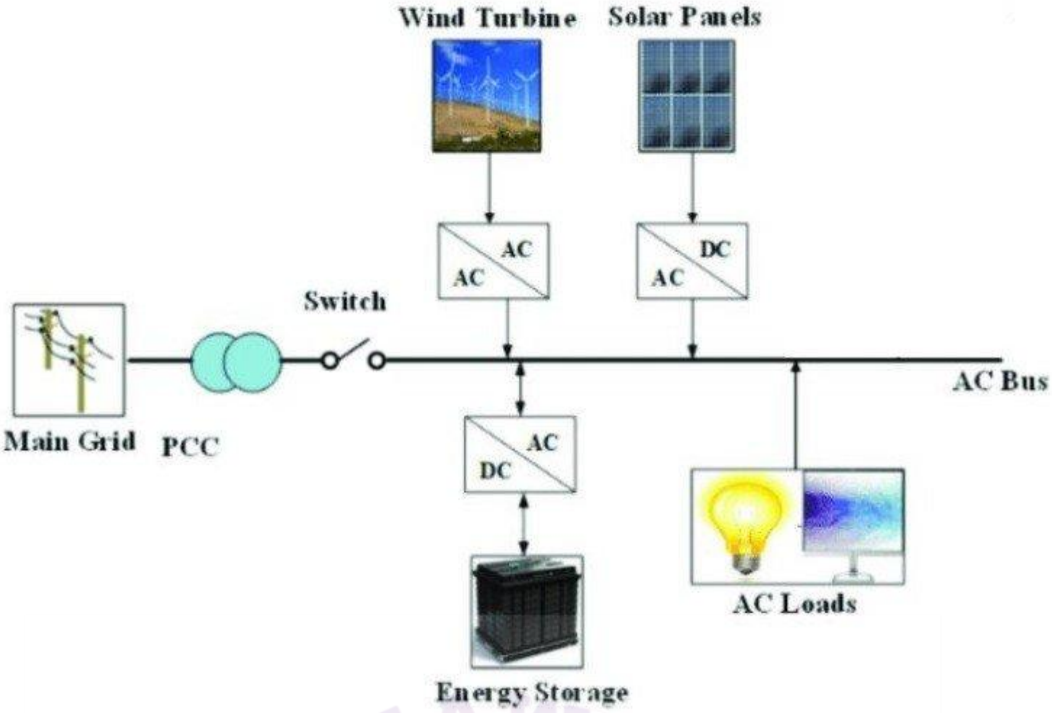
- Control architecture: managing island-grid transition, voltage/frequency control, protection.
- Energy management systems (EMS) for microgrids: coordinating DG, storage, loads. For example, recent work shows microgrids integrating renewables and PHEVs via smart EMS. (Nature)
- Distribution network reconfiguration: microgrids often require network changes and protection schemes adaptable to two-way flows.
- Standards and interoperability: lots of work still needed.

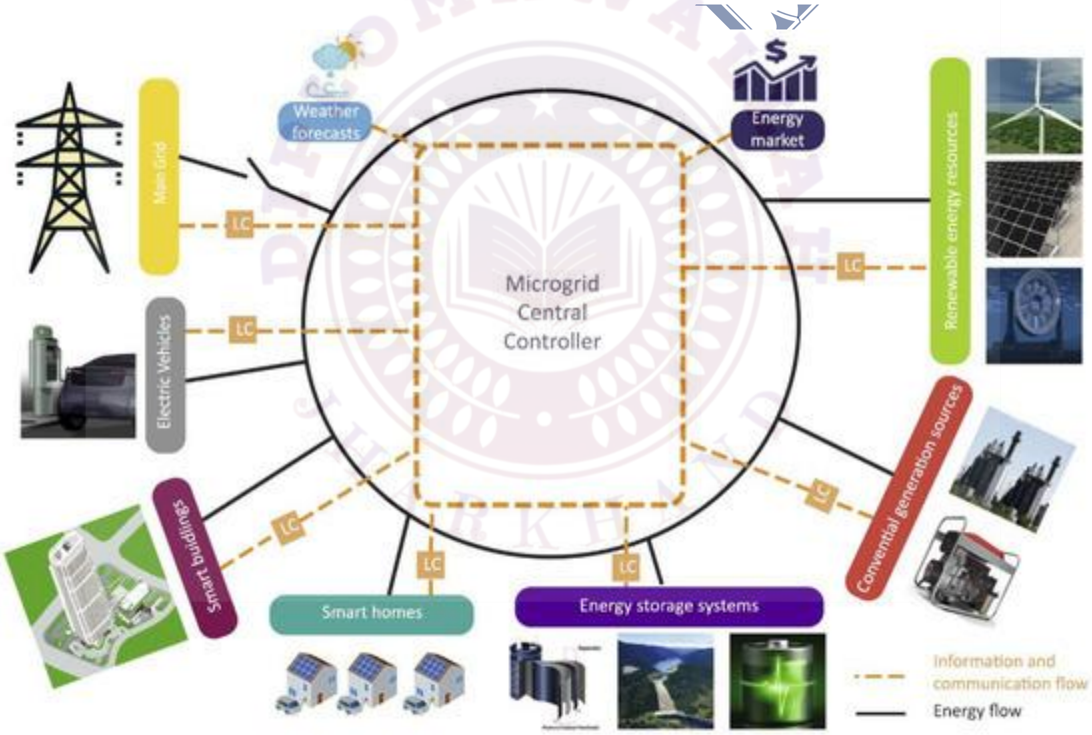



Transmission grid
Distribution grid
Distribution substation
PCC
PV
Transformer
Industrial costumers
Residential costumers
Microgrid
PCC
PV
Load
$G_i(t), L_i(t)$
$L_i(t)$
Microgrid


