Renewable Integration:
An industrial R&D perspective

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Renewables going mainstream

Global installations

Source: GWEC, Navigant, REN21, Bloomberg, MAKE

Competitive costs enable growth

Wind costs ↓ ~70% over the last decade

- Wind >35% of EU/US installs ‘12-’13
- 9 states w/ >10% wind generation

Solar PV costs ↓ 75%+ last 5 years

- Record installs in ’13 … 37GW
- Solar passed **140GW** installed base in ’13

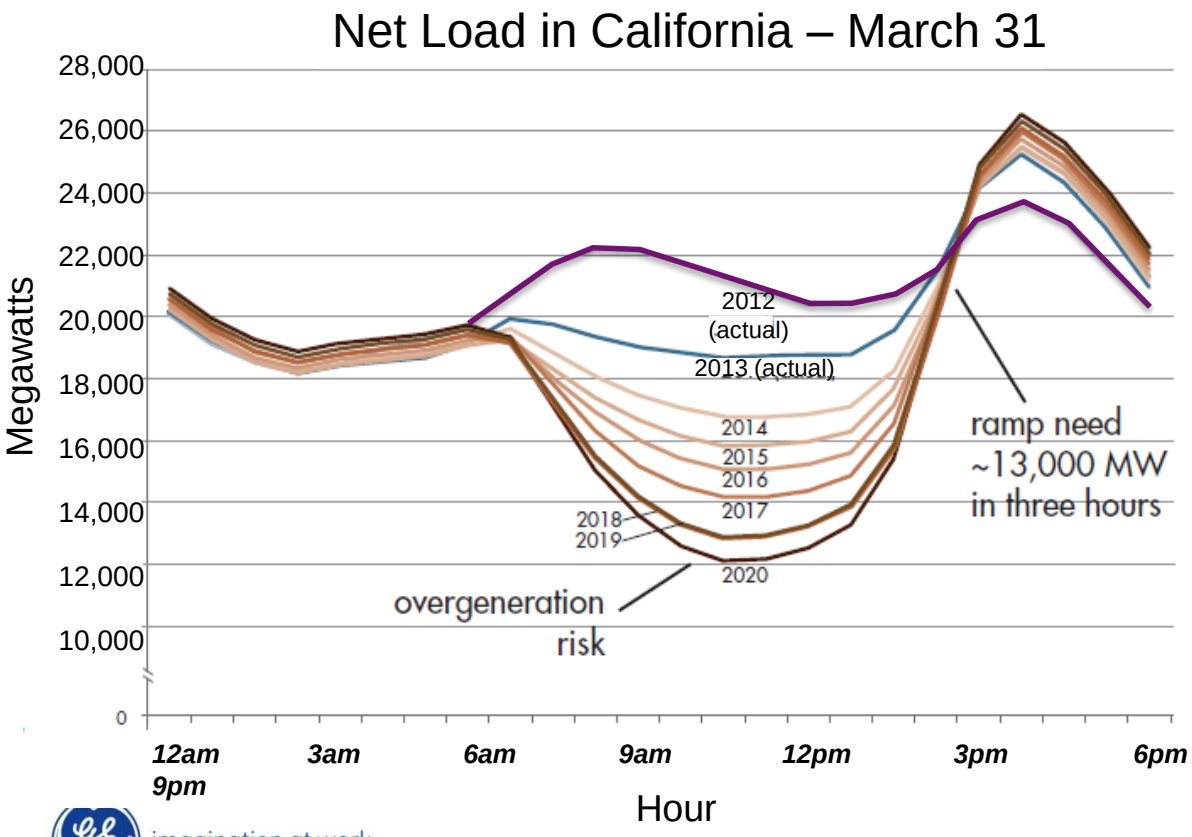
Source: EWEA, AWEA, EIA, GE Marketing

Technology making renewables more economic than ever

High penetration of Solar PV

Challenges of the "Duck Curve"

