

Emerging Renewable Energy Technologies



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 - Wind-Solar Hybrid
 - Off-shore Wind
 - Advanced Bio-mass
 - Firm and Dispatchable Renewable Power
3. Building TOGETHER an Interdependent, Interconnected & Resilient RE System
...for a climate and energy secure BIMSTEC

The Two Fold Challenge

... we all face

ENERGY SECURITY CHALLENGES

- High Import Dependency & Price Shocks
- Disparities in Access & Consumption
- Infrastructure Deficits
- Limited energy trading / bilateral agreements

CLIMATE SECURITY CHALLENGES

- Coastal and Marine Threats
- Hydrological and Mountain Risks
- Livelihoods and Socioeconomic Impacts

The Energy and Climate Security Crisis



The Tragedy in Nepal – A Serious Lesson to Learn

The melting glacier tragedy in Nepal is a powerful reminder that global climate action cannot wait:

- Glacier/ice-rock collapse
- Enormous debris flow
- Catastrophic flooding
- Communities destroyed
- Hydro assets of 431MW damaged (10% capacity)
- Largest PV Plant 25MW damaged
- Over 1,200 lives lost and thousands still missing
- Economic toll \$4 to 6bn



Climate has no Boundary or Border

2. Meeting the Twin Challenges

In Renewable Energy... we ensure our security making

Intelligent choice and mix of RE technology solutions that are.....

Appropriate, Firm, Reliable & Resilient to generate & to

*Interconnect to the
grid*

**Clean Energy Transition:
No longer an Option ... but a Compulsion**

Evolving RE Technologies

enabling faster Energy Transition

Advanced PV → higher energy density

Floating PV → another deployment environment

Offshore wind → another unexploited abundant resource

Wind + Solar → resource diversification & Complementing strengths

Biomass → adding flexibility and firmness

Dispatchable RE → stable and reliable grid

2.1 Advanced Solar PV

Solar PV Evolution to the High-efficiency era

Technology focus from Name plate power to....

Increase energy yield, not just nameplate power

- Al-Back Surface Field (BSF)
- PERC (Passivated Emitter Rear Contact)
- TOPCon (Tunnel Oxide Passivated Contact)
- HJT (Hetero Junction Technology)
- IBC (Interdigitated Back-contact)
- Next-generation concepts

Solar PV Evolution... BSF to TOPCON & Beyond

Category	Technologies
Legacy	Aluminium Back Surface Field (Al BSF)
Mainstream today	Passivated Emitter Rear Contact (PERC), Tunnel Oxide Passivated Contact (TOPCON) + Bifacial
Advanced / emerging commercial	Hetero-Junction Technology (HJT), Interdigitated Back Contact – IBC (Cell Architecture innovation) Zero Bus Bar (OBB), copper metallisation, thinner wafers (Manufacturing/interconnection innovation)
Next-generation frontier – beyond TOPCON	Perovskite–silicon tandem & advanced tandem architectures (enhanced light capture innovation)

PV Cell Efficiencies

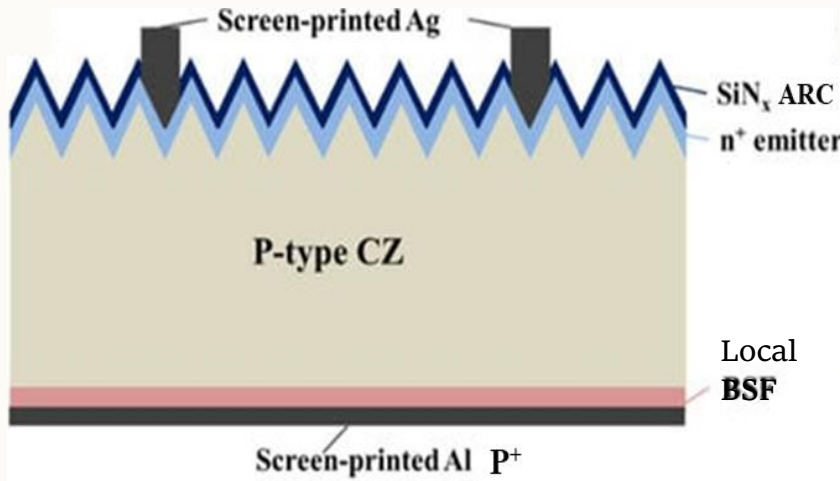
Cell Technology	Max. mass manufacture Efficiency	Key Technological Enhancement
Std. Monocrystalline BSF	19% – 20.5%	Basic uniform mono crystal Si structure utilizing std (Al-BSF).
Polycrystalline (Poly)	17% – 18.5%	Low cost multi Si but higher electron recombination losses.
Mono PERC (P-type)	22% – 23.5%	PERC layers added to reflect unabsorbed light back into the cell.
TOPCon (N-type)*	24% – 26%+	TOPCON layout: an ultra-thin oxide layer to drastically minimize recombination.

*Bifaciality further improves efficiency. In deserts with high sand albedo practical efficiency could be 27 - 31%

Maximum mass manufactured module efficiency is about 1.5 to 2% less than the cell efficiencies

Standard BSF & PERC Cell

Standard Back Surface Field (BSF)



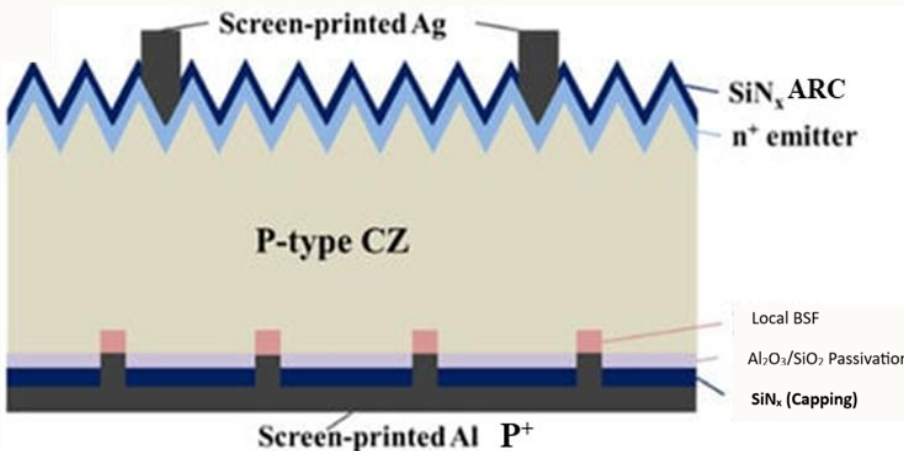
BSF:

- Thick Al. layer at the rear creates electric field: pushes e^- from drifting to the back toward the jn.
- Has high recombination losses that yields lower efficiency, higher temp coefficient and no bifaciality

PERC:

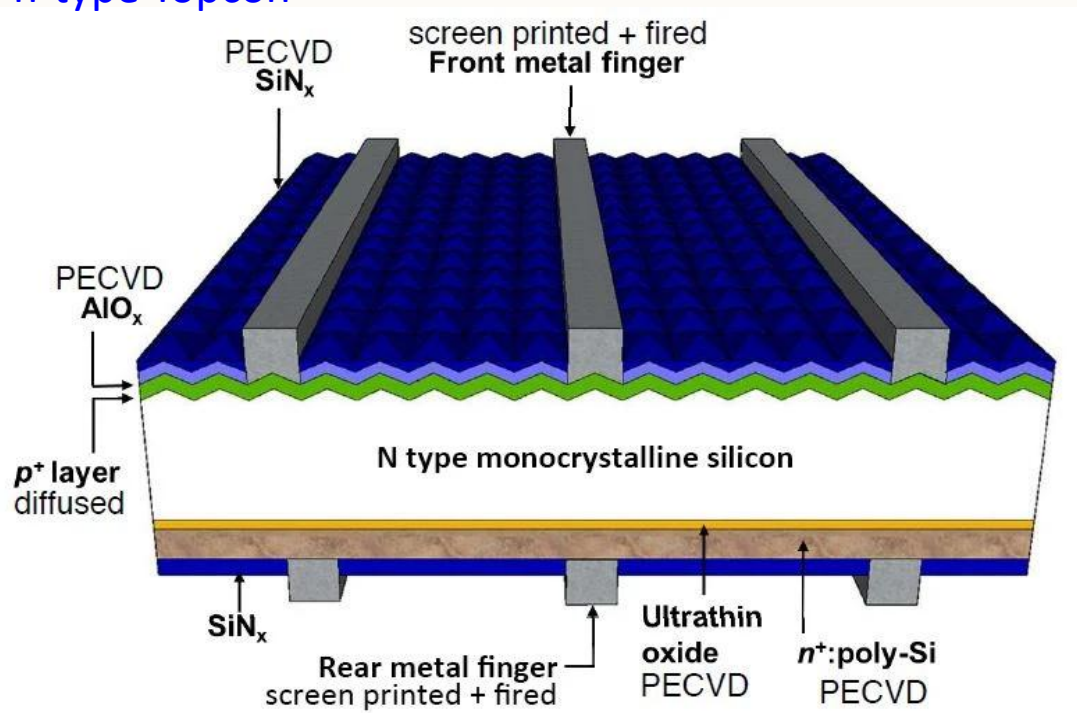
- An upgraded of BSF.
- Thin oxide reflective layer added to the back bounces unused light increasing generation.
- Is budget-friendly and reliable
- Efficiency limited to 22–23%
- Degrades a bit faster over time than newer tech.

Passivated Emitter Rear Contact (PERC)



Tunnel Oxide Passivated Contact

n-type Topcon

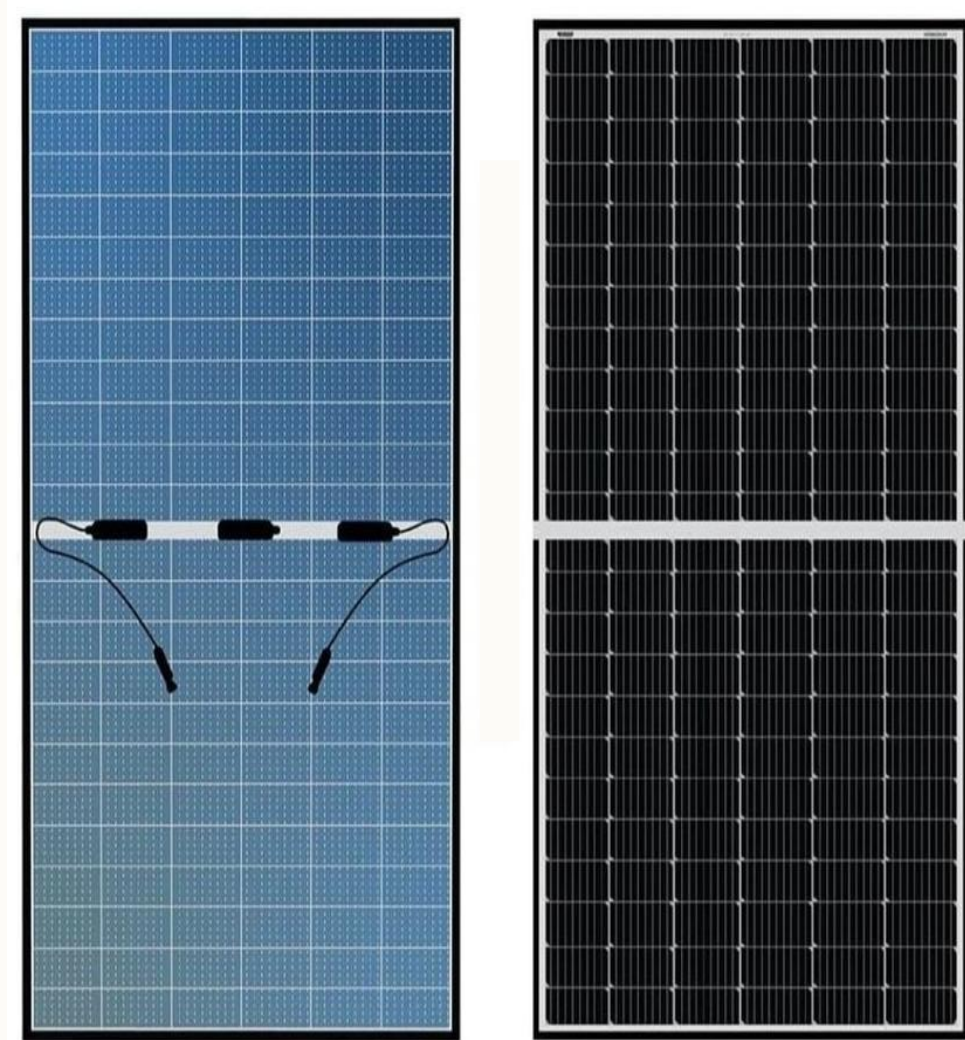


- Next-generation upgrade that follows PERC.
- An ultra-thin tunnel oxide + heavily doped n⁺ layer + passivating layer → reduced carrier loss and hence higher η
- Bulk production efficiency as high as 24–25%+
- Works better in hot weather, performs well in low light
- Has bifaciality and
- Has lower degradation rate
- Costs slightly more to buy upfront than PERC