AC Sources
Geothermal
CHP
Wind Turbne
Back Up
Diesel generator
Load
Solar PV
Energy Storage
DC Sources


SMART MICROGRID
ENERGY COMPANIES
Controlled by
POWER CONTROLLERS
Manage the
ENERGY SYSTEMS
Consists of
MULTIPLE ENERGY RESOURCES
Manage load of multiple
RESIDENCY
Company
Utility Company
Energy Storage Company
Power flow
Information flow
Local Energy Management
Photovoltic
Microgrid
Diesel Generator
Energy System
Home
Hostel
Academic
Residence





3.4 Example Applications

- Campus microgrids (university, industrial) combining solar, battery, backup diesel, loads.
- Rural microgrids serving remote areas with DG + storage.
- Urban microgrids integrated into smart-city infrastructure.

4. Storage Technologies – Electric Vehicles (EVs) & PHEVs

4.1 Storage Technologies Overview

Energy storage is essential for smoothing out variability of renewables, providing grid services (frequency regulation, backup), enabling peak-shaving. Key storage types:

- Battery energy storage systems (BESS) – lithium-ion, flow batteries.
- Pumped hydro storage (for larger scale). (Wikipedia)
- Supercapacitors, flywheels, compressed air energy storage (CAES).
- Vehicle-to-Grid (V2G) systems using EVs as mobile storage.

