

Long Term Resilience of Decarbonization, Electrification, and the Energy Transition



Santa Fe Institute

Pathways to Deep Decarbonization of the Power Grid, February 2020

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“Long Term Resilience of Decarbonization, Electrification, and the Energy Transition”

New words? Think “Synergy”

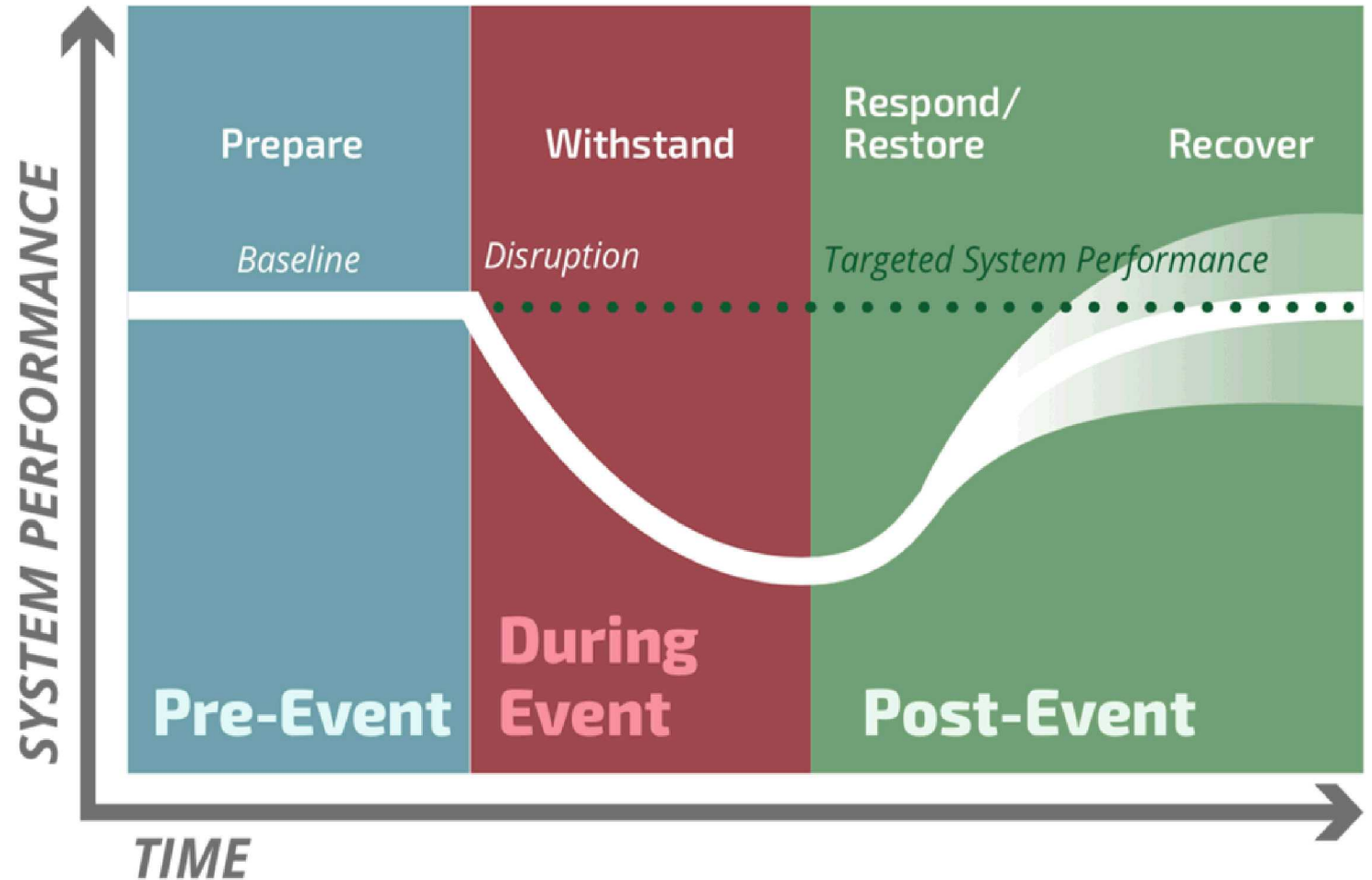
Resilience is not only about responding to acute perturbations, but also to chronic, long term bottlenecks

Defining resilience as it pertains to the grid

“The term ‘resilience’ means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.”