NType Topcon Bifacial Module

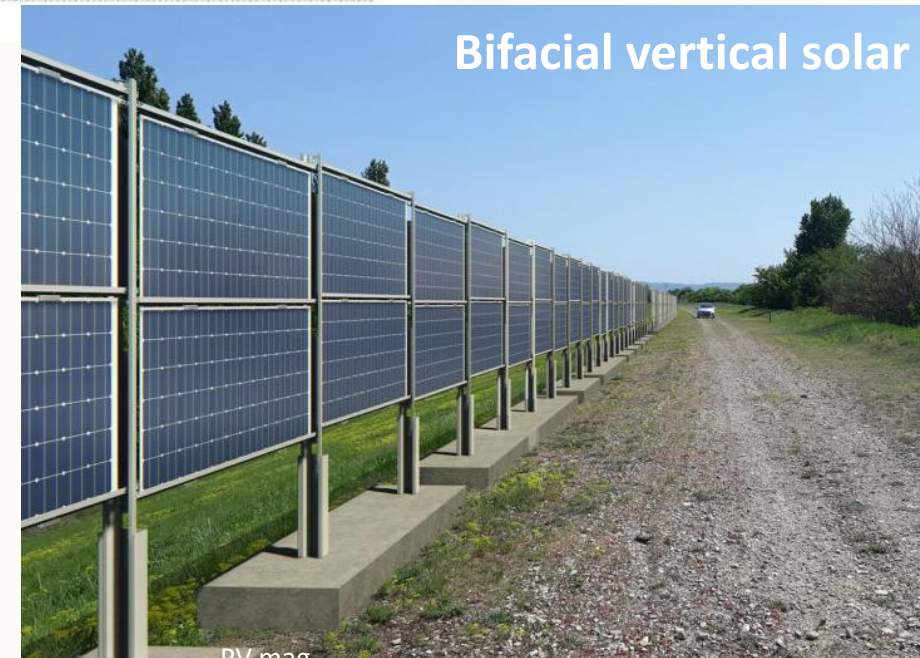
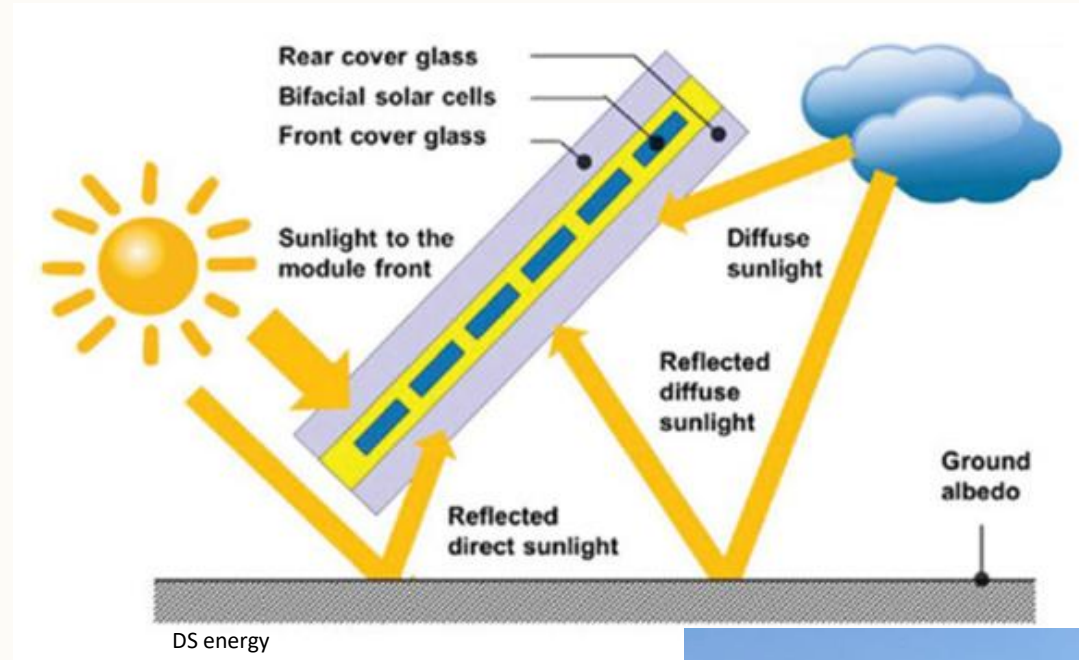
Electricity from both sides

- Grid pattern on the back like the front + Transparent glass
- Reflected & diffused light incident on the back also utilized (gain > 30% possible)
- Is measured as Bifaciality factor (Measure of rear side η : max front to back output (PERC:70–80% TOPCon: 80–85%))
- Single axis tracker gain: 1.3-1.4 & dual: 1.4- 1.6

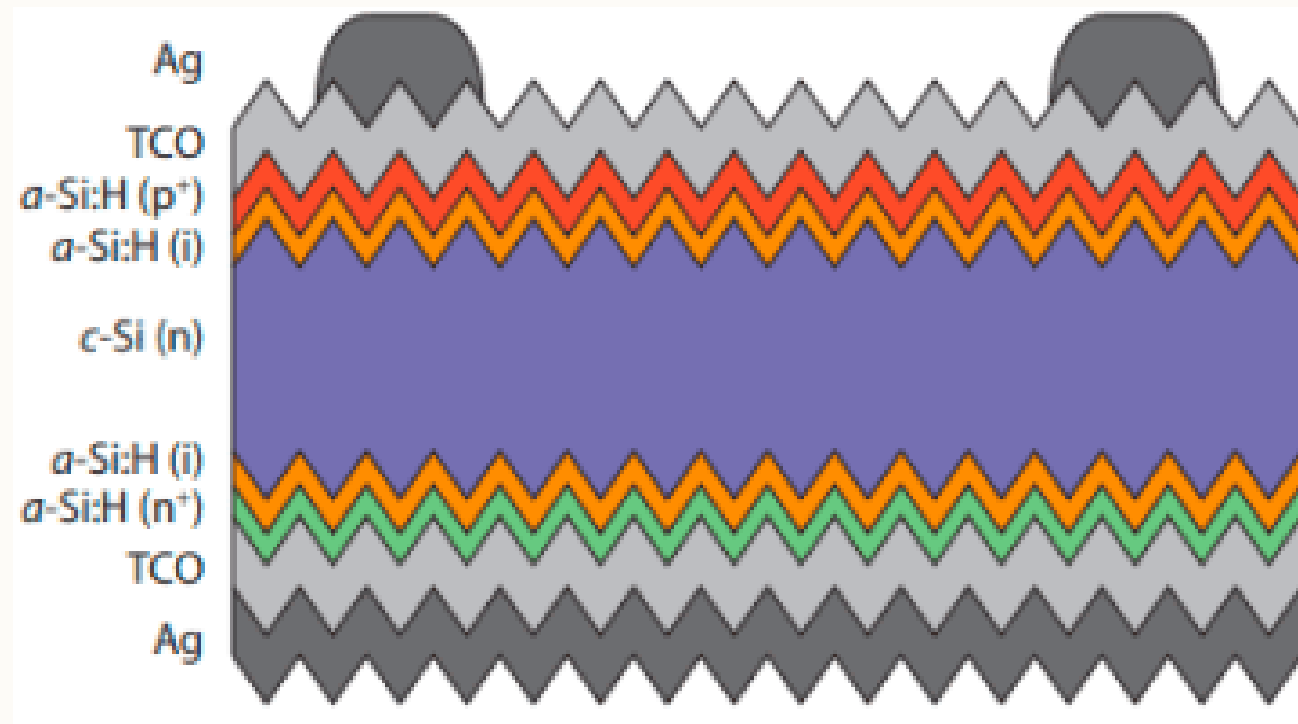


Factors influencing Bifacial Module

- Ground albedo
- Module height
- Row spacing
- Shading
- Tracker configuration
- Ground surface
- Rear-side irradiance

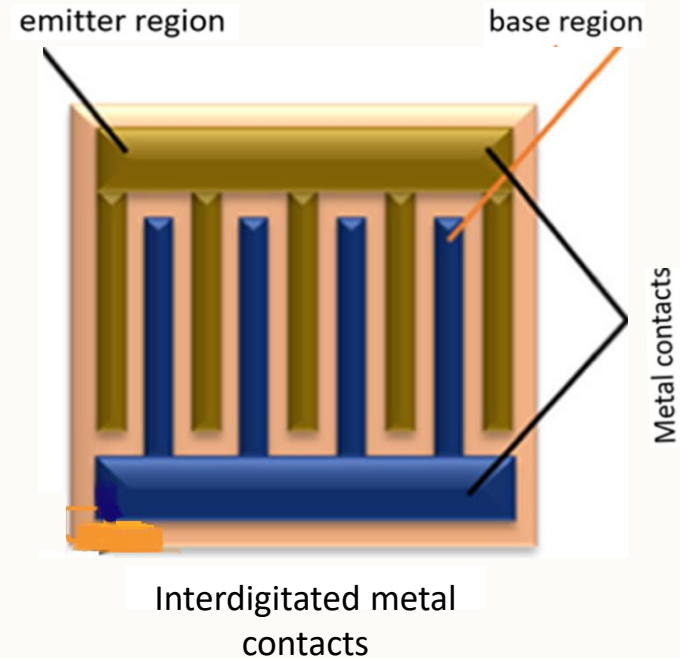
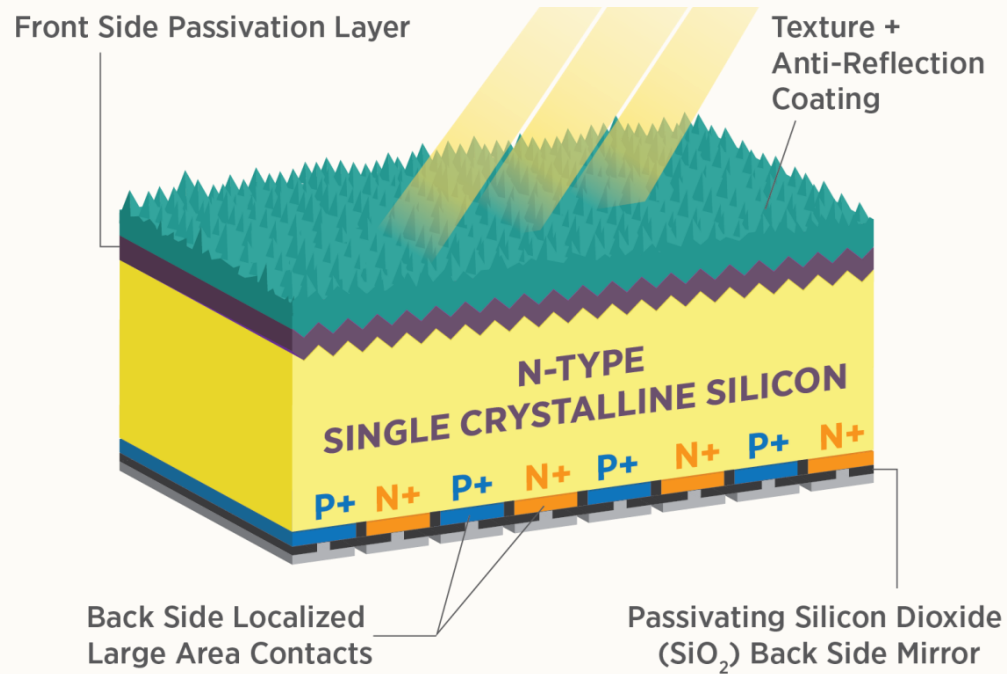


Hetero Junction Technology (HJT)



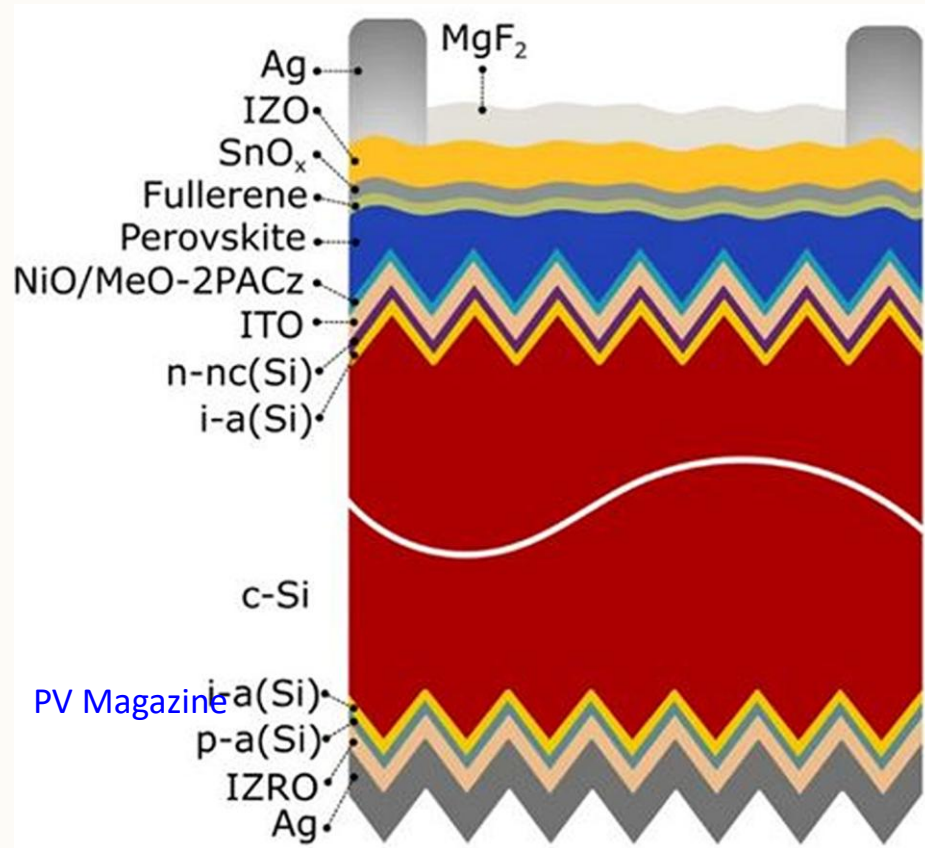
- Combines two different materials: mono Si sandwiched between two ultra-thin a-Si layers
- The layers "passivate" the surface & reduce carrier recombination at the interface
- Yields $\eta > \text{TOPCON}$, has better temp. coeff, and high bifaciality.
- Costs more & has lower market share

