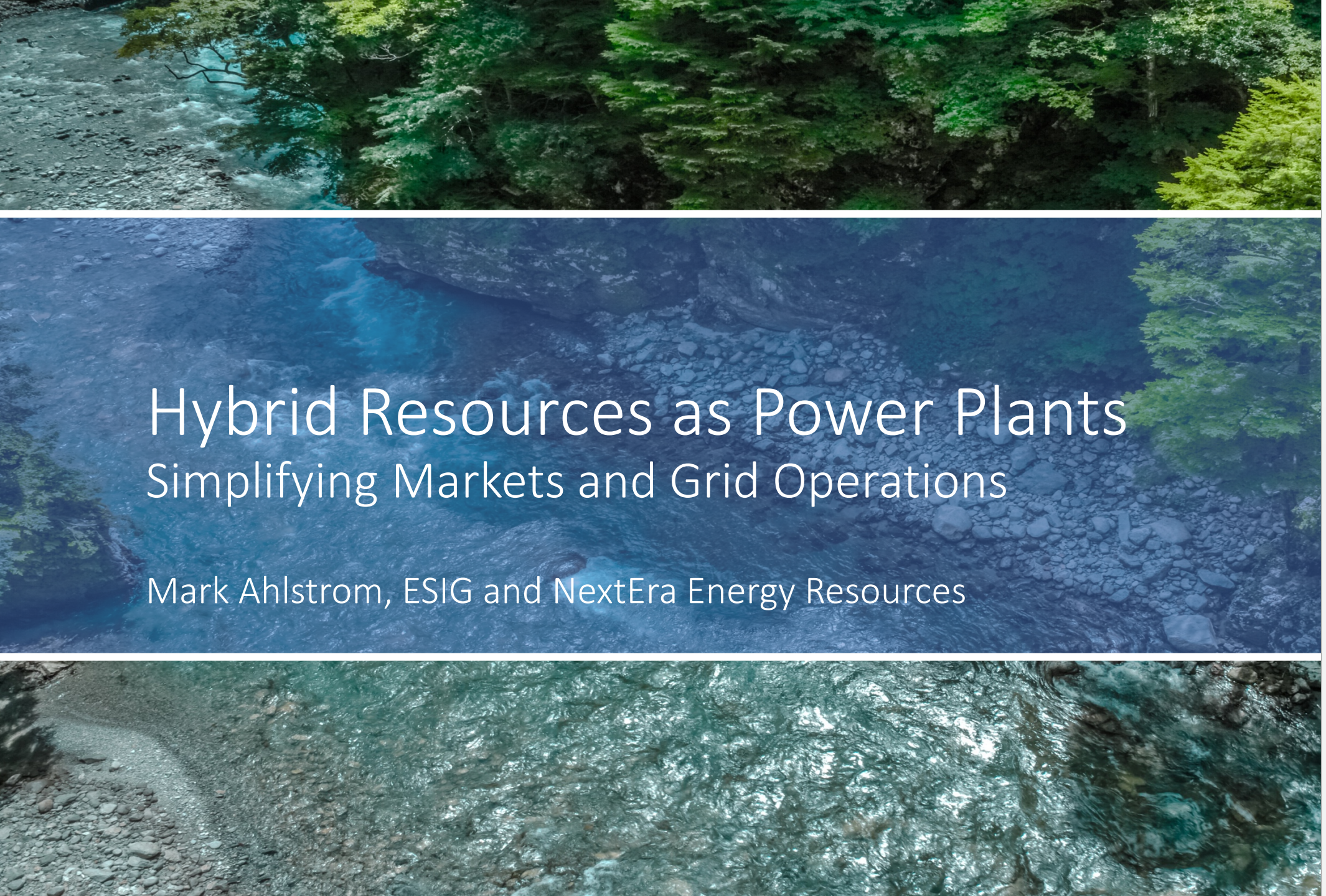

Hybrid Resources as Power Plants

Simplifying Markets and Grid Operations

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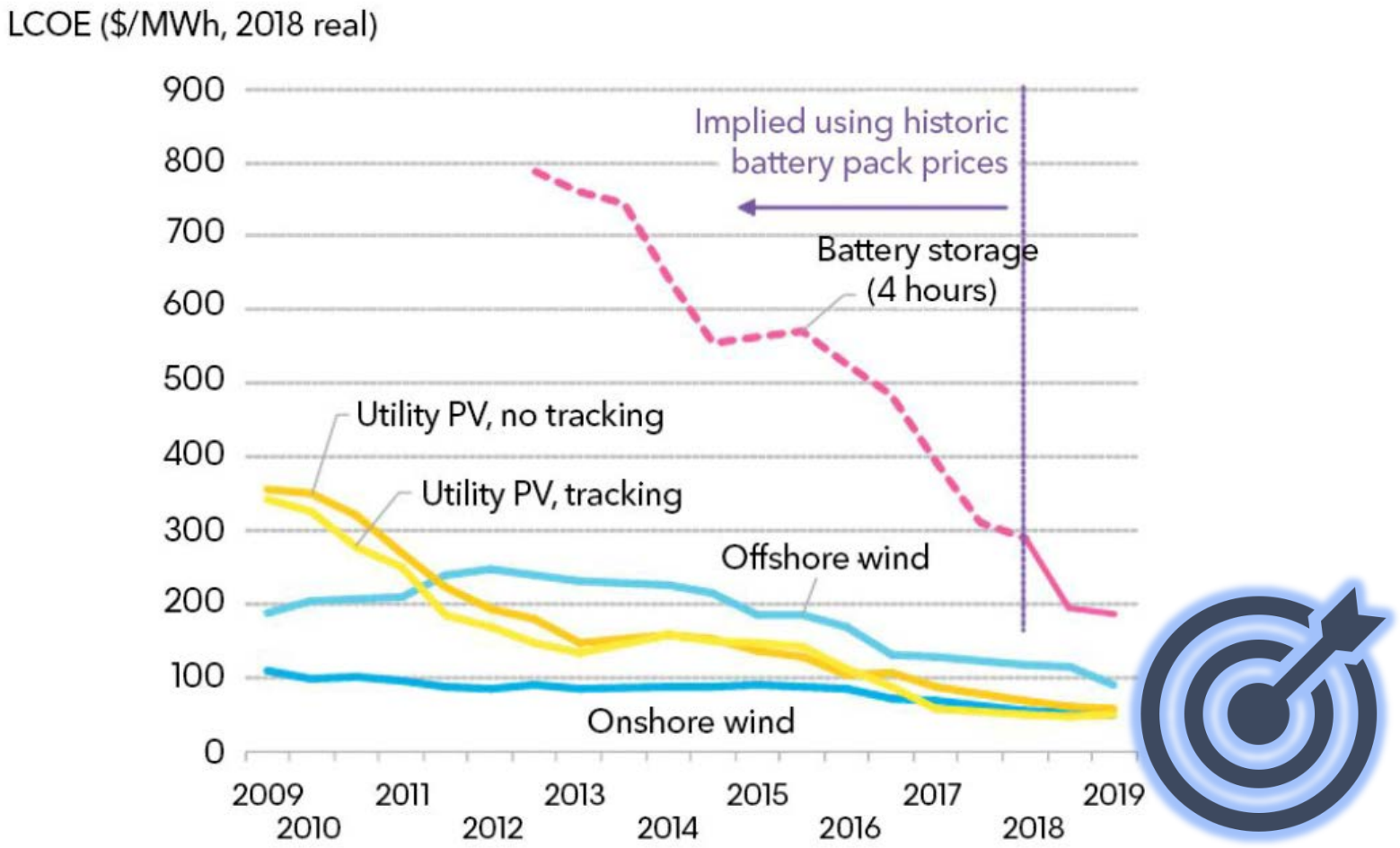
ESIG

ENERGY SYSTEMS INTEGRATION GROUP

Global benchmarks - PV, wind and batteries



Source: BloombergNEF. Note: The global benchmark is a country weighed-average using the latest annual capacity additions. The storage LCOE is reflective of a utility-scale Li-ion battery storage system running at a daily cycle and includes charging costs assumed to be 60% of whole sale base power price in each country.