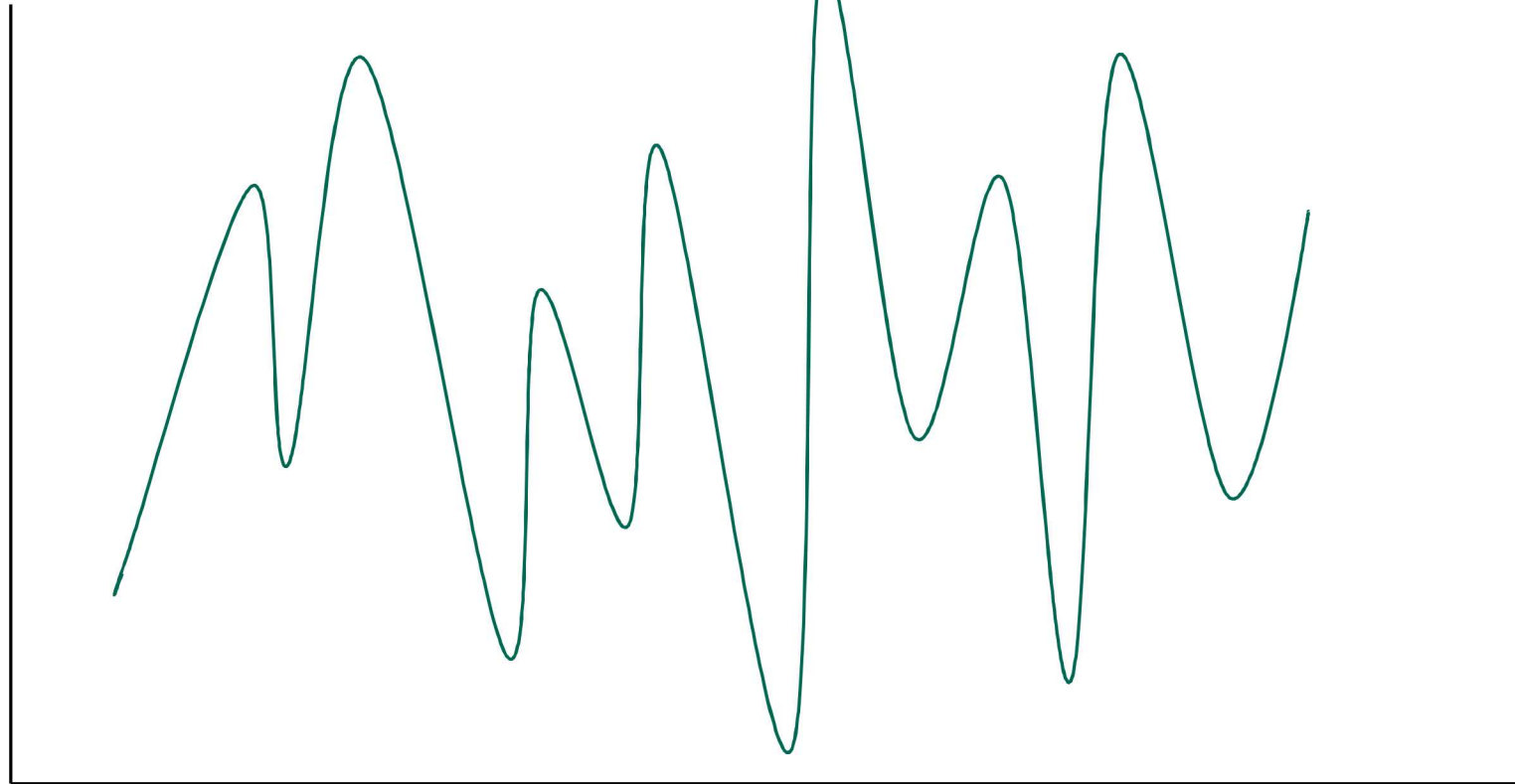
Presidential Policy Directive 21, Critical Infrastructure Security and Resilience, 2013