Interdigitated Back Contact (IBC)



- Front surface: metal grid free - allowing more light capture.
- Back side: alternating p & n-type diffused with interdigitated +ve & -ve metal contacts
- Has better temp performance, lower degradation & uniform and aesthetic top colour
- Higher grade Si + complex manufacturing makes it expensive

Perovskite Silicon Tandem Cells



- Are crystal structure similar to (CaTiO₃)
- Exceptional absorption of blue and green light
- Different element combination in crystal structure, enables light of any specific freq range to be captured
- Si sandwiched between aSi layers lies below it
- Perovskites absorb higher frequency blue & green; silicon the lower freq Red and IR
- Combined conversion η (35+%) which is > the Si Shockley-Queisser η limit of 33.7%

Silicon Cell Technology Variants & The Market Progression Over The Years

Period	Est. Global Shipments (GW)	Dominant Technology (Market Share)	Secondary Technology (Market Share)	Emerging Tech / Niche (Market Share)
2010–2012	17 – 35 GW	 Polycrystalline (~55–60%)	 Monocrystalline (~30–35%)	 Thin Film (~5–10%)
2013–2016	40 – 75 GW	 Polycrystalline (~65–70%)	 Monocrystalline (~20–25%)	 Thin Film (~5%)
2017–2019	90 – 115 GW	 Mono-PERC (~45–65%)	 Polycrystalline (~30–50%)	 Thin Film (~3–5%)
2020–2022	140 – 260 GW	 Mono-PERC (~80–90%)	 Polycrystalline (<5%)	 Thin Film / HJT (~3–5%)
2023–2024	400 – 612 GW	 Mono-PERC (~65–75%)	 n-type TOPCon (~20–30%)	 Thin Film (~2%)
2025	536 – 706 GW	 n-type TOPCon (~65–70%)	 Mono-PERC (~20–25%)	 HJT / Back Contact (~5%)

The Changing PV metric

Traditional question:

“How efficient is the module?” How low the cost is?

Better question:

“**How much electricity** will this technology produce over the life cycle

Even better:

“**What is the delivered cost and value of that electricity from the available land?**”



High Efficiency Modules Reduce the land requirement and Installation Cost

High Efficiency.... Yet land is the constraint...

2.2. Floating Solar PV (FPV)

Floating Solar PV – The offer

1. Land

Avoids /reduces competing land use

2. Reservoirs

Large existing water surfaces utilized

3. Infrastructure

Potential proximity to existing hydro infrastructure – no additional cost

4. System optimisation

Co-location with hydro or thermal plant.



pv-tech.org

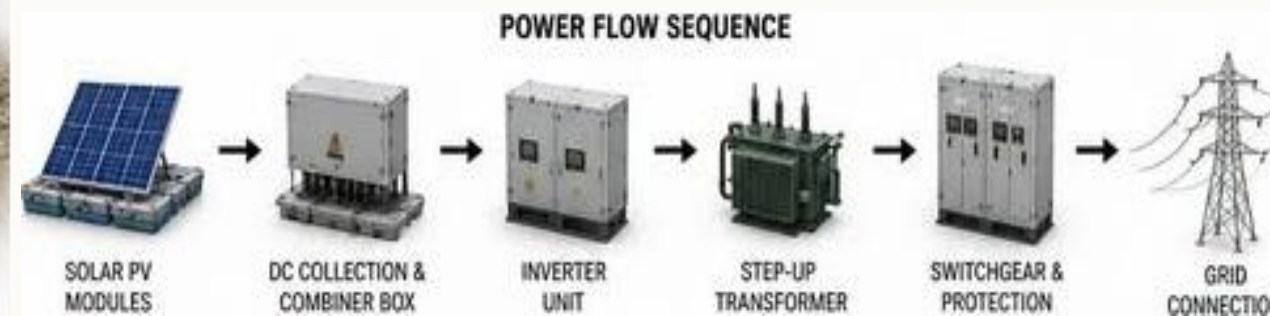
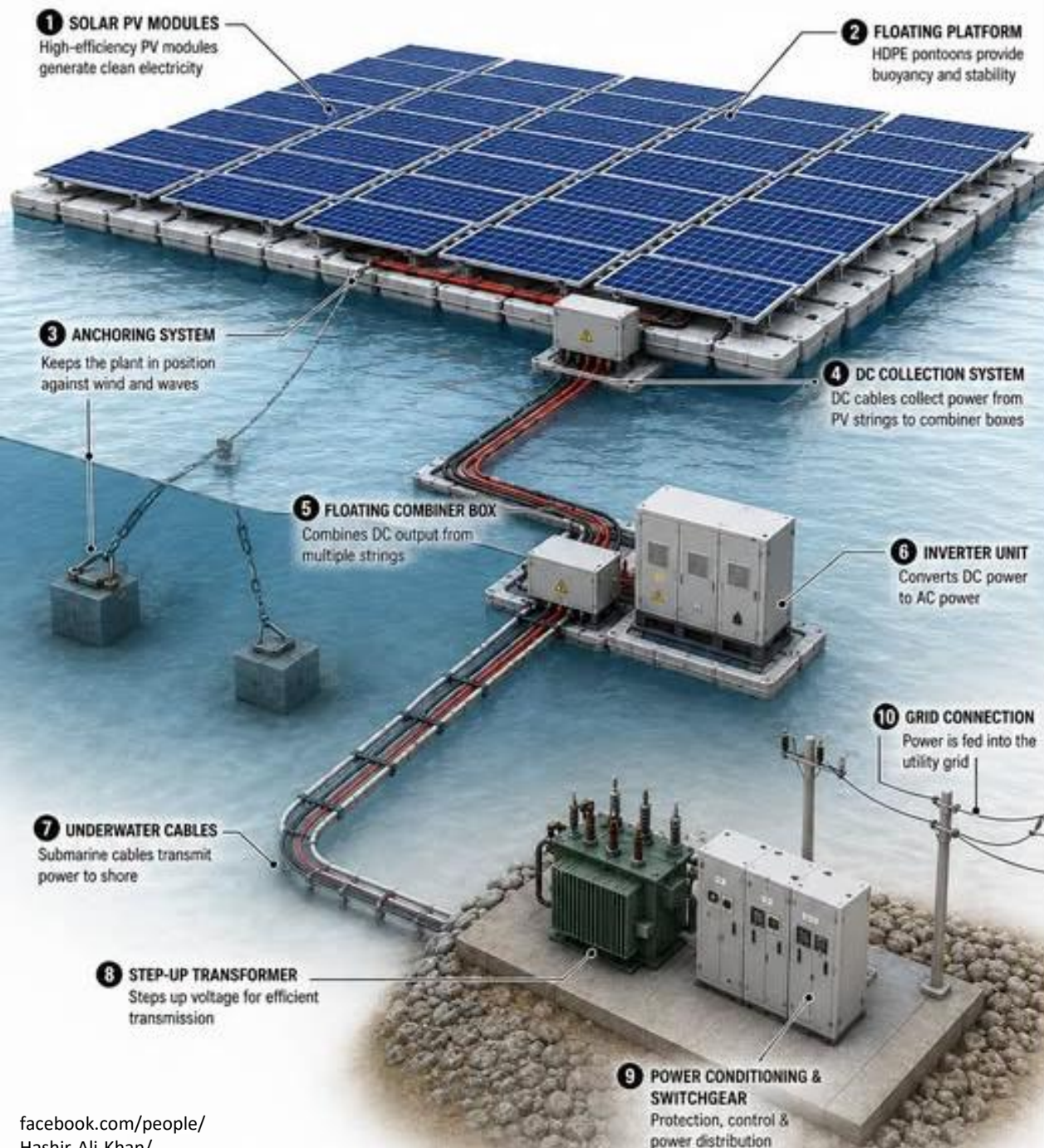
58.5MW floating PV plant Co-located with a hydropower in *Ubon Ratchathani* province in Thailand

FPV

A Marine Power System

FPV Power system Components are:

- PV modules
- Floats / platforms
- Mooring system
- Anchors
- Electrical collection
- Inverter / transformer



Floating PV: Technology choices

In FPV Several key design choices must be made

Float configuration

- Modular floaters
- Pontoon/platform concepts



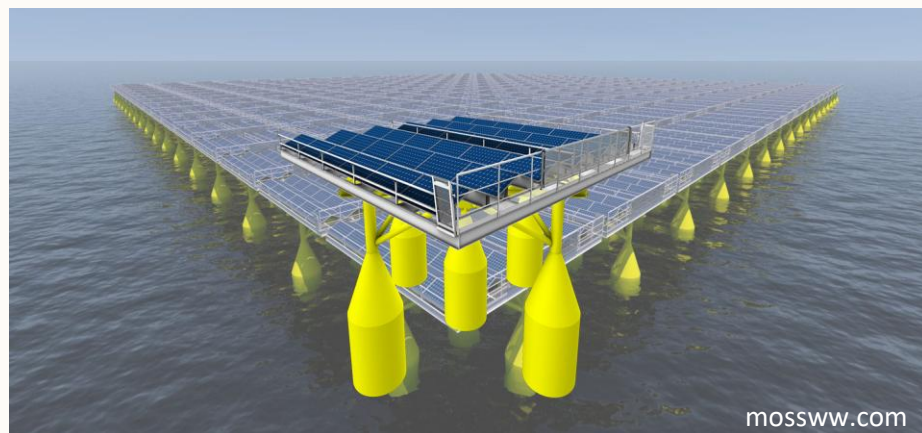
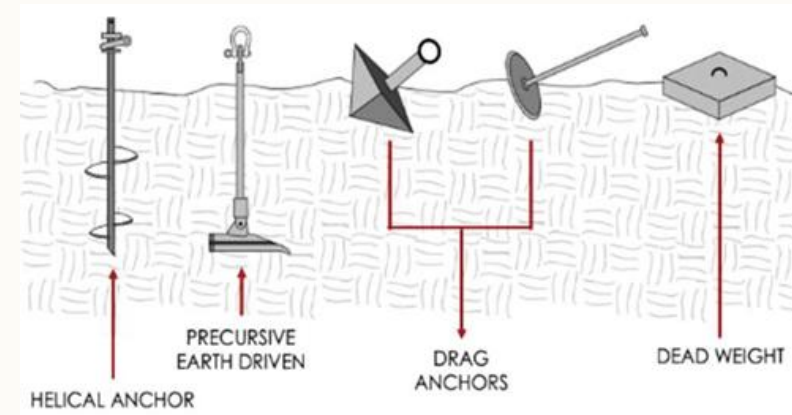
Mooring

- Bank anchoring
- Bottom anchoring
- Flexible systems



PV configuration

- Fixed tilt
- Alternative geometries
- Potential tracking



Potential FPV Benefits and Challenges

Reduction in evaporation losses

Ease of deployment
No leveling or laying of foundation needed

No land requirement

by birds

Synergy with electric infrastructure
In particular when combined with existing hydropower plants

Electrical safety and longevity of equipment

Water available for cleaning

Possible reduction in algae growth

Increased energy yield from cooling effect of water

Mooring and anchoring
Complexity depending upon reservoir type

Possible environmental impact from light reduction

Maintenance
May require boats and divers

Key Design Considerations

Geotechnical

- Water Depth
- Waterbed Soil Composition
- Currents & Tides

Structural and Material

- Mooring and Anchoring
- Wind & wave loading
- UV Degradation & Aging
- Corrosion
- Fatigue & Mechanical Stress

Electrical

- Floating & Subsurface Cabling
- Earthing
- Isolation
- Maintenance Access

Environmental

- Water Quality
- Biofouling
- Light Penetratin
- Aquatic ecology

New Innovations in Floating PV

Innovations focused on:

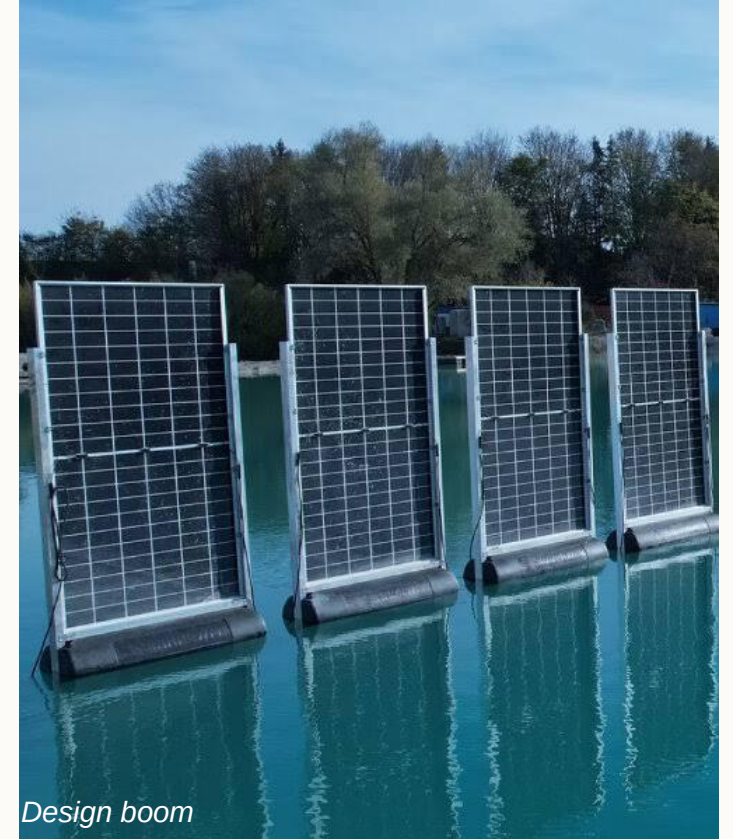
Evolution from inland reservoir systems toward harsh offshore marine environments

New designs to withstand climate driven extreme conditions: waves, currents, and fluctuating water levels.