- Steep ramping needs
- Over-generation risk
- Decreased freq response



Potential Solutions

- Time-of-use pricing
- Energy efficiency from new building codes
- Demand response
- South-to-West PV orientation
- Smart inverter regulations
- Grid energy storage mandate

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http://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf

Instantaneous penetration of Wind

122% - Denmark
93% - Portugal
61% - Germany (w/ solar)
61% - Xcel (CO)
45% - Ireland
36% - ERCOT (TX)
34% - BPA (OR/WA)
33% - SPP (NE/KS/OK)
25% - MISO (Midwest)
… & more!

*Instantaneous penetration.
Sources: AWEA, America's Power Plan

Flexibility of grid is dominant factor in to predict disruption due to high penetration

Wind is a ‘good citizen’ of the grid

… when allowed to act like a power plant

All power plants…	**Wind** plants achieve this through …
Commit … power in advance	**Forecasting** free wind fuel →1st dispatched → ↓ curtailment
Dispatch … power as grid operators demand	**Power controls** control flexibility → ↓ curtailment, revenue opportunity
Regulate … transmission voltage	**Voltage controls** connect to weak grids, utility trust → ↓ curtailment
Stabilize … grid during disturbances	**Ride-thru controls** interconnect site, avoid curtailment by supporting grid

Operating wind as a power plant helps the grid and the economics

Integrated storage to improve flexibility

Short-term predictability … when utilities want fixed power

Help plant owner forecast output

Lower integration cost or avoid penalties with 15-30min firm output

Frequency regulation … offer additional power control services

Help grid operator control power

Get paid for controlling power output quickly

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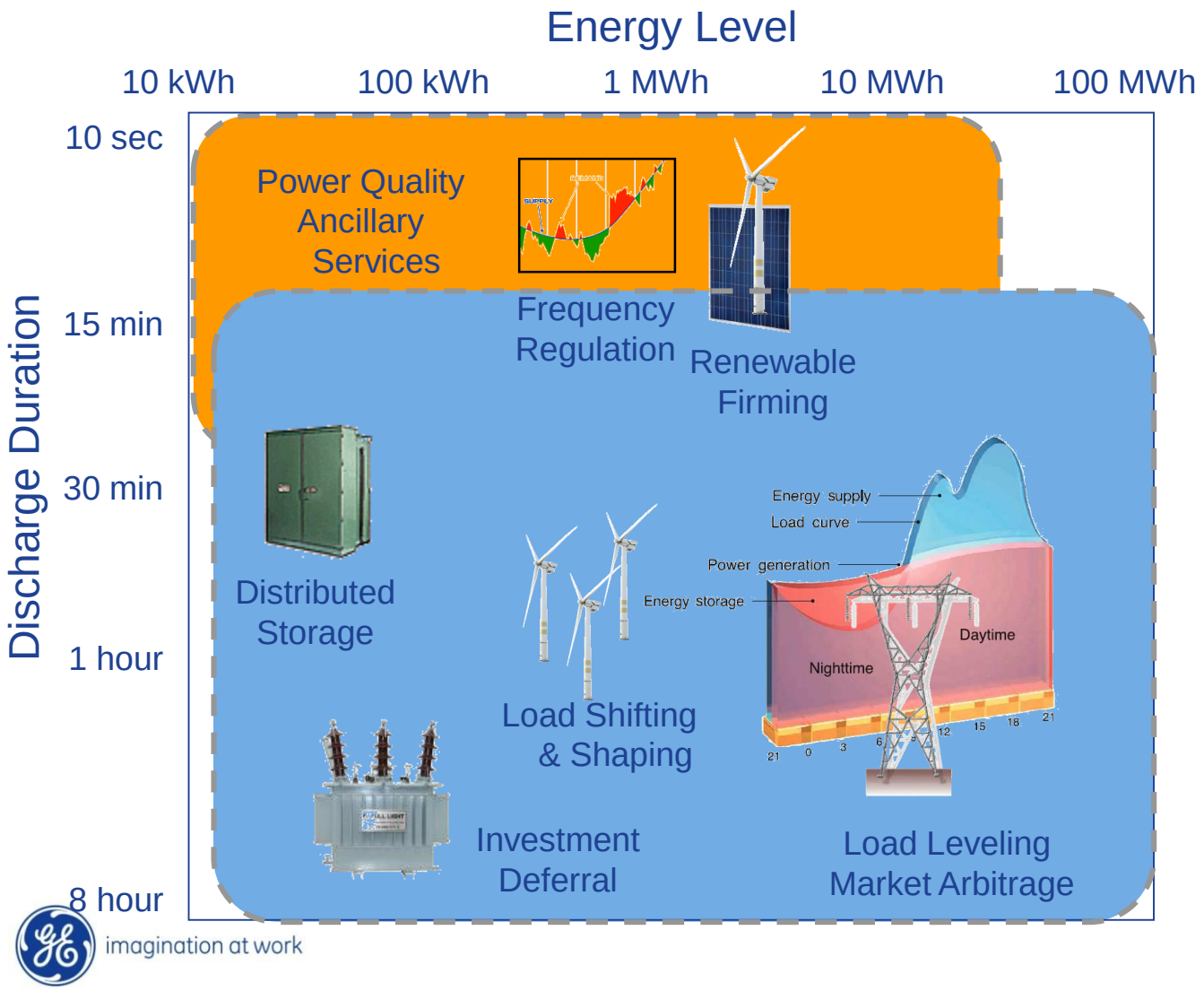
Storage enhances wind power plant controls