1. Resilience is contextual – defined in terms of a threat or hazard
 - A system resilient to hurricanes may not be resilient to earthquakes
2. Includes hazards with low probability but potential for high consequence



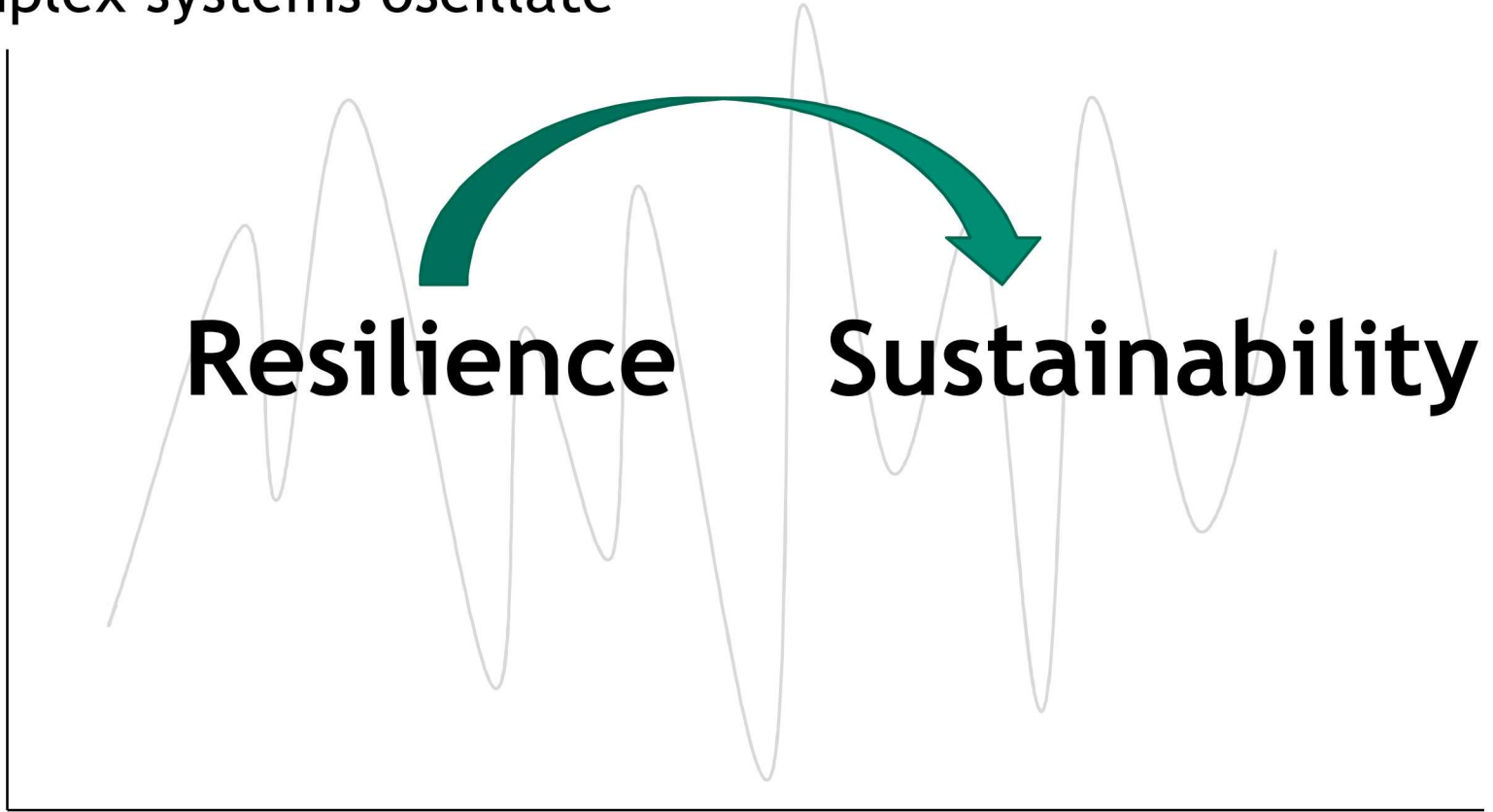


Complex systems oscillate



5 Resilience confers sustainability

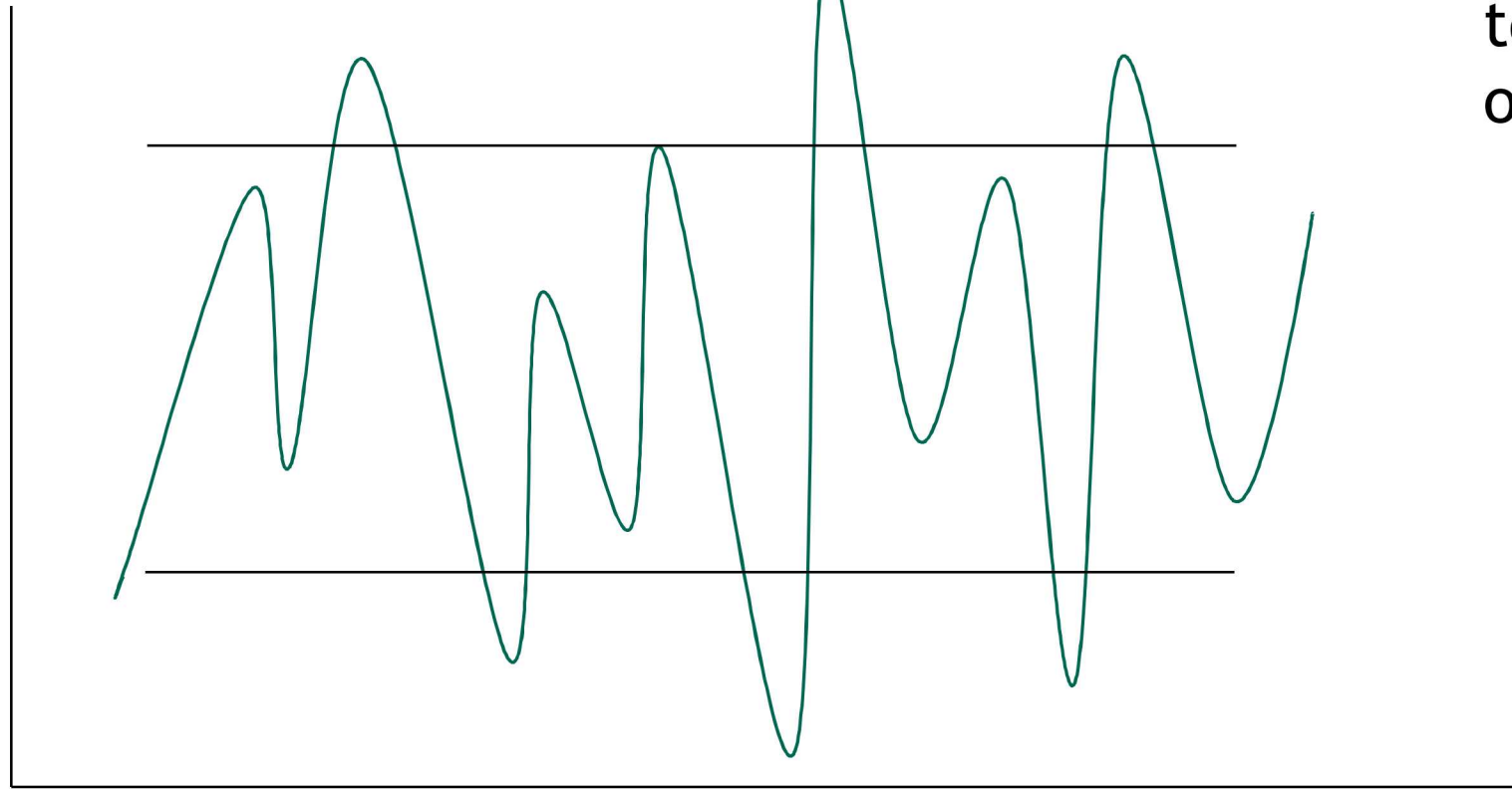
Complex systems oscillate