Specialized software for water reflectance estimation, pontoon layout & cable routing

Hybrid integration with storage and Hydropower.

Cost reduction efforts



Floating solar is no longer niche RE—it is evolving into a mainstream, utility-scale solution.

FPV-Thermal /FPV-Hydropower Hybrid



From PV Plant Over Water to Wind Plant Over Water

2.3 OFFSHORE WIND

Location Based Wind Farms

Onshore Farms:

Most common, easiest to build, and cheapest to connect to grid.

Nearshore Farms:

Close to the coastline in shallow coastal waters and lakes

Offshore Farms:

Further out in the sea where winds are stronger and steadier, allows larger turbines

Offshore Wind Benefits

- Minimal Land acquisition issues
- Larger development areas
- Stronger and more consistent winds
- Large turbines possible
- Near major coastal demand centres
- Potentially high capacity factors
- Low Visual and Noise Impact



Foundation Challenges

Foundations is a key challenge in Wind Generation Systems

- Need to provide structural support the massive weight
- Need to withstand heavy wind loads.
- Need to provide stability

Offshore Foundations are Extra Important

- Harsh Environment: Ocean waves, strong currents & salty water
- Higher Forces: Lower part of the structure faces heavy wave impact.
- High Risk: Fixing a broken foundation costs time and money.
- Logistics nightmare

Foundation Technology

Fixed-Bottom Foundations:

Attached directly to the seabed (shallow waters <60 to 80m).

Common types:

- **Monopiles** (a single large steel tube driven into the seabed),
- **Jacket foundations** (latticed steel frames)
- **Tripods**
- **Gravity-based**

Floating Foundations:

Used in deep ocean waters where fixed foundations cannot reach.

Common types:

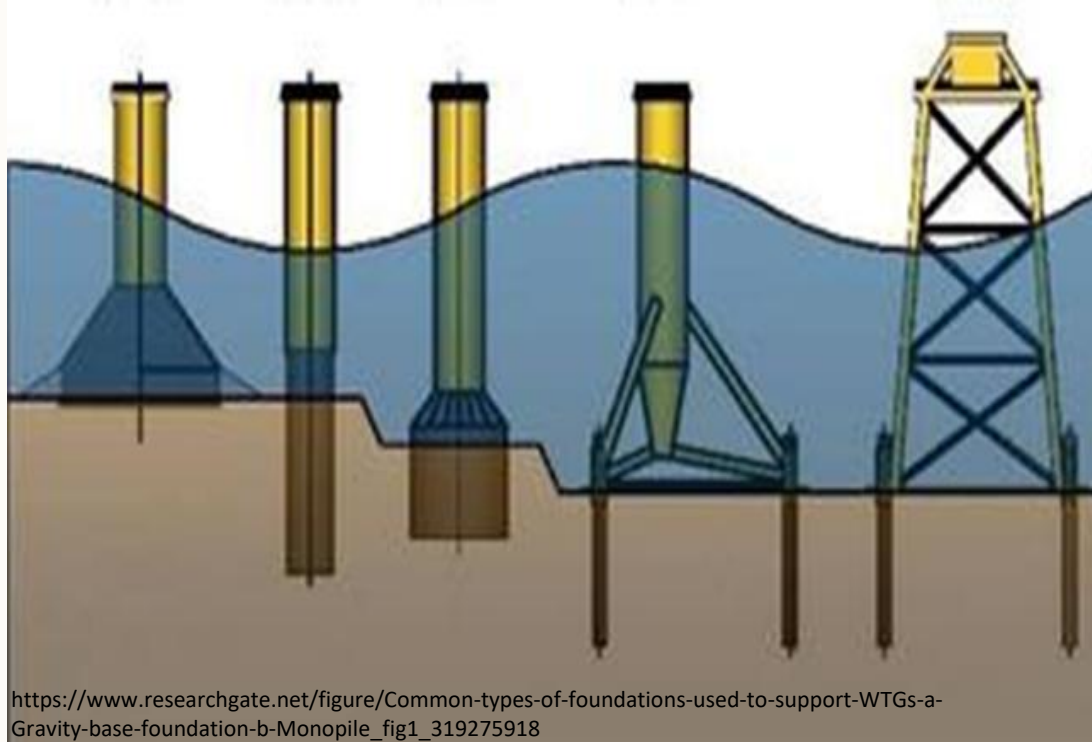
- Semi-Submersible Platforms
- Spar Buoys
- Tension-Leg Platforms

Foundation is chosen based on **water depth**, **seabed conditions**, and **economics**

Fixed-bottom offshore wind is the most mature offshore Wind technology

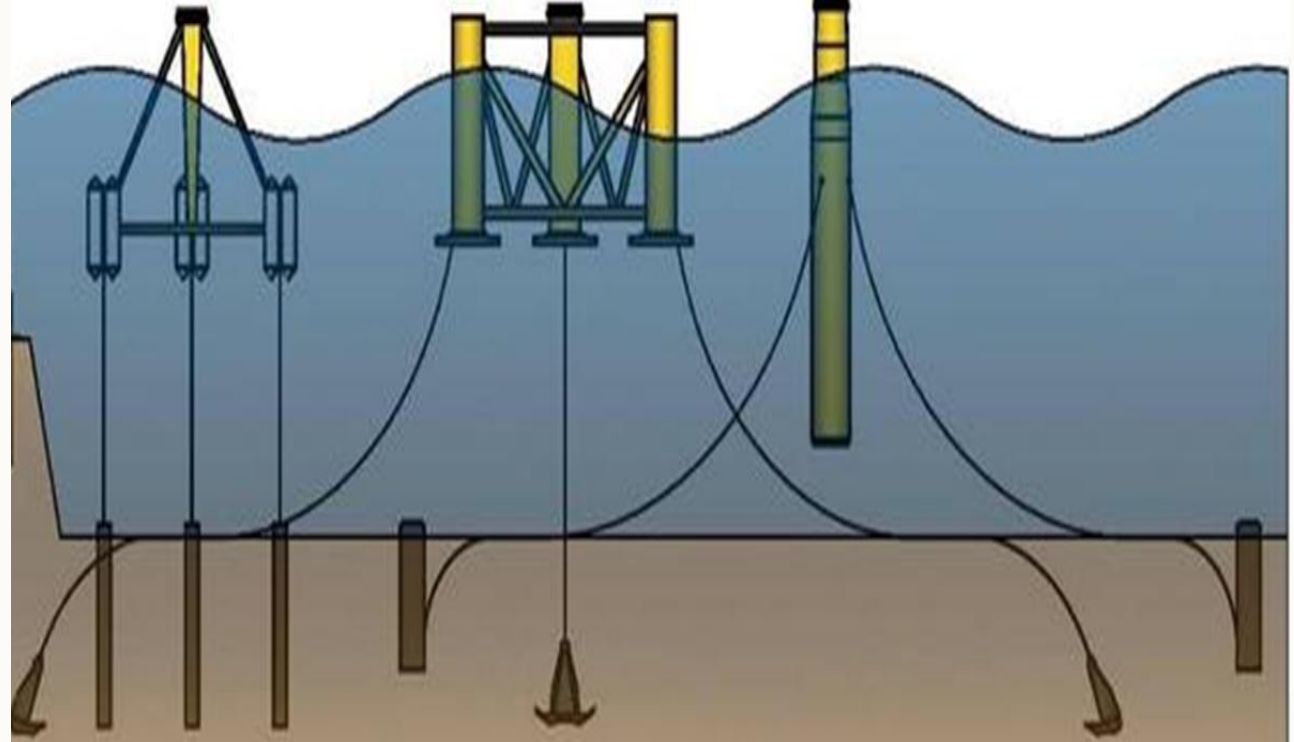
Offshore Foundation Technology

Fixed-Bottom Foundations



Gravity, Monopile, Suction, Tripod,
Jacket

Floating Foundations



Tension leg, Semi-submersible, Spar

Offshore Wind Development Chain

1. Marine Survey	2. Env Studies	3. Site Development	4. Foundation	5. Turbine
6. Array Cables	7. Offshore Substation	8. Export Cable	9. Onshore Grid	10. O&M

Bringing Offshore Electricity Ashore

Wind farm → Grid

Array Cables: Connect turbines in strings & route the power to offshore Substation (SS)

Modern large output farms: MV Cables (66KV)

3-core AC bundled a single subsea cable sleeve.

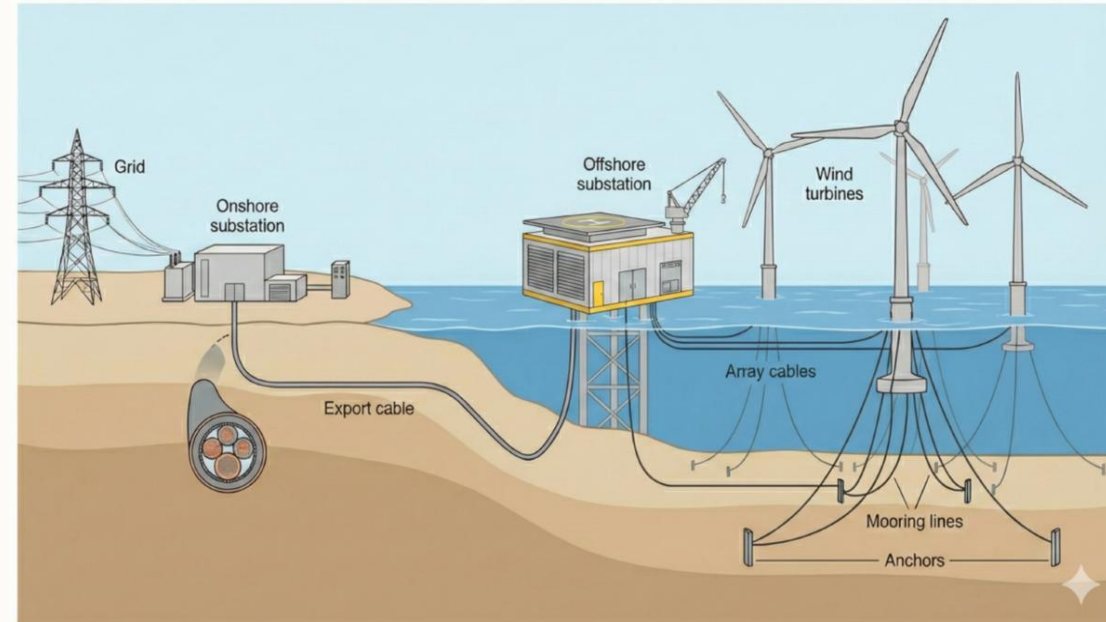
Export Cables: From offshore SS to onshore SS (HV to EHV from 132 to 525 kV)

Cable type:

Cu/Al cores, XLPE insulation, waterproof sheaths & GI armor

Fiber optic cables bundled to transmit real-time data and signals

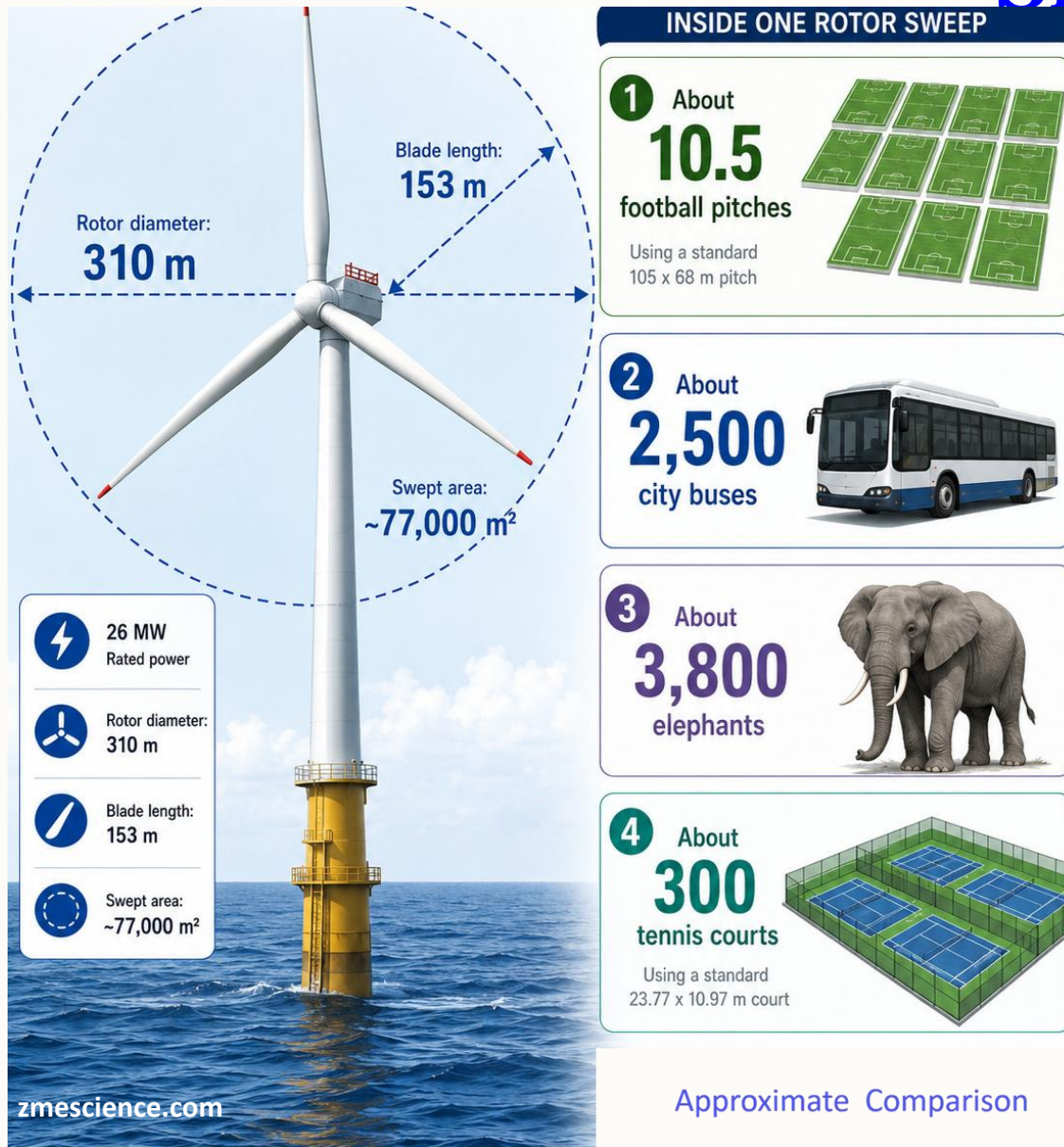
Cables are buried to protect from ships/boats/anchors and hydrodynamic forces