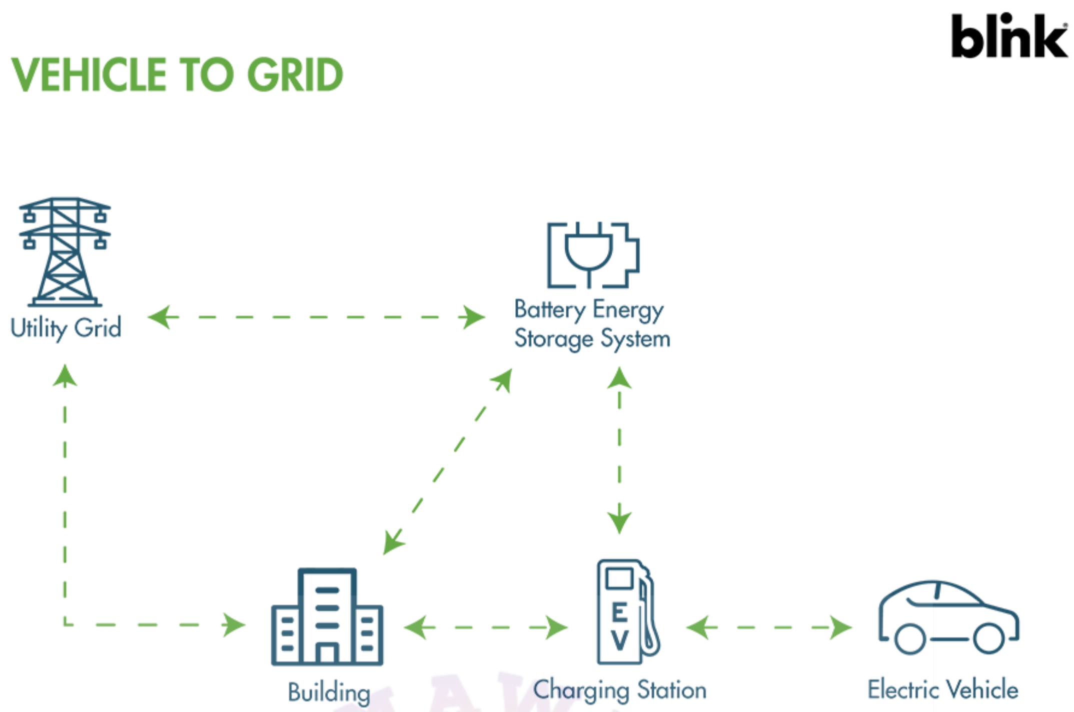
4.2 EVs & PHEVs in the Grid

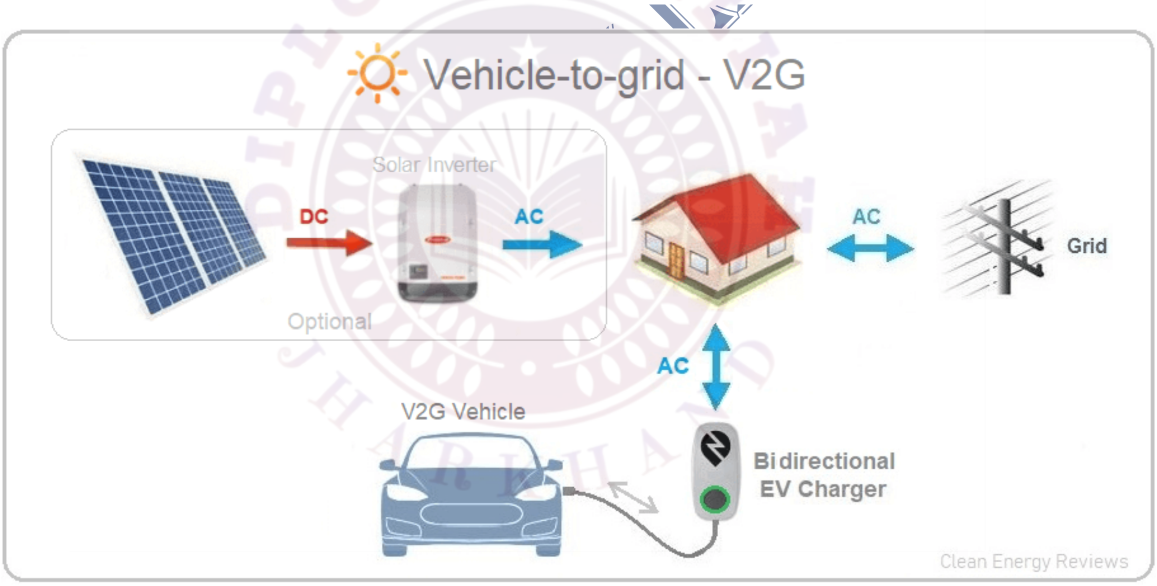
- A Plug-in Hybrid Electric Vehicle (PHEV) or full EV can act as load (charging) *and* potentially as storage (discharging back to grid) in a V2G scenario. (Nature)
- They enable load shifting (charging at low-price hours), peak-management, smoothing renewable generation, and grid support.
- Research shows that integrating PHEVs and storage into microgrids improves cost efficiency and reduces generation from fossil plants. (SpringerLink)