Range of energy storage grid applications



Power Capable

Ultra Capacitors

Advanced Batteries

Flywheel

Energy Capable

Thermal

Advanced Batteries

CAES

Gravity P.Hydro

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Challenges to Conventional Systems

Data & Analytics

Energy Efficiency

Rooftop Solar

Energy Storage

On-Site Power

What are the Disruptors?

Data & Analytics

Elec. Costs ↓ 20%

"Optimizing power use through software"

~$3T/Yr

"Lowering Energy Costs"

Energy Efficiency

TWh ↓ 10%+

"Less kWhrs"

Rooftop Solar

25+GW/yr.

"Biz models make it cheaper than grid"

On-Site Power

Efficiency 80%+

"Reliable power is critical"

Energy Storage

Cost ↓ 40%

"The Holy Grail"

Disruptors dramatically impacting the electrical power industry

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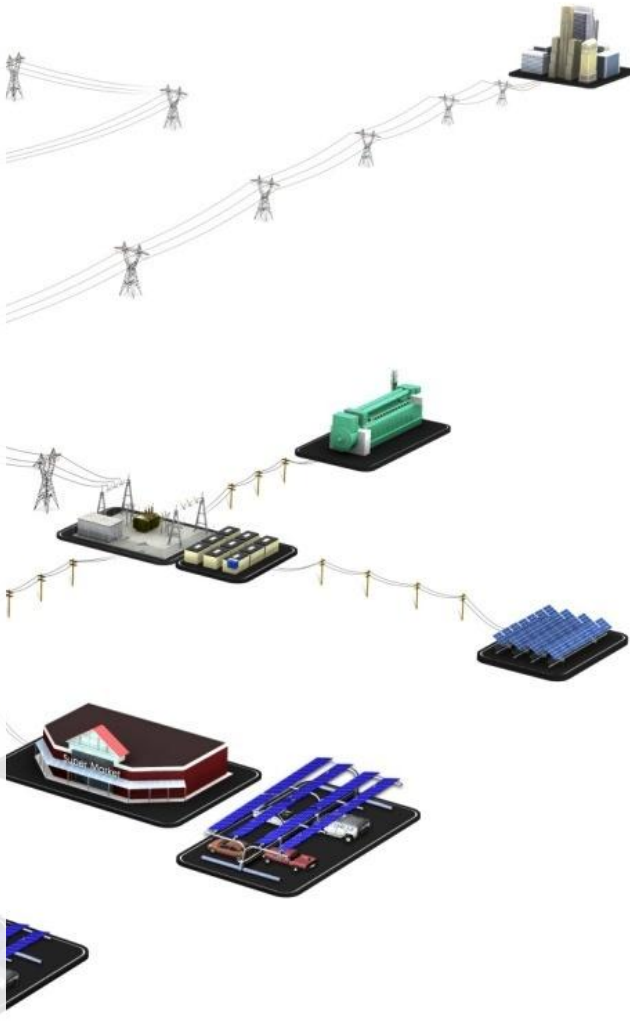
Source: Washington Post, Bloomberg, GE Marketing Analysis