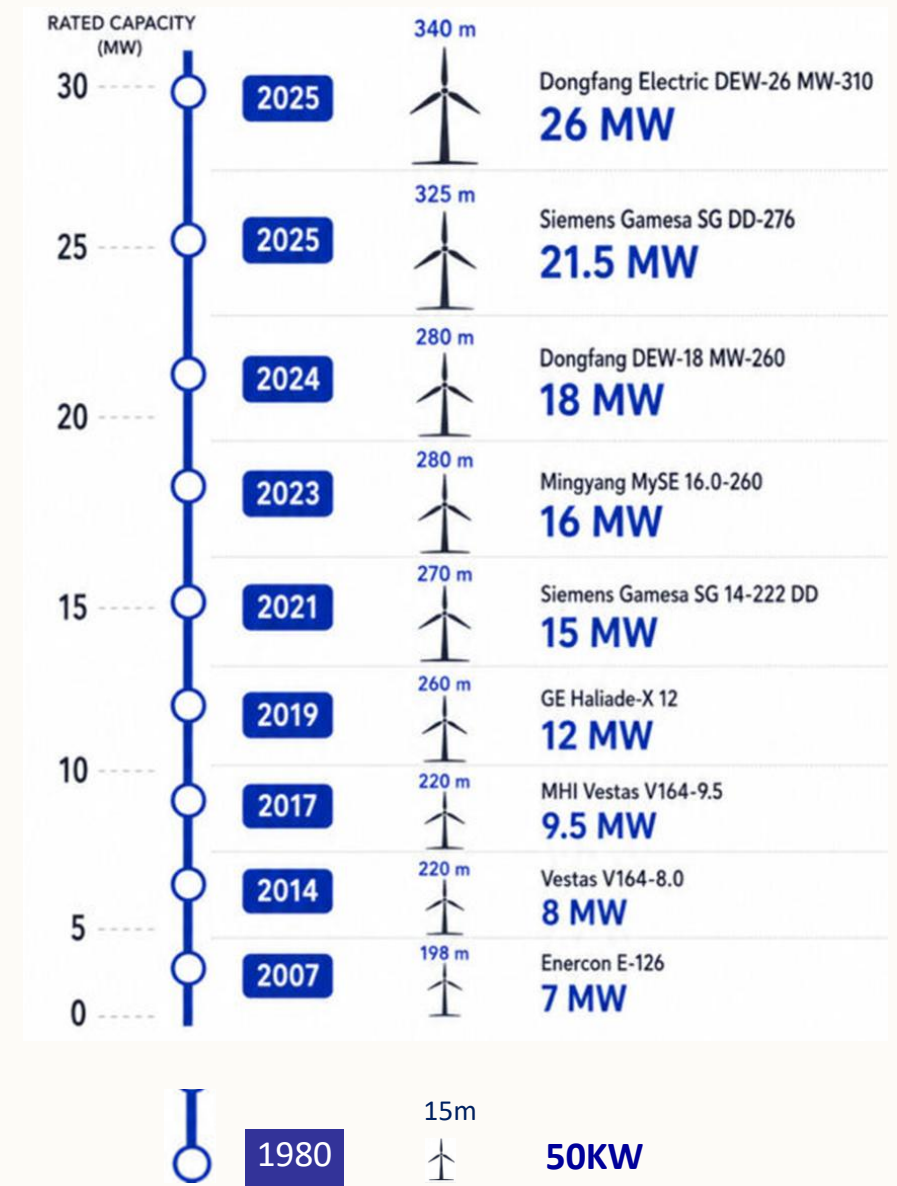
Advanced Engineering Breakthroughs

- Record-Breaking Sizes
- Taller tower/hub heights
- Advanced material: Carbon-Fiber Reinforcements
- Segmented Blades
- Recyclable Resins.
- Direct-Drive Systems
- Hybrid-Drives
- Smart Controls and AI Integration
- Real-Time Adaptation
- Typhoon-Resilient Deep-Water Floating Foundations

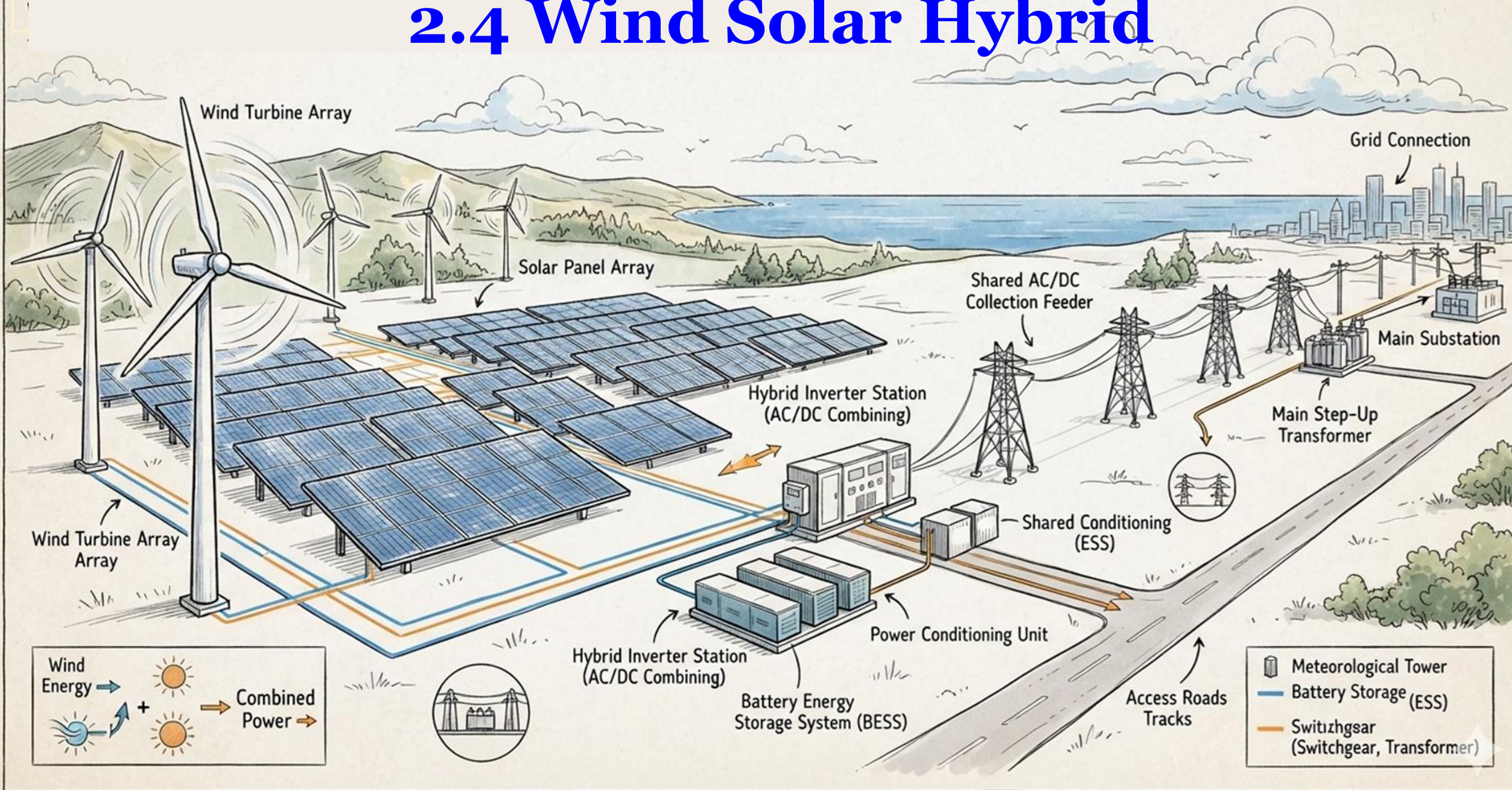
The Scaling of Wind Turbines to Monster Size



Approximate Comparison



2.4 Wind Solar Hybrid



Solar and Wind

...Complementary Resources

Solar

- Zero at night
- Morning ramp to Midday peak
- Evening decline
- Follows a dependable curve every day
- Peaks in Summer

Wind

- Weather, not hour driven
- Highly variable (varies daily & seasonally)
- Peaks in winter and spring
- Often peaks in late evening, nights and predawn complementing solar.

Different profiles can create a better combined profile.

Shared Infrastructure...

Solar-Wind Hybrid Systems

Integrating solar & wind helps leverage common infrastructure and reduce CapEx significantly:

Shared Infrastructure

- Transmission Infrastructure
- Substation & Transformers

Operational & Regulatory Synergies

- Permits & Clearances
- Land & Access Infrastructure

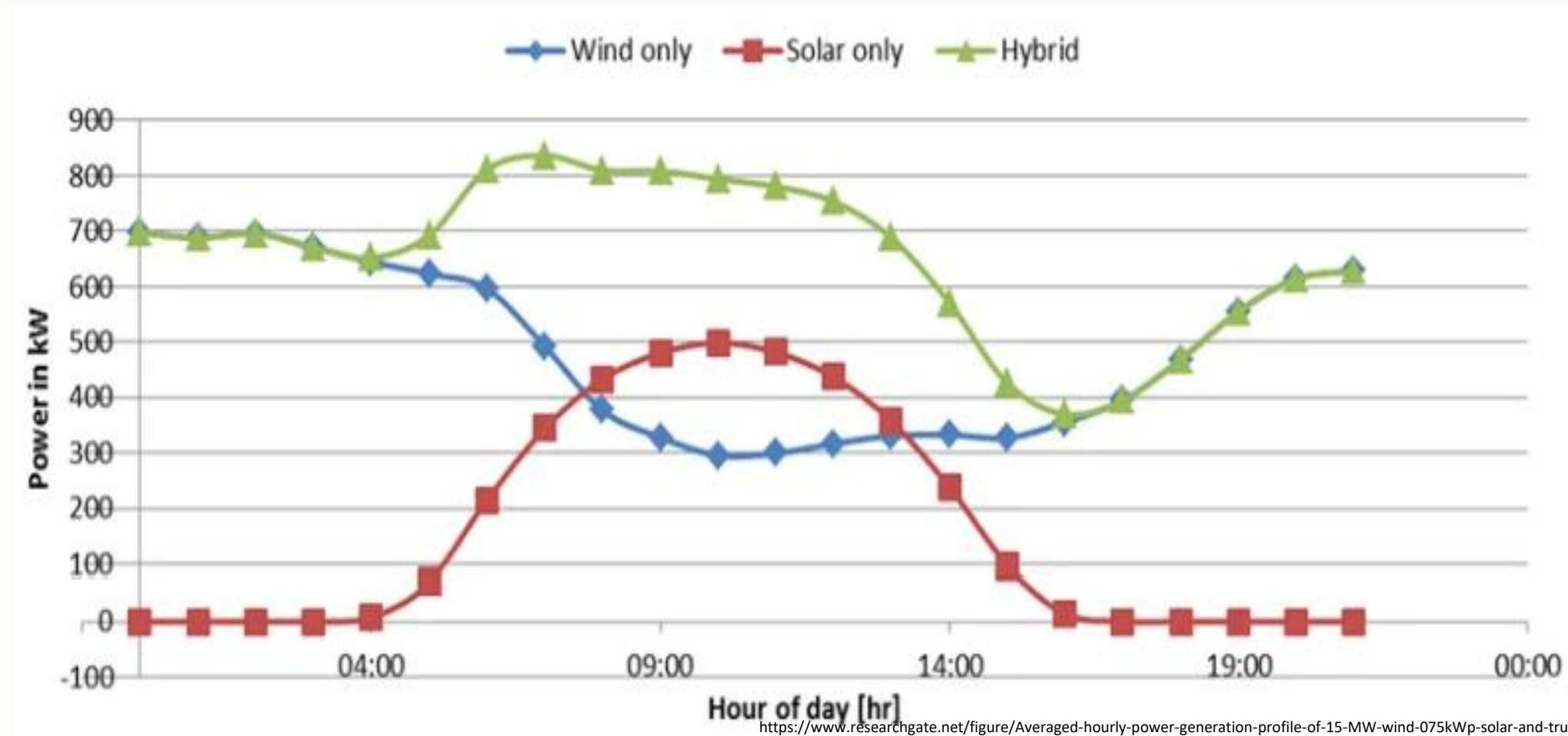
Grid Stability & Smart Management

- Co-located BESS / Hydro
- Integrated SCADA & Control Systems

Benefits of Hybrid Systems

- Higher utilisation of evacuation capacity
- Smoother aggregate generation
- Better reliability
- Reduced variability
- Better land utilisation
- Less BESS requirement
- Potentially lower curtailment
- Lower Cost

The Complementing Wind Solar Generation Profile



Value of stand-alone solar / wind plant whose generation peaks when the demand dips is typically $<$ a lower capacity Wind + Solar hybrid producing power when the demand is more

Technical Consideration for Wind-Solar Hybrid

Site Assessment & Resource Complementarity

- Meteorological correlation
- Shading and wake effects
- Geotechnical and land constraints

Electrical Integration & Power Electronics

- Coupling architecture (Shared/separate inverter/battery; peak generation without clipping)
- Harmonics and power quality

Balance of Plant (BOP) & Infrastructure

- Shared infrastructure
- Cabling and Cable layout
- SCADA & EMS (Ener. Mgmt Sys.)