Our Digital Revolution

Non-synchronous resources are electronically coupled to the grid

- This is a digital revolution in power generation, with the ability to program the behaviors that we desire, but the need to understand exactly what we want

Storage – What is it?

- We are familiar with generators and loads, but storage is both and neither
- Does some storage enhance almost everything?

Storage Hybrids – Even more disruptive? Or are they easier?

- Hybrid “solar + storage” power plants… or “anything + storage” power plants
  - May also apply to virtual power plants and aggregated distributed energy resources

Hybrid Resources – Definition

A combination of multiple technologies that are physically and electronically controlled by the Hybrid Owner/Operator behind the point of interconnection (“POI”) and offered to the grid as a *single resource* at that POI

Proposed Hybrid Resources Concept

An “intelligent agent” approach whereby the Hybrid Owner/Operator internalizes the characteristics of the components behind the POI and offers energy and/or ancillary services at the POI in the same way as a conventional resource, but with more flexibility and fewer constraints through coordinated use of energy, storage, power electronics and software technologies

Benefits to System/Market Operator

- Use existing “conventional” market participation models
- Treat hybrid like conventional resources, not renewable or storage resources
- Hybrid Owner/Operator manages state-of-charge through their offers
- Hybrid offers of energy and ancillary services in both DA and RT markets
- Offers of energy and ancillary services co-optimized from all resources
- Doesn’t curtail renewable for headroom – services from battery rate-of-charge
- Provides fully convex, single-part bids without advance commitment requirements, startup costs, minimum generation levels or other constraints

Benefits to Hybrid Owner/Operator

- Can participate in all market products using an existing market participation model
- Treated like conventional resource with full co-optimization of energy and ancillary services offers using existing day ahead and real time constructs
- Allows the renewable component of the Hybrid Resource to generate fully without the need to be curtailed to retain headroom
- Allows the storage component of the Hybrid Resource to be charged from the renewable component of the Hybrid Resource
- Same incentives/penalties for performance as for conventional resources

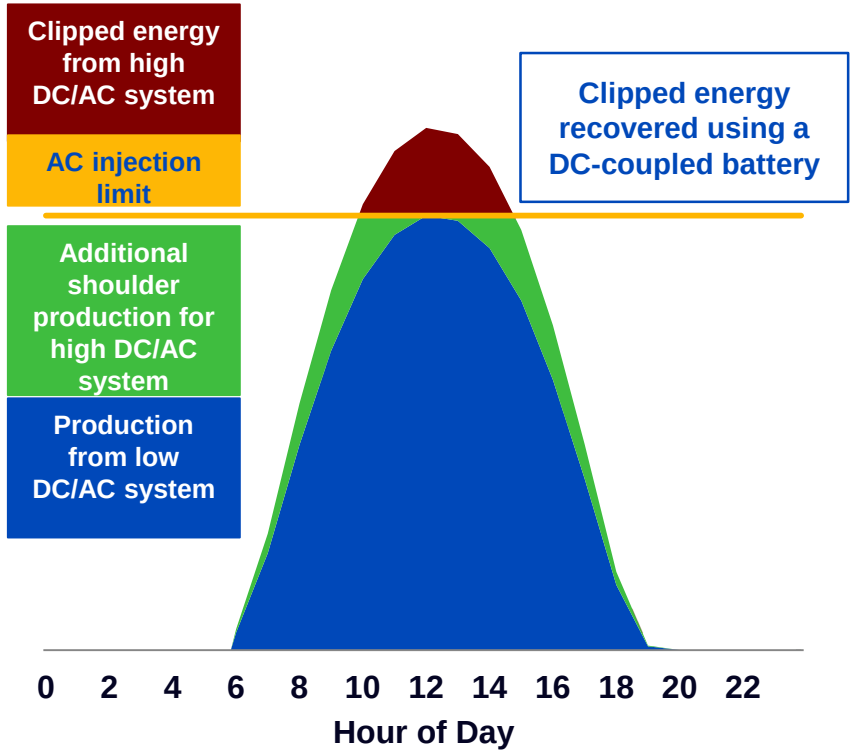
Motivations Aligned with System Benefits