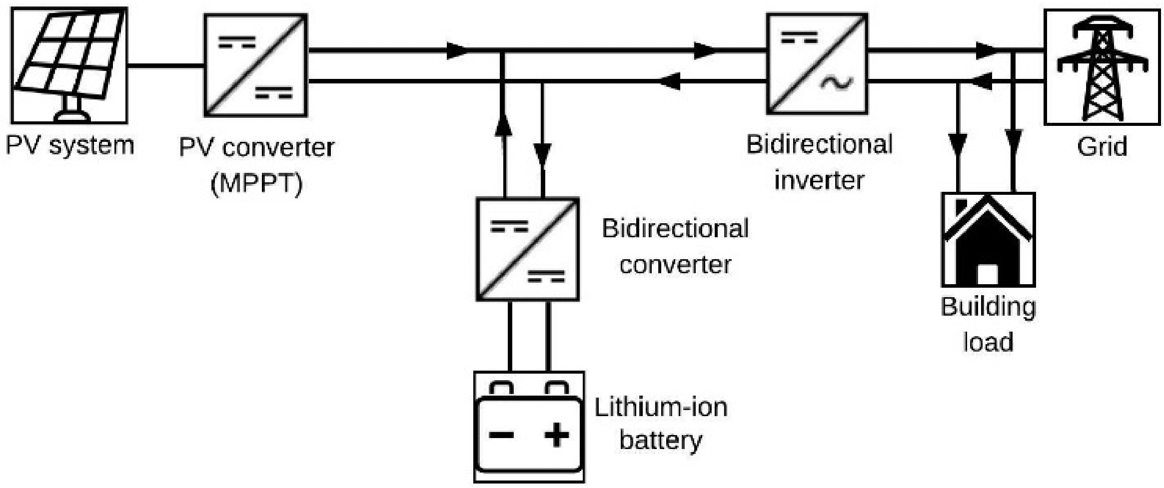
4.3 Benefits & Challenges

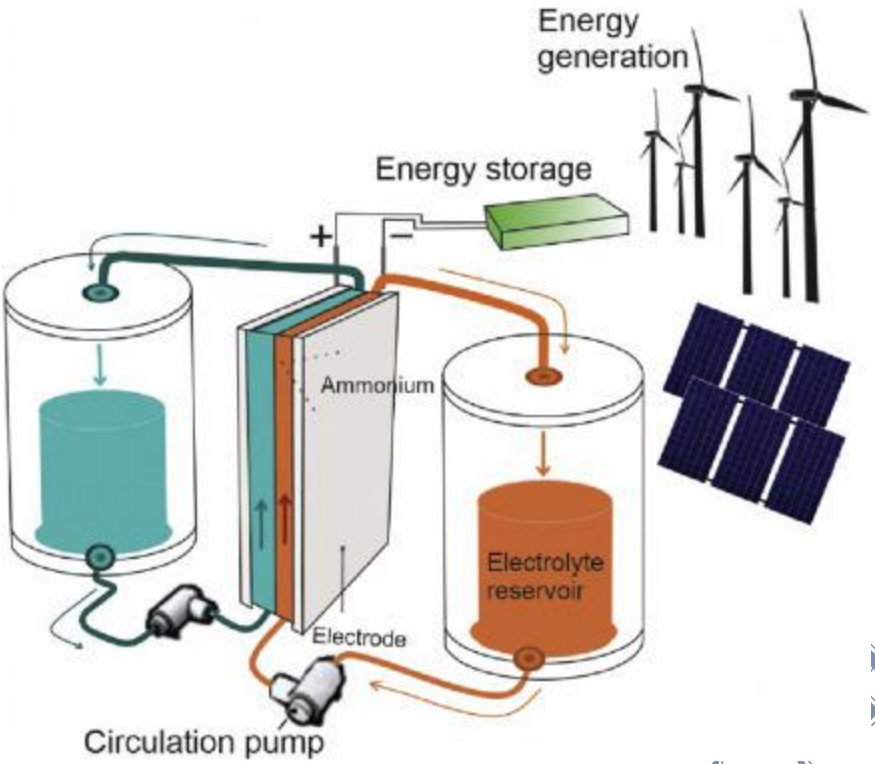
Benefits

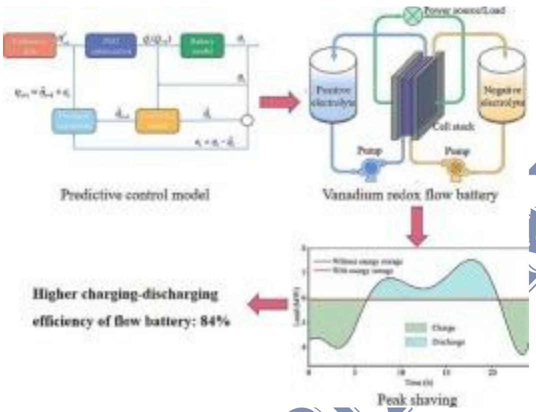
- Enhances grid flexibility, supports higher renewable penetration.
- Reduces need for additional generation capacity for peaks.
- Enables new business models (vehicle owner paid for grid support).
  Challenges
- Battery degradation, lifecycle costs, investment.
- Infrastructure for charging/discharging and communication/control.
- Coordination and optimisation: when to charge/discharge considering grid needs, tariffs, user convenience.
- Interoperability, standards, cybersecurity.


VEHICLE TO GRID
blink
Utility Grid
Battery Energy Storage System
Building
Charging Station
Electric Vehicle


Vehicle-to-grid - V2G
Solar Inverter
DC
AC
Optional
AC