Storage & Grid Compliance

- BESS
- Grid code adherence

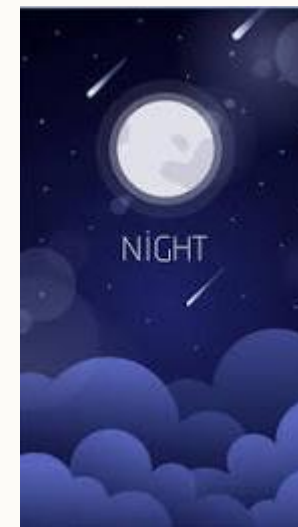
The Power of Three **for a more controllable generation profile** **Wind + Solar + Battery**



Solar → Grid
Solar → Battery

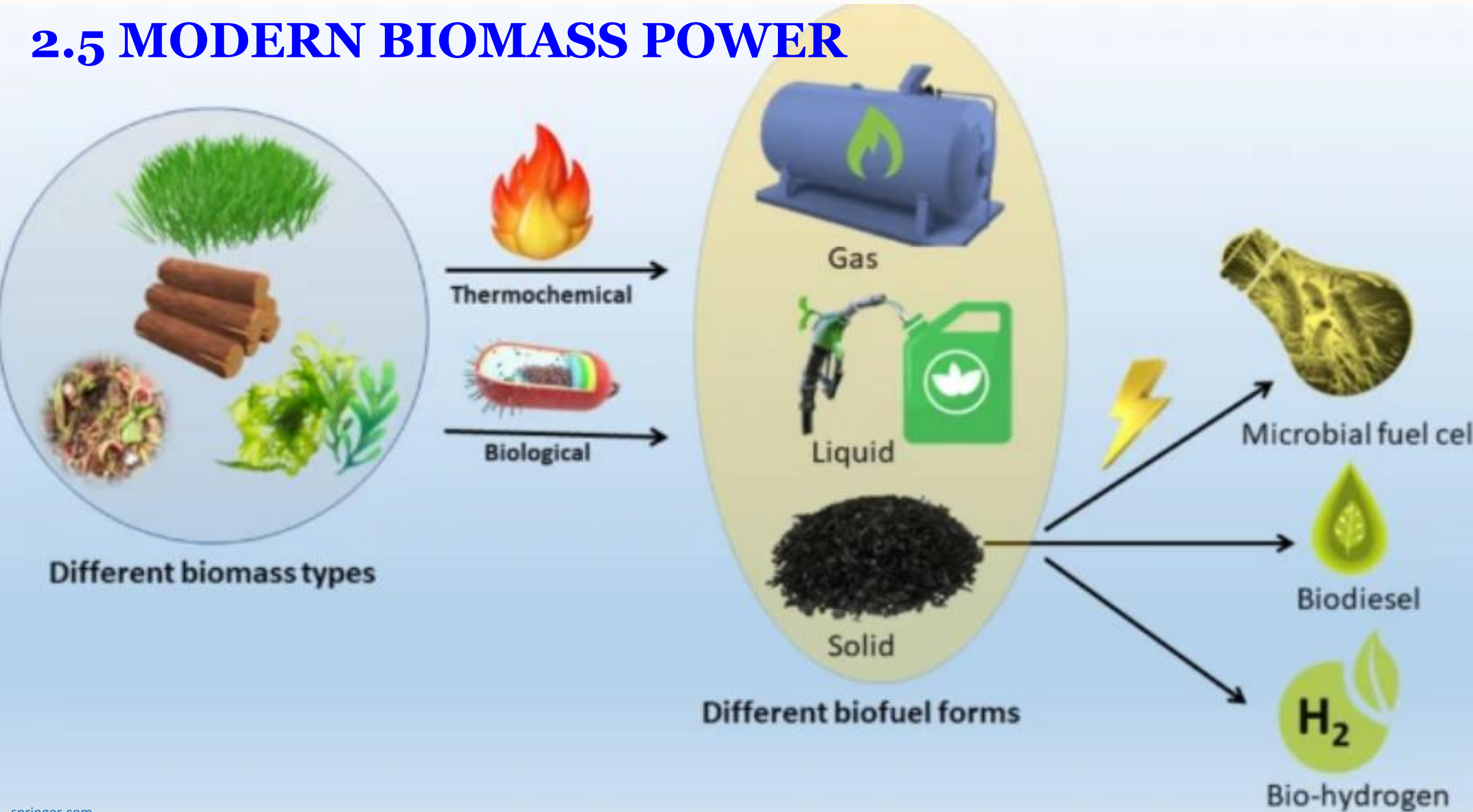


Battery → Grid
Wind → Grid



Wind → Grid

2.5 MODERN BIOMASS POWER



Transition from Traditional to Modern Biomass

Traditional

- Dominated by fuelwood, charcoal, and agricultural residues
- Characterized by low η (10–20%) and high indoor air pollution

Modern bioenergy

- Engineered fuels, controlled combustion & conversion technologies for heat, power, and transport.
- Emphasis on η , emissions control, and sustainability of feedstock

Transitioning from Poverty fuel to a Climate and Energy-Security tool

Biomass Technologies

1. Modern direct combustion

- Stoker, fluidized-bed & pulverized biomass boilers (η 25-35%)
- Co-firing with coal

2. Thermochemical Conversion – Gasification and Pyrolysis

- Syngas Gas: Partially oxidizing biomass @ high temp. (for IC engines / power gen)
- Pyrolysis (O₂ starved thermal decomposition)  bio-oil/biochar/syngas

3. Biochemical Conversion

- Fuels from bacteria/enzyme break down (bio-methane, advanced fuels: Aviation fuel, Diesel, Cellulosic ethanol, biomethane)

4. Integrated Flexible Energy Systems

- CHP and District Energy: for power gen and district heating (η >70%)
- Integration as firm dispatchable RE

Role & Importance of Bioenergy in RE Mix

- Can be compacted / converted to ready to use fuels
- Bioenergy can be stored unlike the flow resources Solar and Wind
- Is dispatchable and available at scale
- Would be key to tide over the intermittency of solar and wind
- Key to mitigate climate vulnerability of large solar and wind farms

Potential Biomass Feedstock and Applications in BIMSTEC

Feedstock



Rice residues



Agricultural residues



Plantation/agro-industrial residues



Animal waste



Food-processing waste



Organic municipal waste

Potential applications



Power



CHP



Industrial heat



Biogas/bio-methane

The Question is not which RE technology is the best.

But

**Which combination of technologies gives the best
RE Power-system solution.**

Biomass + Hydro + Battery + Variable Renewables

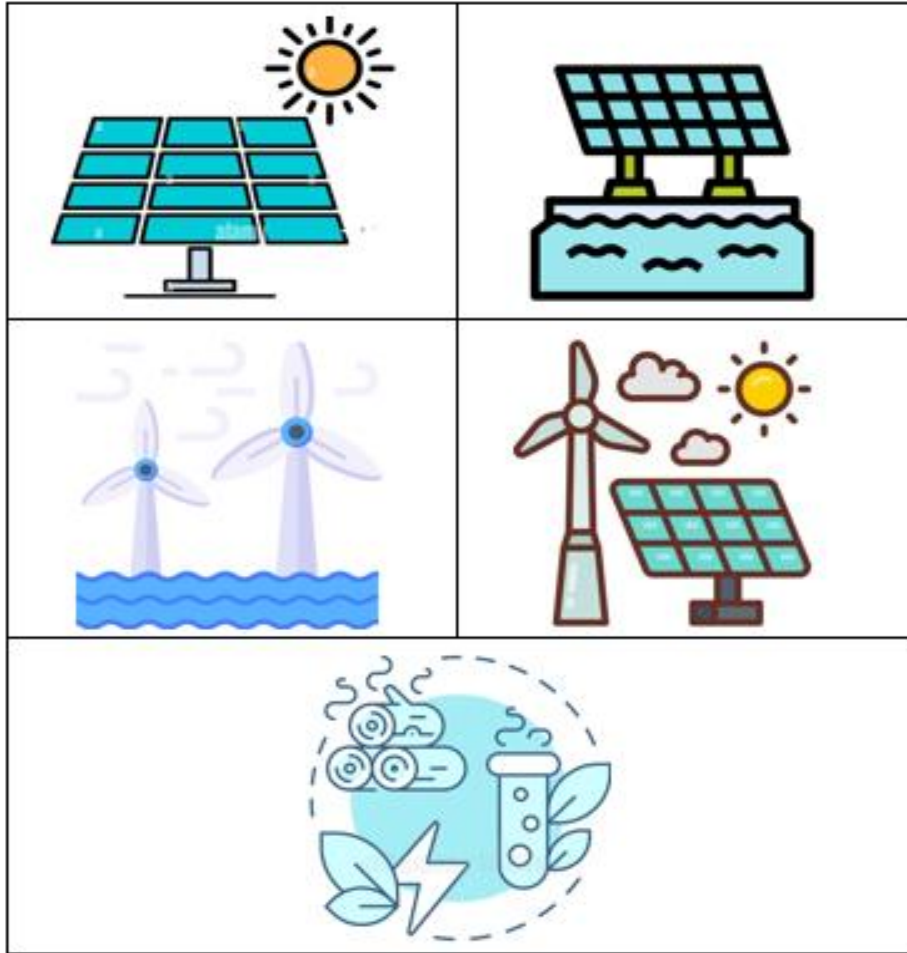
A Powerful Complement

Solar	→ daytime generation
Wind	→ variable generation
Hydro	→ flexible generation
Battery	→ short-duration balancing
Biomass	→ stored renewable fuel adding flexibility

Together: A more controllable renewable portfolio

From Stand-alone to Reliable Integrated RE System

Are they really separate solutions



But Pieces of one large integrated system

That generates more energy from land

Uses free water surfaces

Access the hugely unexploited sea wind

Combine solar and wind complementary profiles

Combine with firm and flexible bioenergy

Delivers Reliable, Resilient and
Round the Clock Clean Energy

Hybridisation at System Scale

From Variable to Firm RE

Unlocking the variable but cost effective independent Solar or Wind is possible through hybridization at system scale, using diverse resource:

D1. Technological Diversity

The Solar-Wind Complementarity

The Hydro-Biomass Stabilizer

D2. Geographic Diversity

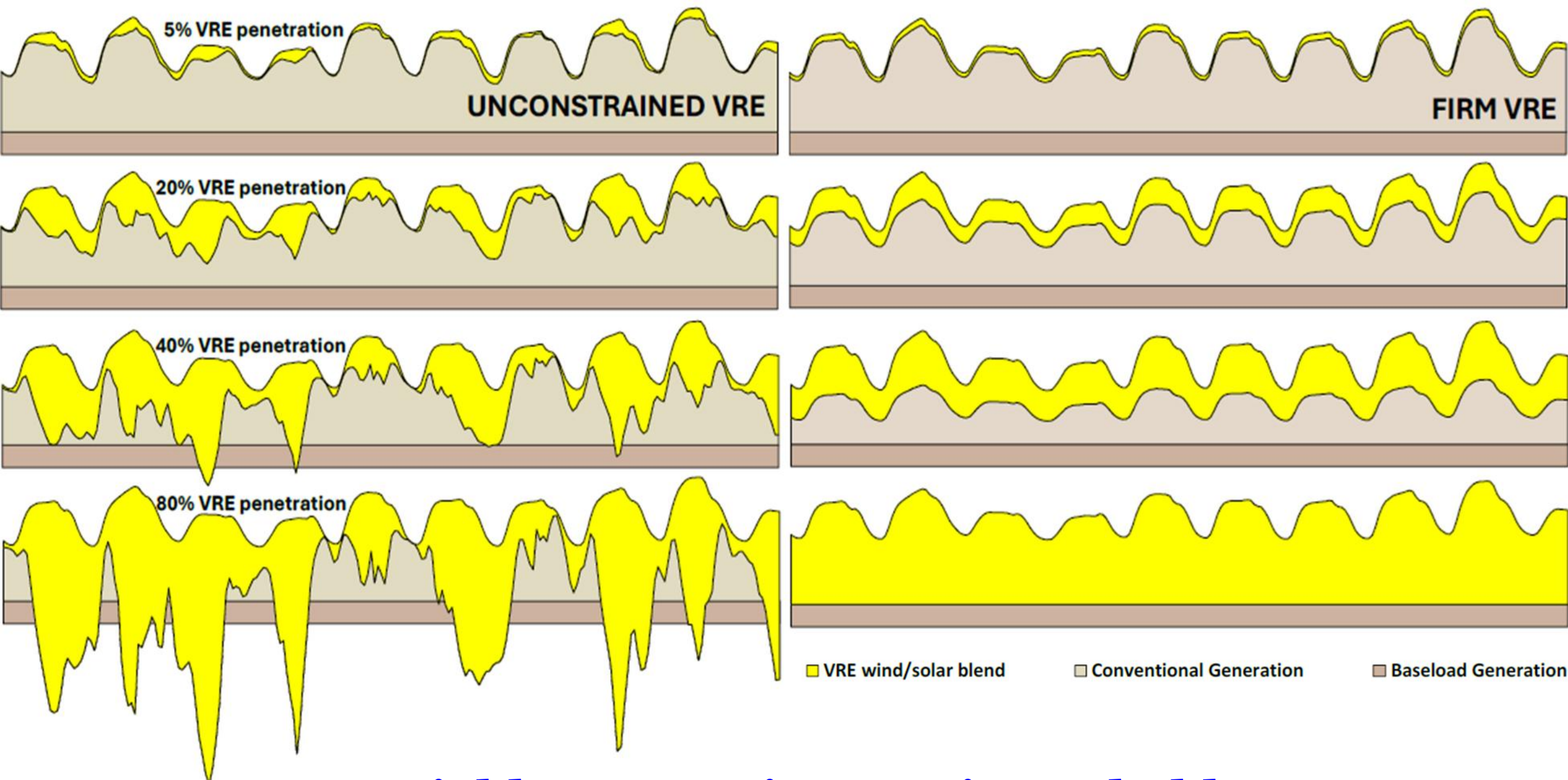
Spreading the generation across geographies to even out the fluctuations

Reducing the Storage Burden

D3. Seasonal Diversity

Complementary seasonal variation: Monsoon (hydro) vs. Summer (solar)

Anchor system integration on RE diversity and convert
localized variability into collective grid stability



2.6 From Variable RE to Firm & Dispatchable RE Power

Variable Vs Firm Renewable Power

Variable Renewable energy (VRE)

“Electricity generated when the resource is available.”