Transformational Challenges

Grid Infrastructure	• Variability of renewables • Distributed generation
Grid Stability	• Frequency response • Reduced system inertia
Transmission	• Wind relative to load centers • Conservative margin limits
Electric Vehicles	• Harmonics and overloading • Shift in load timing
Planning & Operations	• Bi-directional power flow • Contingency planning
Policy & Standards	• RPS and Storage mandates • IEEE 1547, UL1741 BDEW
Distributed Models	• Dispersed kW scale generation • Dispersed generation ownership
Economic Uncertainty	• Market transformation • Economy of scale



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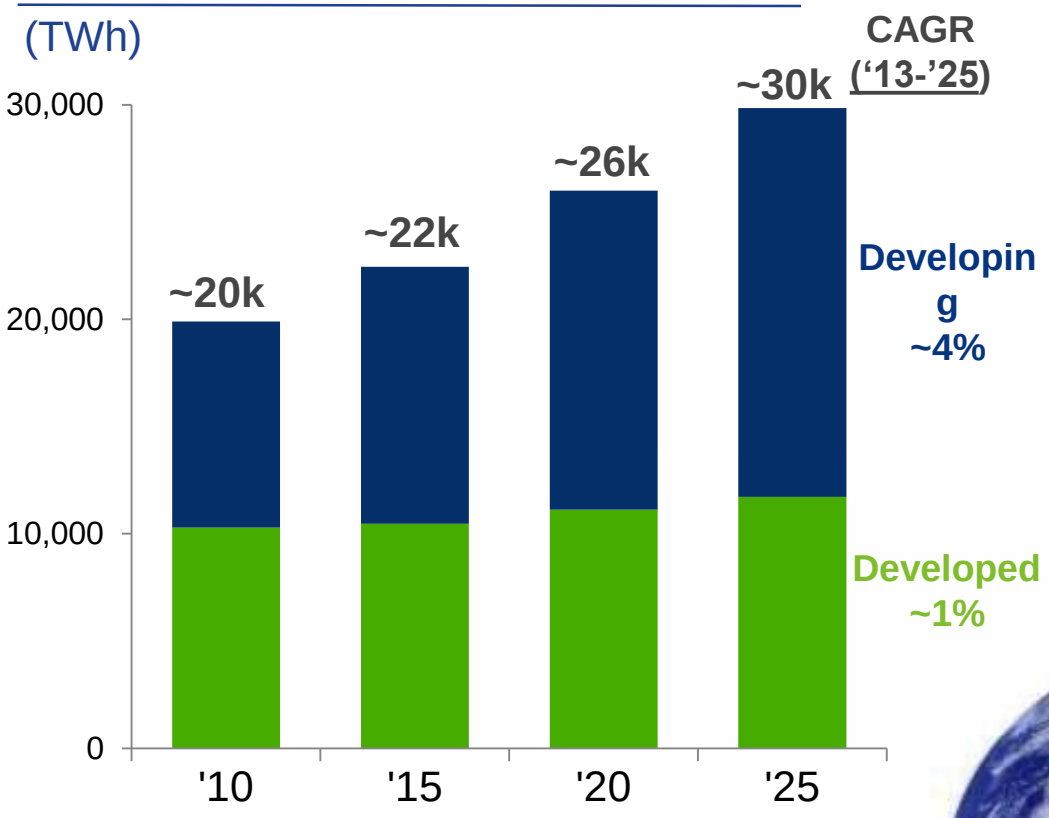
Growth centers are shifting