Grid
AC
V2G Vehicle
Bidirectional EV Charger
Clean Energy Reviews


PV system
PV converter (MPPT)
Bidirectional converter
Lithium-ion battery
Bidirectional inverter
Grid
Building load





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5. Environmental Impact & Climate Change

5.1 Environmental Impact of Distributed Generation & Renewables

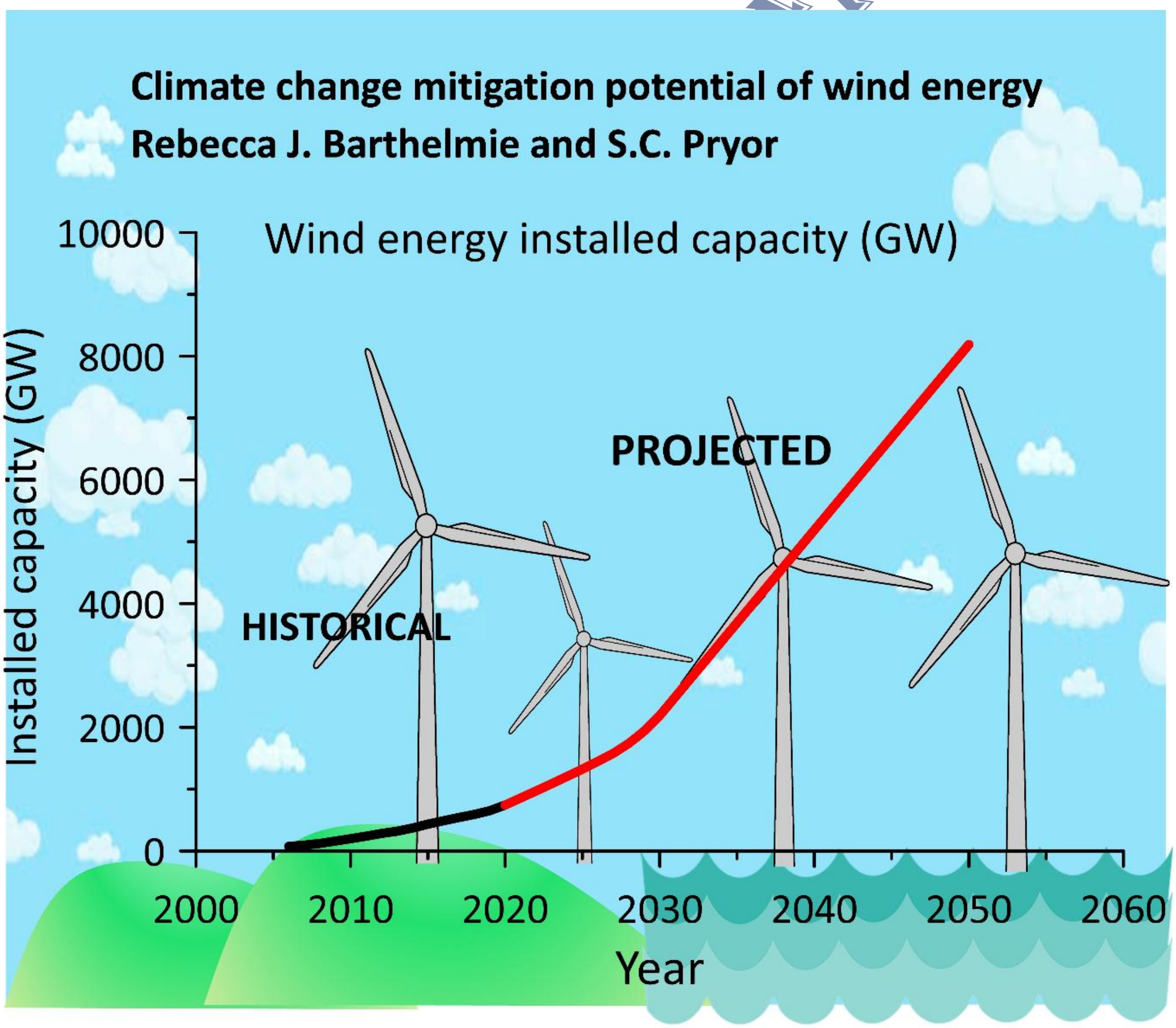
- Switching from fossil-fuel central plants to renewables reduces greenhouse gas (GHG) emissions, particulate pollution, water usage, land impacts.
- Localised DG reduces transmission losses (which are a source of wasted energy) so improves the overall energy-efficiency and hence lower emissions per useful output.
- Microgrids with high renewables + storage increase resilience to climate events (storms, grid failures).