- Optimizing their power plant design to maximize the services that are useful to and valued by the system while minimizing their risk of delivering such services
- Using the best available forecasts of the renewable resource (and investing in improving those forecasts, including probabilistic forecasts that better reflect risk and certainty around the forecasts), because this allows them to offer larger volumes of the services while managing their risks
- Building battery state-of-charge assumptions and battery degradation costs into offers using their access to all components and information, and analyzing how forecast errors will relate to state-of-charge and degradation characteristics
- Forecasting and offering their services to be most available during the most critical hours of system need, as this should align with periods of highest value

DC-coupled PV + Storage Hybrid Resources

Hybridizing changes plant design

- Leads to dramatic internal design changes and higher effective renewable capacity factors
- Variability is eliminated by pushing much of it into clipped region and controlling battery charge rate
- Forecasting skill is improved
- Many options to optimize layout, orientation, bifacial PV panels, etc.
- Optimized use of interconnection



PV Hybrid Resources – Offers and Operations

Offer strategy based on high-confidence PV forecast (DA and RT)

- Offers use probabilistic PV forecast (~P95) backed by storage to firm variability and forecast uncertainty
- Creates products by controlling battery charge rate, NOT by retaining headroom on PV
- Battery is usually charging and is NOT an energy-limited resource during daylight hours
- Battery state-of-charge controlled via offer strategy (reg-up and spin is usually charging)
- Supports energy & ancillary product offers that can be co-optimized by the market

Hybrid Resources internalize the non-convexities and the renewable forecasts

- Single-part offers, Pmin=0, Pmax=offer based on P95+ forecast
- No startup time, startup cost, min-run time or other constraints

Hybrid Resources – Summary and Future Steps

Hybrid Resources can initially compete as “generic flexible generators”

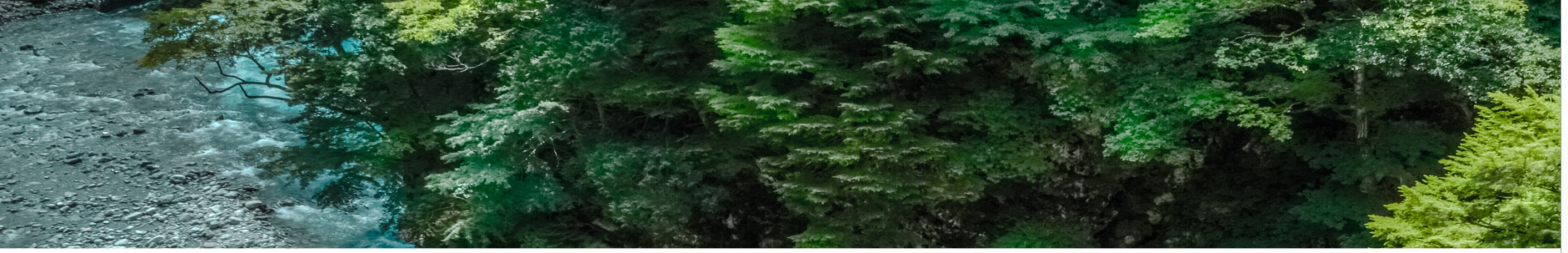
- Allow treatment as a single resource – a unified system controlled by an intelligent agent
- Hybrid would give up renewable DIR/PIR-type settlement and other VER accommodations
- Treat Hybrid Resource comparably to a conventional generation resource with a typical forced outage rate, including comparable incentives/penalties for performance and contingency treatment

Eventually, market designs will evolve to use “flexible generators” even better

- Simpler markets based on internalization of non-convexities, single-part bids, multiple settlement intervals closer to real time, no uplift payments, and services that correspond to higher-level grid services for balancing, flexibility, reliability and various types of capacity will become compelling

Will we build standalone storage, or mostly just Hybrid Resources?

- Which is better for you, a highly flexible generator or a battery storage resource?
- What, exactly, is the difference? How does it affect planning, markets and operations?



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