Electricity consumption



Developing economies

2x demand '10-'25

60% of global economy

85% of kWh

Developing countries will account for +60% of electricity consumption by '25

Source: IEA, GE P&W estimates

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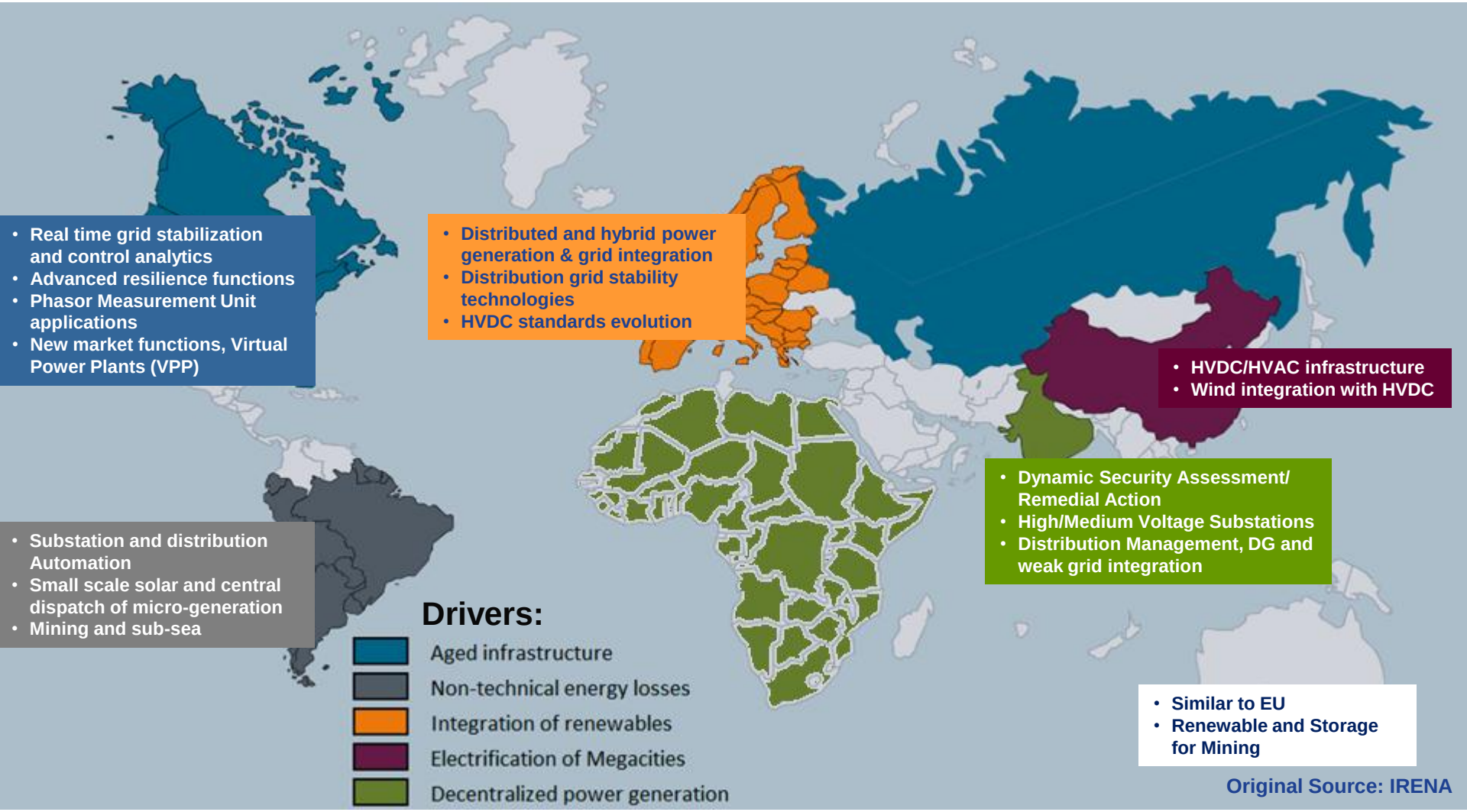
Drivers for energy system innovation