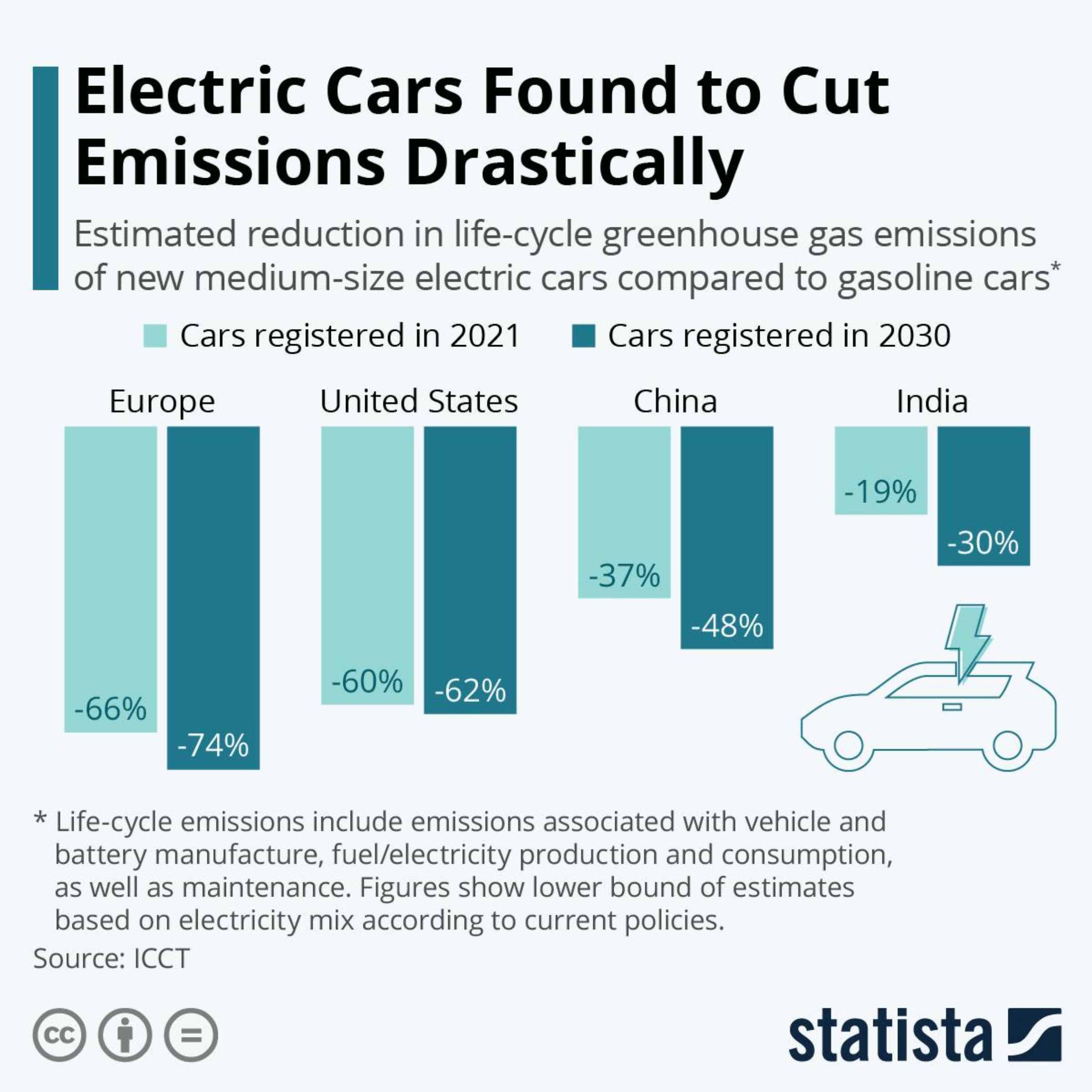
5.2 Effects & Considerations

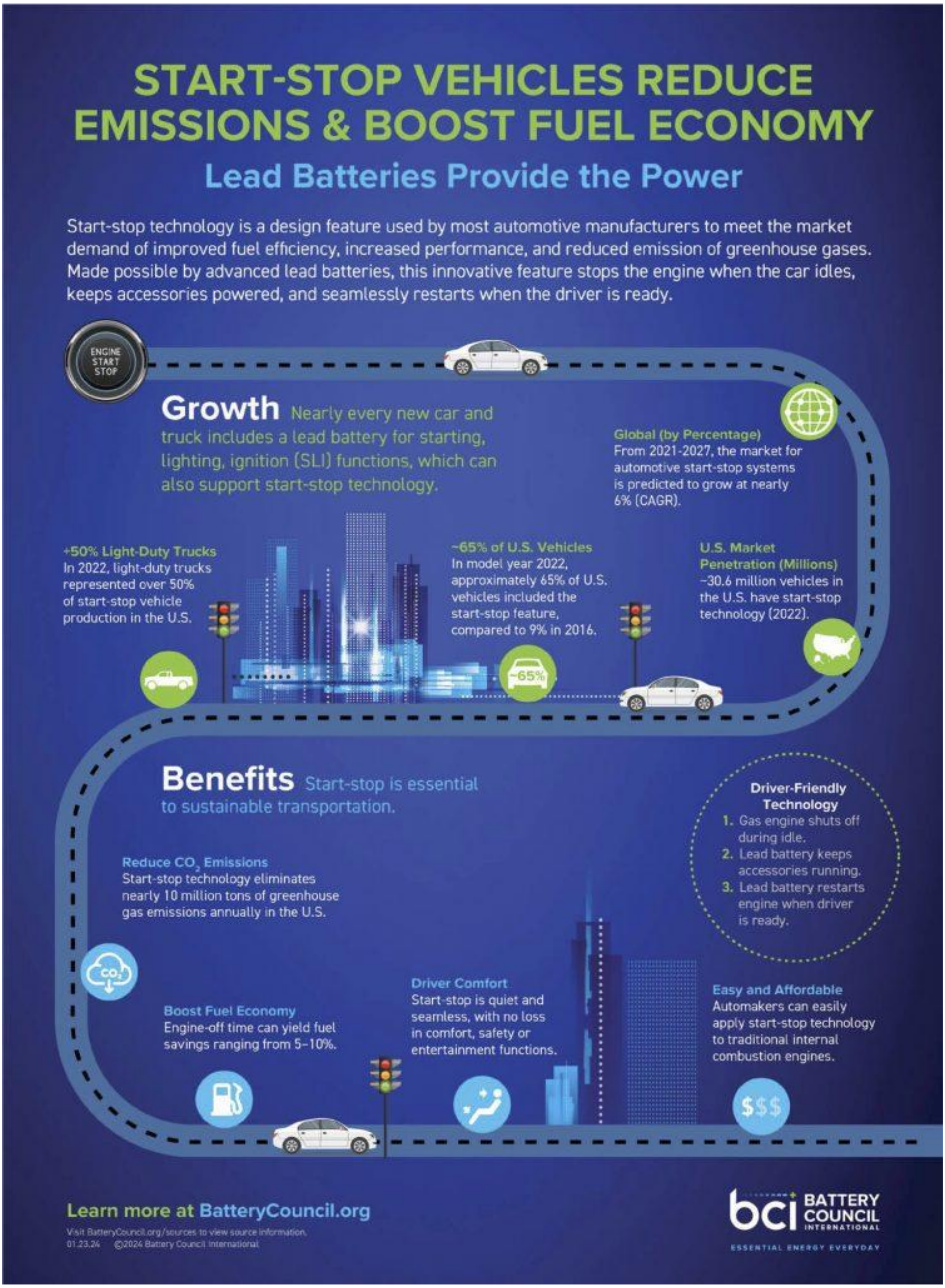
- Variability of renewables causes challenges for grid stability; if poorly managed may require backup fossil plants, negating some benefits.
- Some environmental costs: manufacturing of batteries, disposal, mining for raw materials, life-cycle emissions.
- Climate change demands increased deployment of renewables plus adaptation of grids; distributed renewables plus storage help meet decarbonisation goals.