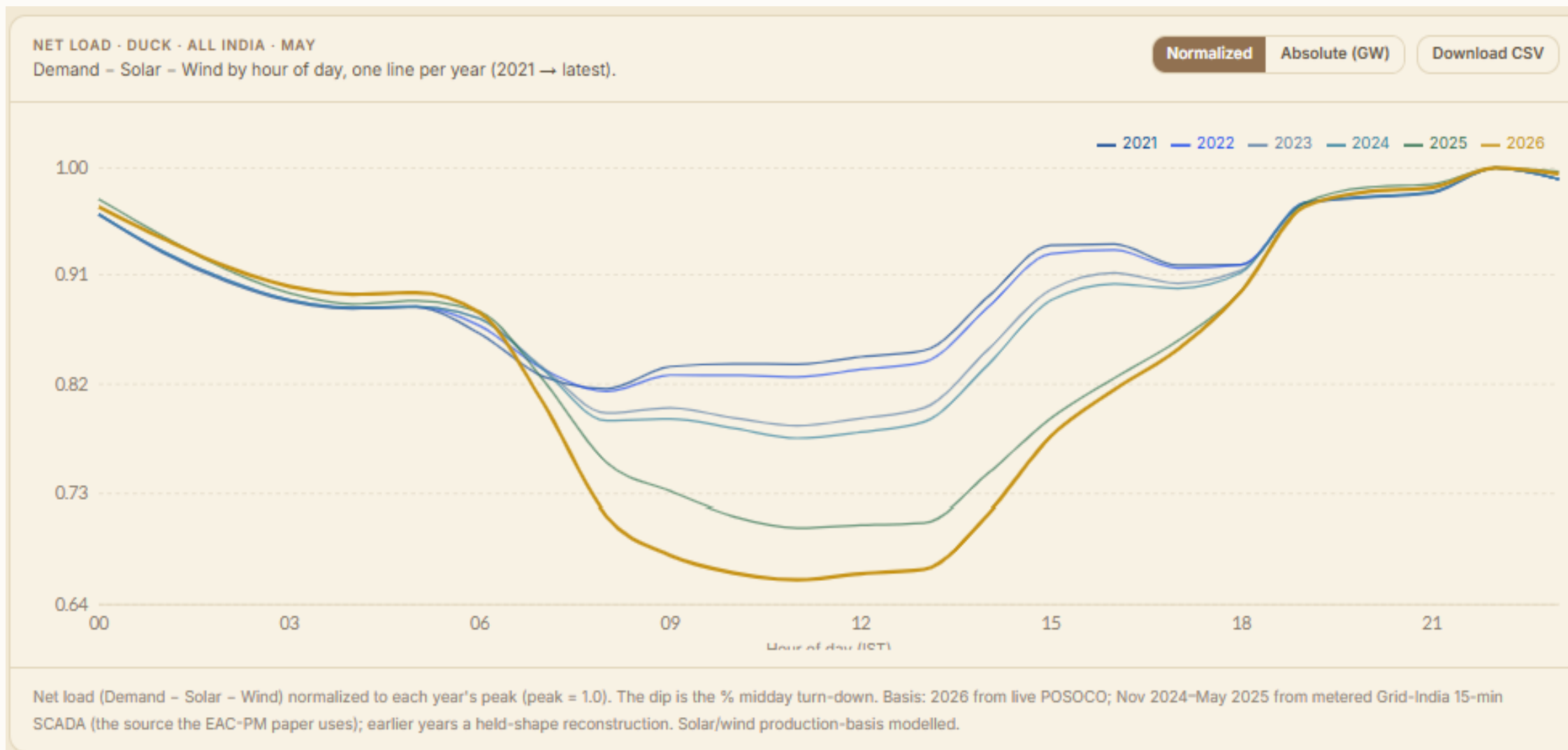
Firm Renewable electricity (FRE)

“Electricity made available when the system needs it.”

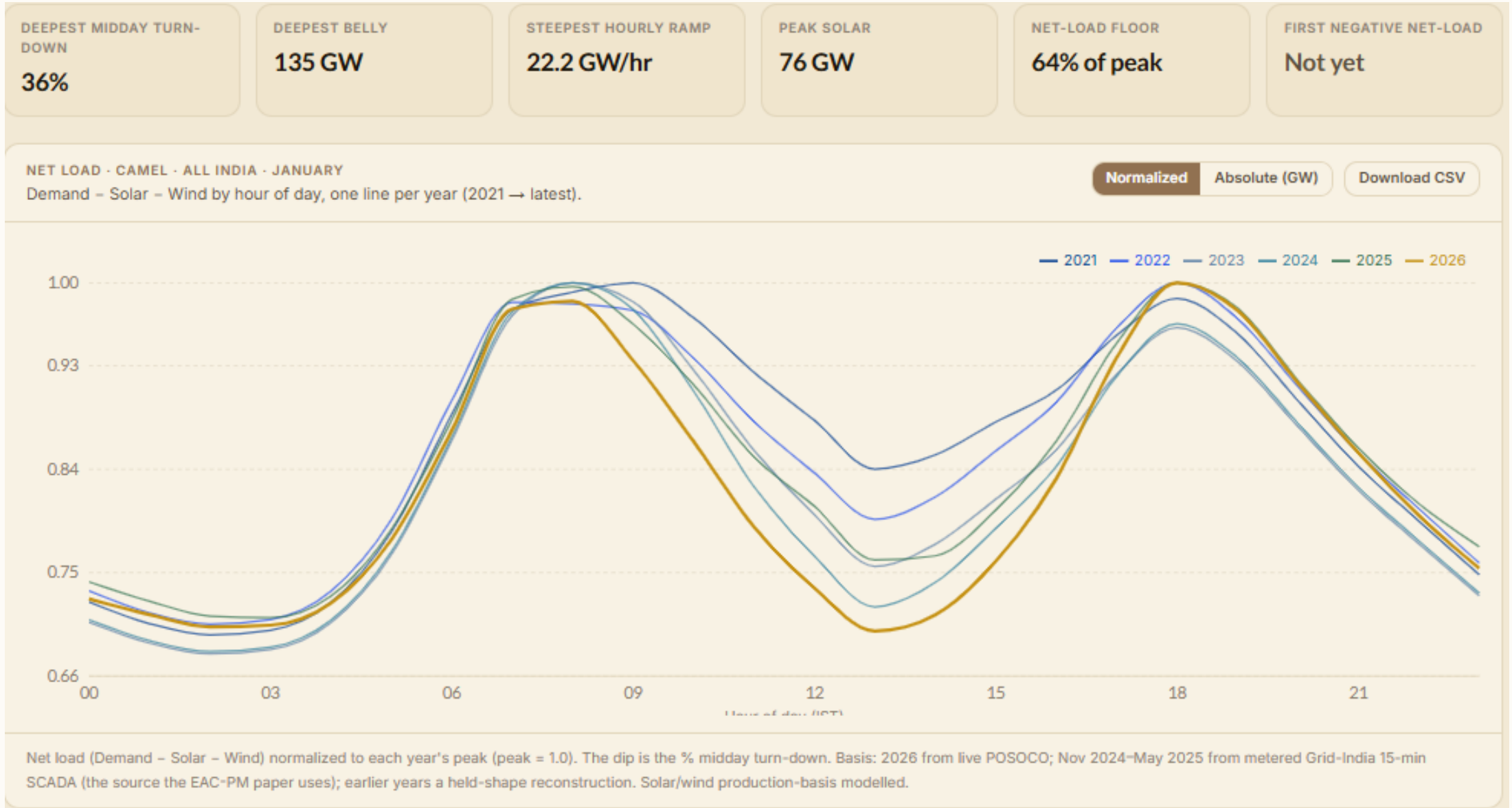
RE Power Delivered with

A high degree of reliability as per agreed schedule/system requirement

The Summer Duck Curve - India



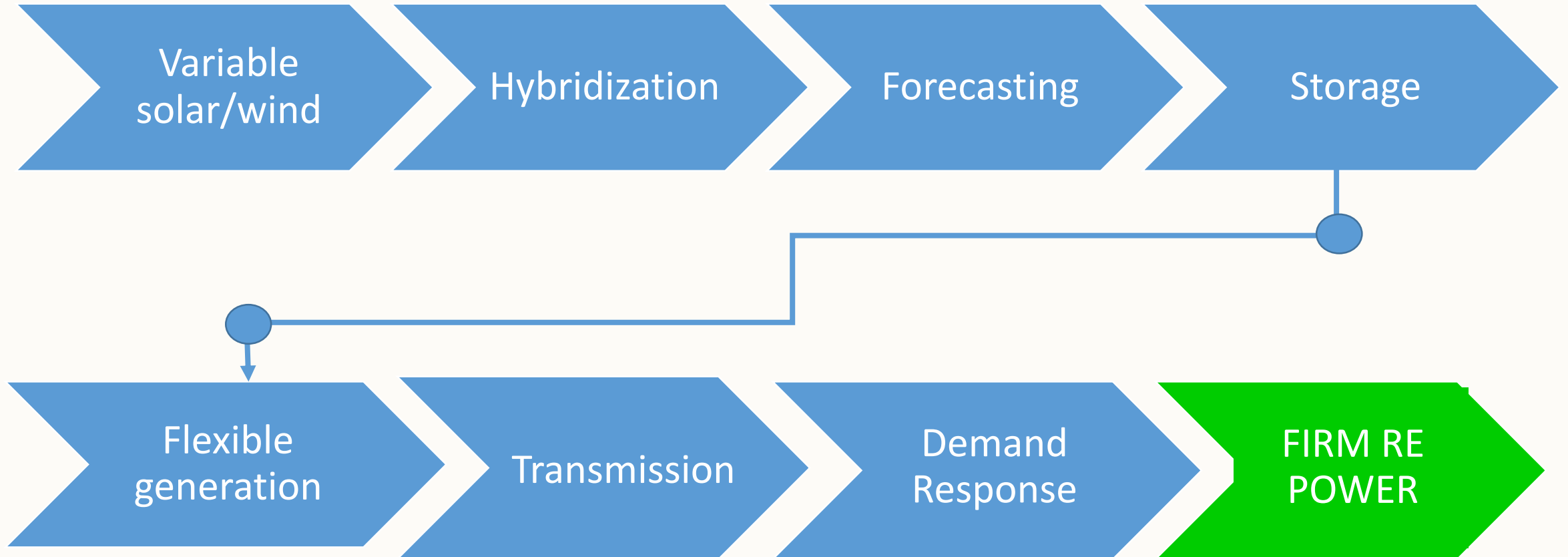
The Winter Camel Curve Curve - India



Net Load Ramps – Summer & Winter - India

NET-LOAD RAMPS - SUMMER DUCK The daily swing the dispatchable fleet must follow (GW), by year. The steepening is the flexibility problem					
YEAR	MORNING RAMP-DOWN (6→11H)	EVENING RAMP-UP (13→20H)			
2021	-4 GW	+20 GW			
2022	-8 GW	+27 GW	NET-LOAD RAMPS - WINTER CAMEL The daily swing the dispatchable fleet must follow (GW), by year. The steepening is the flexibility problem.		
2023	-17 GW	+34 GW			
2024	-23 GW	+43 GW			
2025	-35 GW	+54 GW			
2026	-47 GW	+67 GW			
			YEAR	MORNING RAMP-UP (4→8H)	EVENING RAMP-UP (13→19H)
			2021	+41 GW	+18 GW
			2022	+38 GW	+27 GW
			2023	+53 GW	+32 GW
			2024	+55 GW	+41 GW
			2025	+52 GW	+42 GW
			2026	+53 GW	+56 GW