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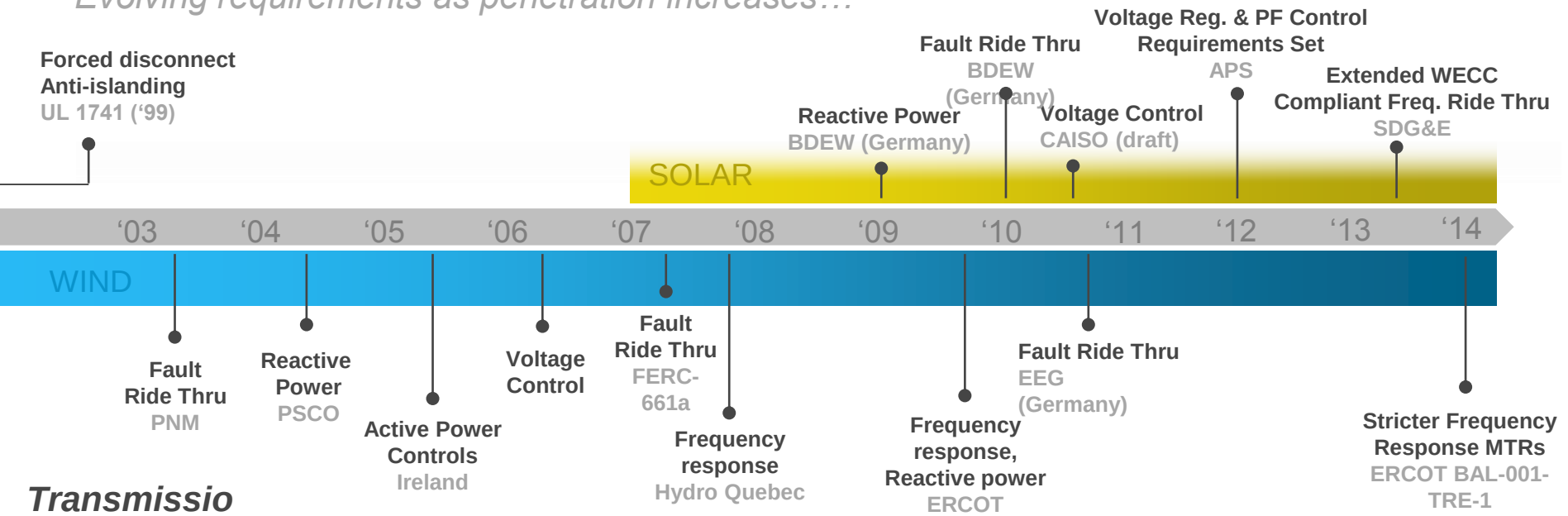
Tech development strategy depends on local needs


Questions/Comments?

Renewables

Evolving requirements as penetration increases…



Transmission

Early stages
- No frequency support
- Optional fault ride –thru

Increasing GW online
- Frequency response
- Mandated globally fault ride-thru
- Virtual inertia

Next Gen Tech
- Energy storage integration
- Virtual synchronous generator

Distribution

Early stages
- Trip offline w/ grid disturbance
- No reactive power

Increasing GW online
- Ride-thru grid disturbances
- Dynamic voltage control

Next Gen Tech
- Blackstart
- Smart distribution voltage reg.