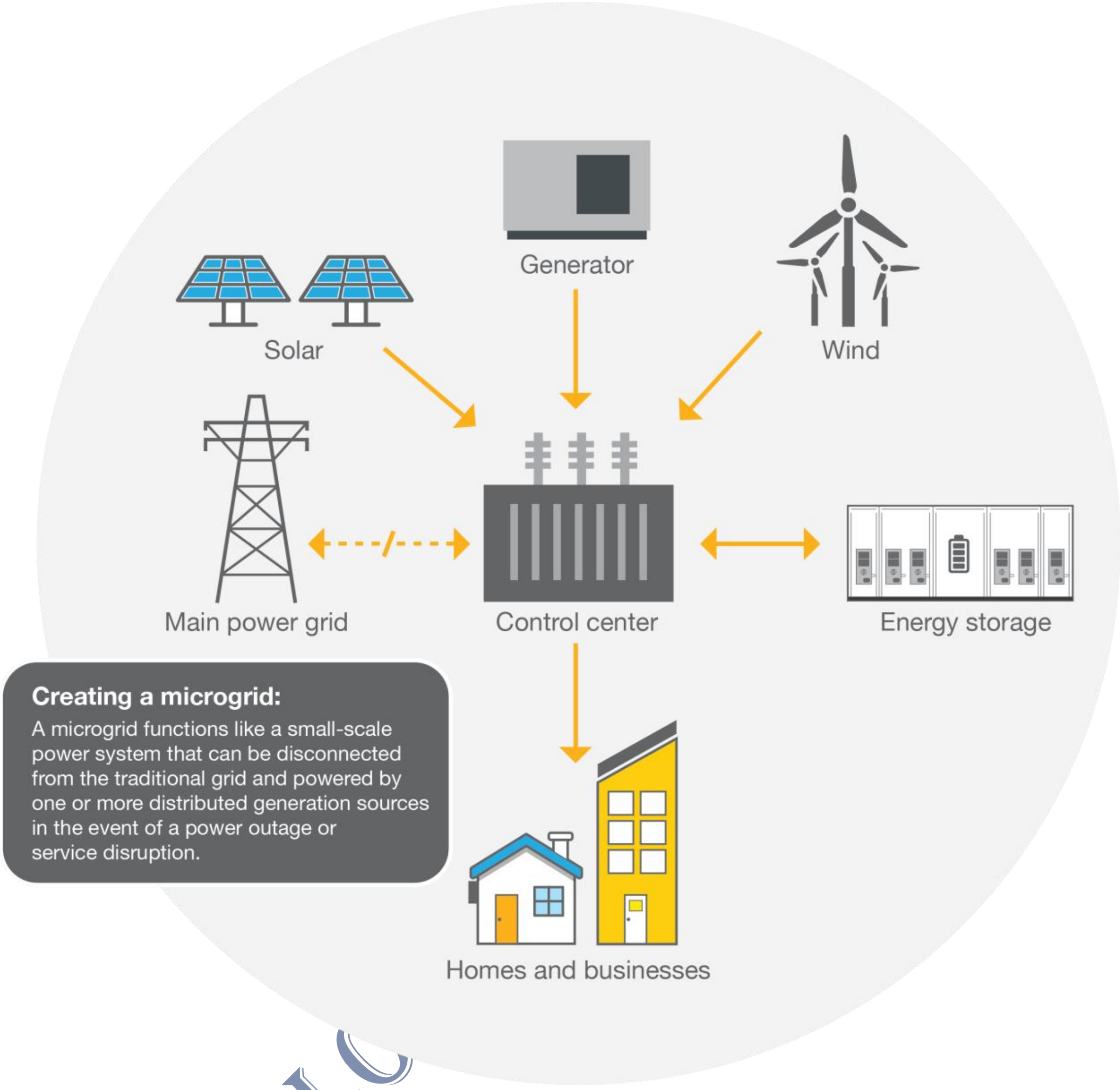
5.3 Role in Climate Change Mitigation

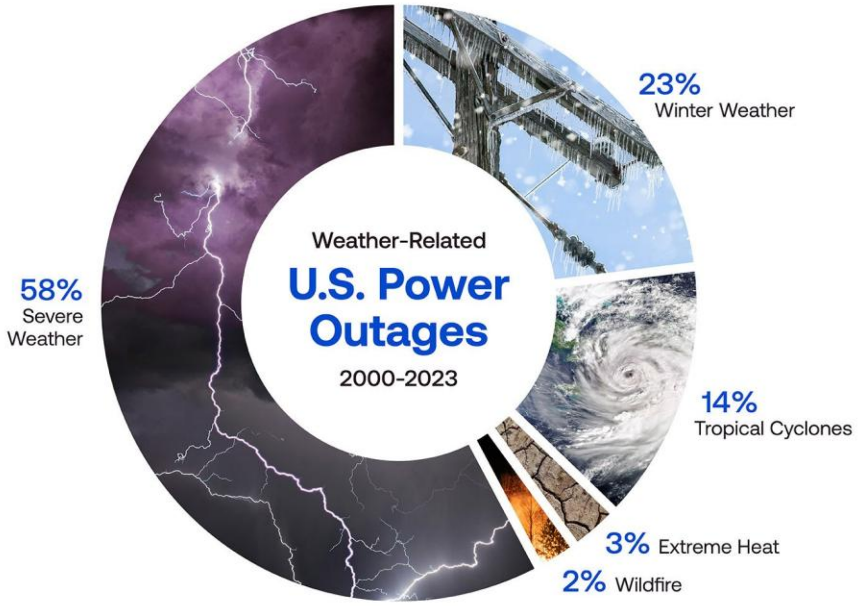
- DG + renewables are key to meeting renewable energy targets and GHG reduction commitments (e.g., under Paris Agreement).
- Storage + EV integration help decarbonise transport and stationary sectors.
- Microgrids can maintain power during extreme events (which are more frequent due to climate change), improving resilience.