Progression from Variable to Firm RE

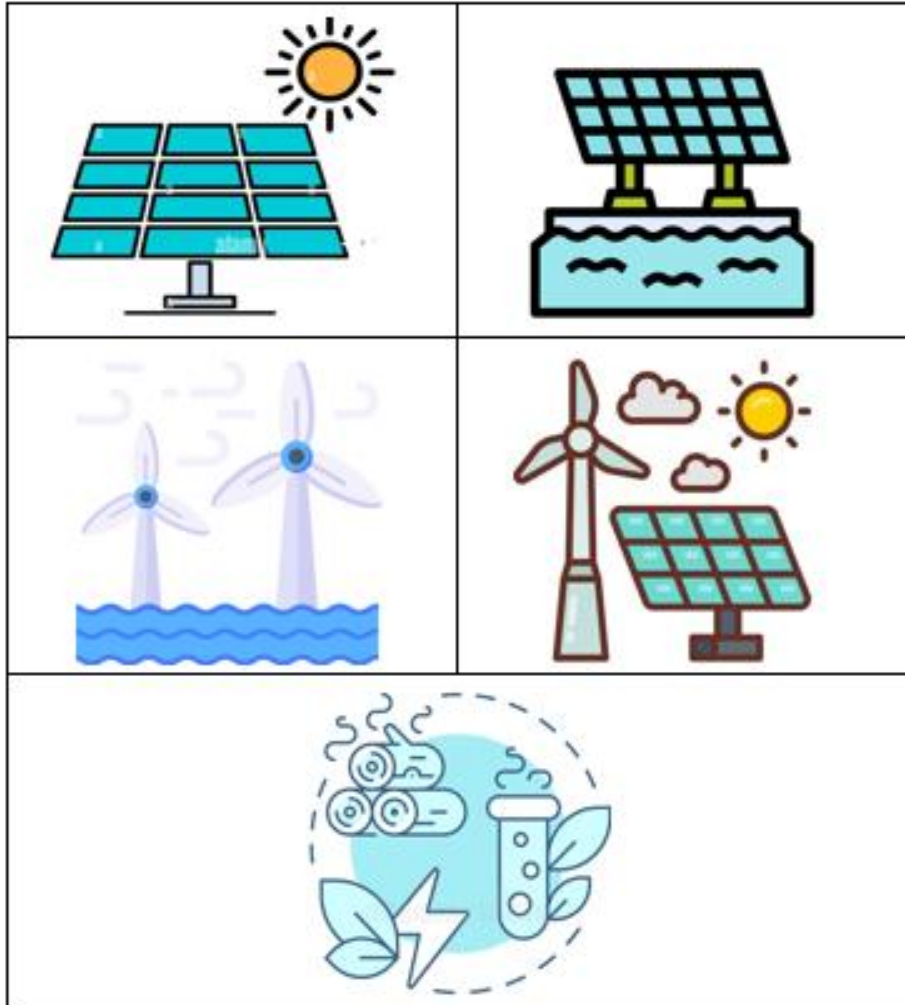


Storage: Different Technologies, Diverse Fulfillments

Technology	Typical role
Battery	Seconds to several hours
Pumped hydro	Hours to longer-duration storage
Thermal storage	Heat/electricity shifting
Hydrogen	Potential long-duration/seasonal applications
Reservoir hydro	Flexible generation; duration depends on reservoir/system

From Stand-alone to Reliable Integrated RE

Standalone solutions



TO

Pieces of one large integrated system

That generates more energy from land

Uses free water surfaces

Access the hugely unexploited sea wind

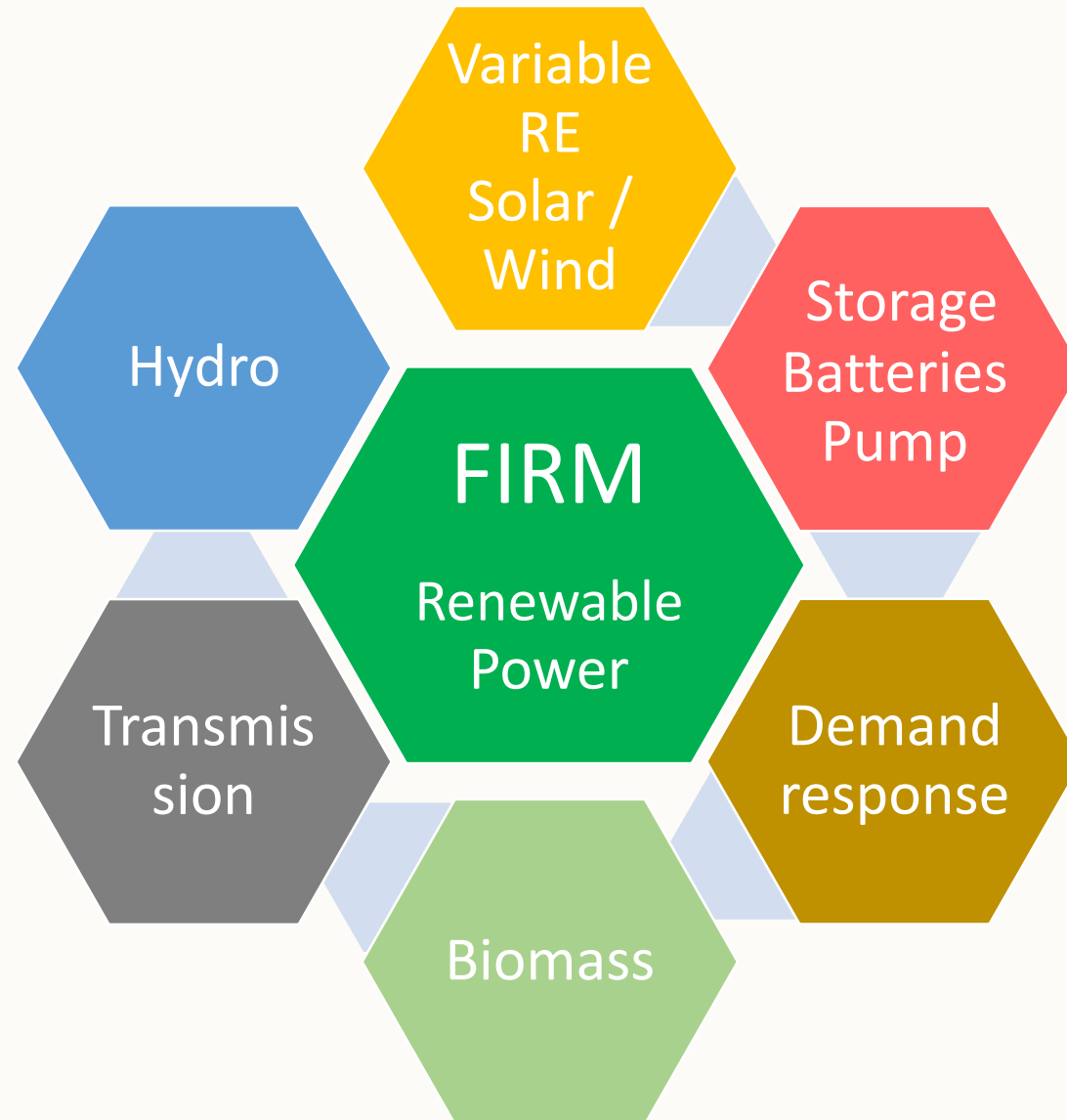
Combine solar and wind complementary profiles

Combine with firm and flexible bioenergy

That

Delivers Reliable, Resilient and
Round the Clock Clean Energy

Toolkit for Firm Renewable Power



Cost of Fixing the Variability

To make variable RE to Firm / Round the clock RE, additional costs involved:

- Additional generation capacity
- Storage
- Transmission
- Forecasting
- Grid reinforcement
- Reserve capacity
- Curtailment management
- Flexible demand

As RE gains prominence, the delivered cost of electricity—rather than LCOE—will emerge as the more meaningful metric for assessing economic viability and system

BIMSTEC's Extraordinary Resource Diversity

BIMSTEC nations are blessed with diverse RE resources and opportunities waiting to be exploited, at a far greater pace:



Solar

Tropical/subtropical solar resources



Biomass

Agricultural and agro-industrial residues



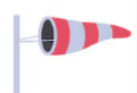
Hydro

Himalayan and regional hydropower resources



Water bodies

Reservoirs suitable for floating PV



Wind

Bay of Bengal - Onshore and potentially offshore resources

*Intelligent selection and mix of RE solutions that generates
Firm, Reliable & Resilient power and delivers to the grid*

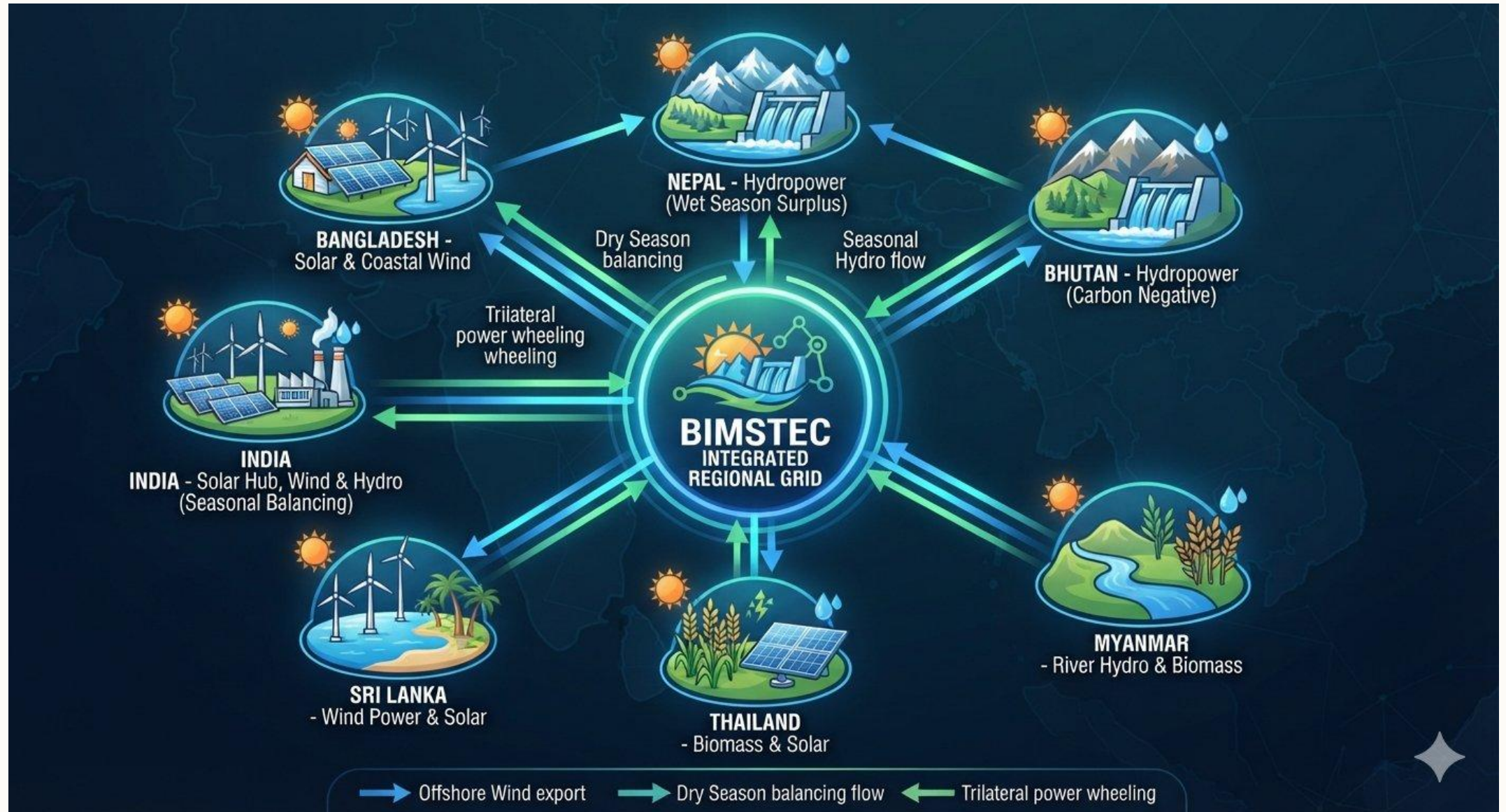
BIMSTEC Energy Profile: Predominant RE Resources

Country	Solar	Onshore/ Offshore Wind	Hydro	Biomass	Installed RE (GW)	Reference Date
India					239.66	Sep-26
Nepal					3.43	Dec-26
Bhutan					3.49	Jun-25
Myanmar					3.2	Jan-26
Bangladesh					1.56	Jun-26
Thailand					10.4	Apr-26
Sri Lanka					3.49	Dec-25

Potential Areas of Regional Cooperation

1. Regional renewable-resource assessment
2. Cross-border electricity trade
3. Grid interconnection
4. Floating solar + hydropower
5. Offshore wind knowledge and infrastructure
6. Hybrid renewable projects
7. Regional balancing and storage
8. Common technical standards
9. Data sharing and forecasting
10. Capacity building

From National to Regional RE System Integration



Blueprint for BIMSTEC RE Cooperation

- Geographic & Resource De-Risking
- Multilateral Power Trading
- Regional Electricity Market
- Unified Grid Codes
- Strategic Financial Pools
- Climate-Proofing Infrastructure
- Exploiting Seasonal Synergy
- Localized Supply Chains

The BIMSTEC Geo-economics Dividend

Securing a Resilient, Interconnected, and Zero-Carbon Future Together

- Total Energy Security and Access
- Reducing carbon emission and Climate impacts
- Affordable, accessible & Cost-Effective energy
- Reliable and Resilient grid
- Strong and sustained economic growth
- Improved quality of life

Together we build ...

a Secure, Resilient, Interconnected, and Zero-Carbon Future





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