Electric Cars Found to Cut Emissions Drastically
Estimated reduction in life-cycle greenhouse gas emissions of new medium-size electric cars compared to gasoline cars*
Cars registered in 2021
Cars registered in 2030
Europe
United States
China
India
-66%
-74%
-60%
-62%
-37%
-48%
-19%
-30%
* Life-cycle emissions include emissions associated with vehicle and battery manufacture, fuel/electricity production and consumption, as well as maintenance. Figures show lower bound of estimates based on electricity mix according to current policies.
Source: ICCT
statista


START-STOP VEHICLES REDUCE EMISSIONS & BOOST FUEL ECONOMY
Lead Batteries Provide the Power
Start-stop technology is a design feature used by most automotive manufacturers to meet the market demand of improved fuel efficiency, increased performance, and reduced emission of greenhouse gases. Made possible by advanced lead batteries, this innovative feature stops the engine when the car idles, keeps accessories powered, and seamlessly restarts when the driver is ready.
ENGINE START STOP
Growth Nearly every new car and truck includes a lead battery for starting, lighting, ignition (SLI) functions, which can also support start-stop technology.
Global (by Percentage)
From 2021-2027, the market for automotive start-stop systems is predicted to grow at nearly 6% (CAGR).
+50% Light-Duty Trucks
In 2022, light-duty trucks represented over 50% of start-stop vehicle production in the U.S.
~65% of U.S. Vehicles
In model year 2022, approximately 65% of U.S. vehicles included the start-stop feature, compared to 9% in 2016.
~65%
U.S. Market Penetration (Millions)
~30.6 million vehicles in the U.S. have start-stop technology (2022).
Benefits Start-stop is essential to sustainable transportation.
Driver-Friendly Technology
1. Gas engine shuts off during idle.
2. Lead battery keeps accessories running.
3. Lead battery restarts engine when driver is ready.
Reduce CO_2 Emissions
Start-stop technology eliminates nearly 10 million tons of greenhouse gas emissions annually in the U.S.
CO_2
Boost Fuel Economy
Engine-off time can yield fuel savings ranging from 5–10%.
Driver Comfort
Start-stop is quiet and seamless, with no loss in comfort, safety or entertainment functions.
Easy and Affordable
Automakers can easily apply start-stop technology to traditional internal combustion engines.
$$$
Learn more at BatteryCouncil.org
Visit BatteryCouncil.org/sources to view source information.
01.23.24 ©2024 Battery Council International
bci BATTERY COUNCIL INTERNATIONAL
ESSENTIAL ENERGY EVERYDAY


Generator
Solar
Wind
Main power grid
Control center
Energy storage
Creating a microgrid:
A microgrid functions like a small-scale power system that can be disconnected from the traditional grid and powered by one or more distributed generation sources in the event of a power outage or service disruption.
Homes and businesses



6. Economic Issues

6.1 Economic Benefits

- Reduced operational costs: DG near load reduces transmission/distribution losses and may defer investments in network expansion.
- Lower fuel costs when renewables are used (zero fuel cost), plus potential revenue streams (selling power, ancillary services).
- Opportunities for new business models: local energy markets, peer-to-peer trading, aggregated storage services.
- Cost savings in reliability/resilience (fewer outages, reduced downtime) especially for critical loads.

6.2 Investment, Cost & Business Challenges

- High upfront capital cost: DG units, storage, control systems, EV infrastructure.
- Payback analysis: what are the tariffs/incentives required? What is the business model? For instance, scheduling microgrid with PHEVs shows better economics when grid acts bidirectionally. (SpringerLink)
- Tariff/regulatory issues: many distribution networks are regulated; how to value services of DG/storage/EVs?
- Cost of integration and system upgrades: legacy systems need adaptation for two-way flows, protection, communication, which adds cost.

- Uncertainty: technology evolution, regulatory risk, market evolution.
- Need for appropriate incentives, subsidies, tariff design (e.g., time-of-use pricing, dynamic pricing) to make models viable.

6.3 Economic Models & Considerations

- Life-cycle cost analysis: consider upfront cost + operational + maintenance + lifetime + residual value.
- Business case for storage/EV: benefit from demand-charge reduction, participation in ancillary services, grid support.
- Revenue stacking: storage + EV can earn from multiple streams (energy arbitrage, demand charge reduction, grid services).
- Grid externalities: benefits (like reduced losses, reduced carbon) sometimes are not directly monetised → may require policy/incentive.
- Cost-benefit for utilities/distribution companies: how to recover costs, align with regulated models.

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7. Summary

- Introduction to DG and its role in modern power systems.
- Renewable energy technologies as key DG resources.
- Microgrids: architecture, benefits, control.
- Storage technologies, especially EVs & PHEVs, and how they integrate into the grid.
- Environmental/climate change implications — how DG + storage help decarbonise and improve resilience.
- Economic issues — benefits, costs, business models, regulatory/market considerations.

Diploma Wallah

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