6 Resilience confers sustainability



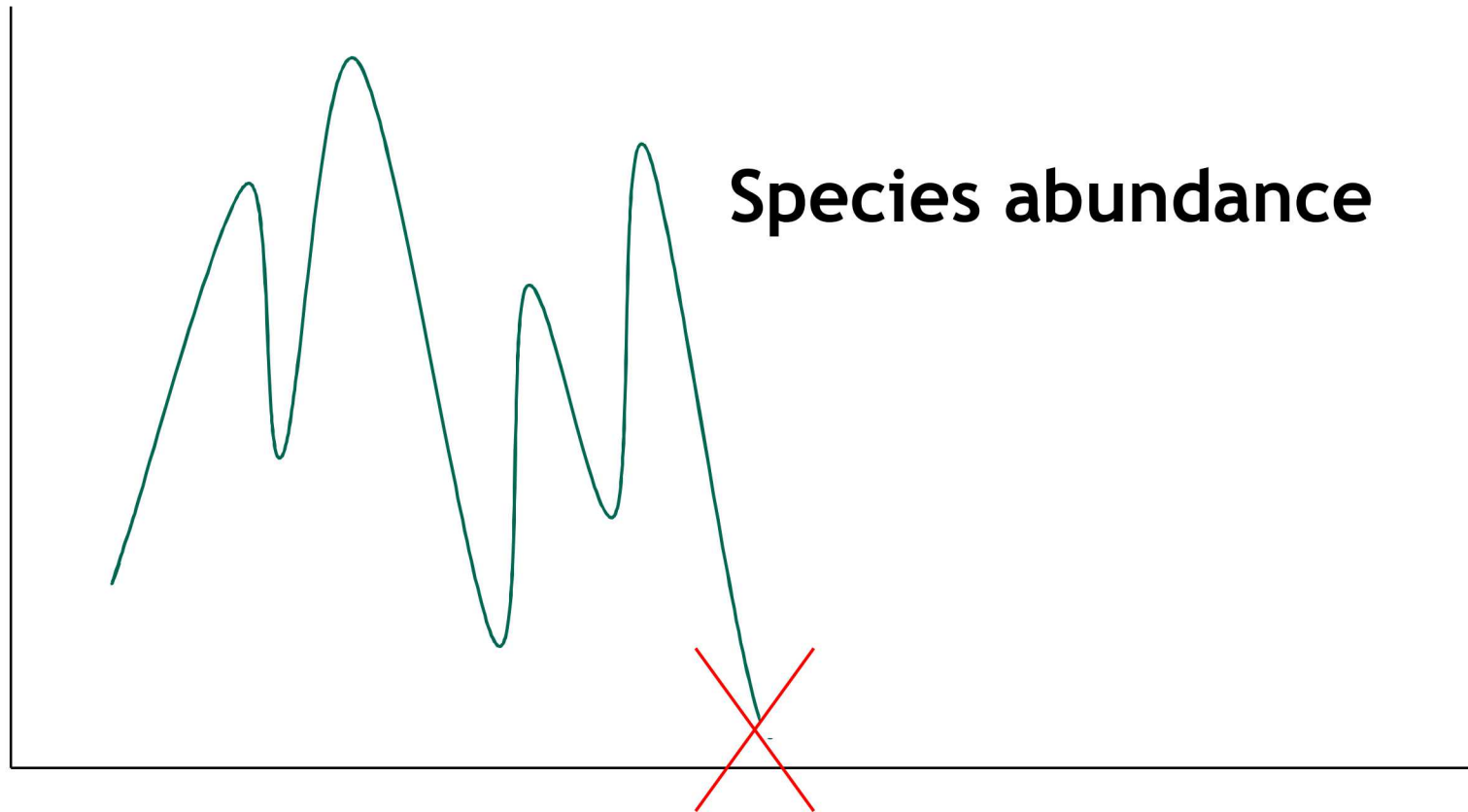
Complex systems oscillate



Humans want to dampen the oscillations

Resilience confers sustainability

Complex systems oscillate

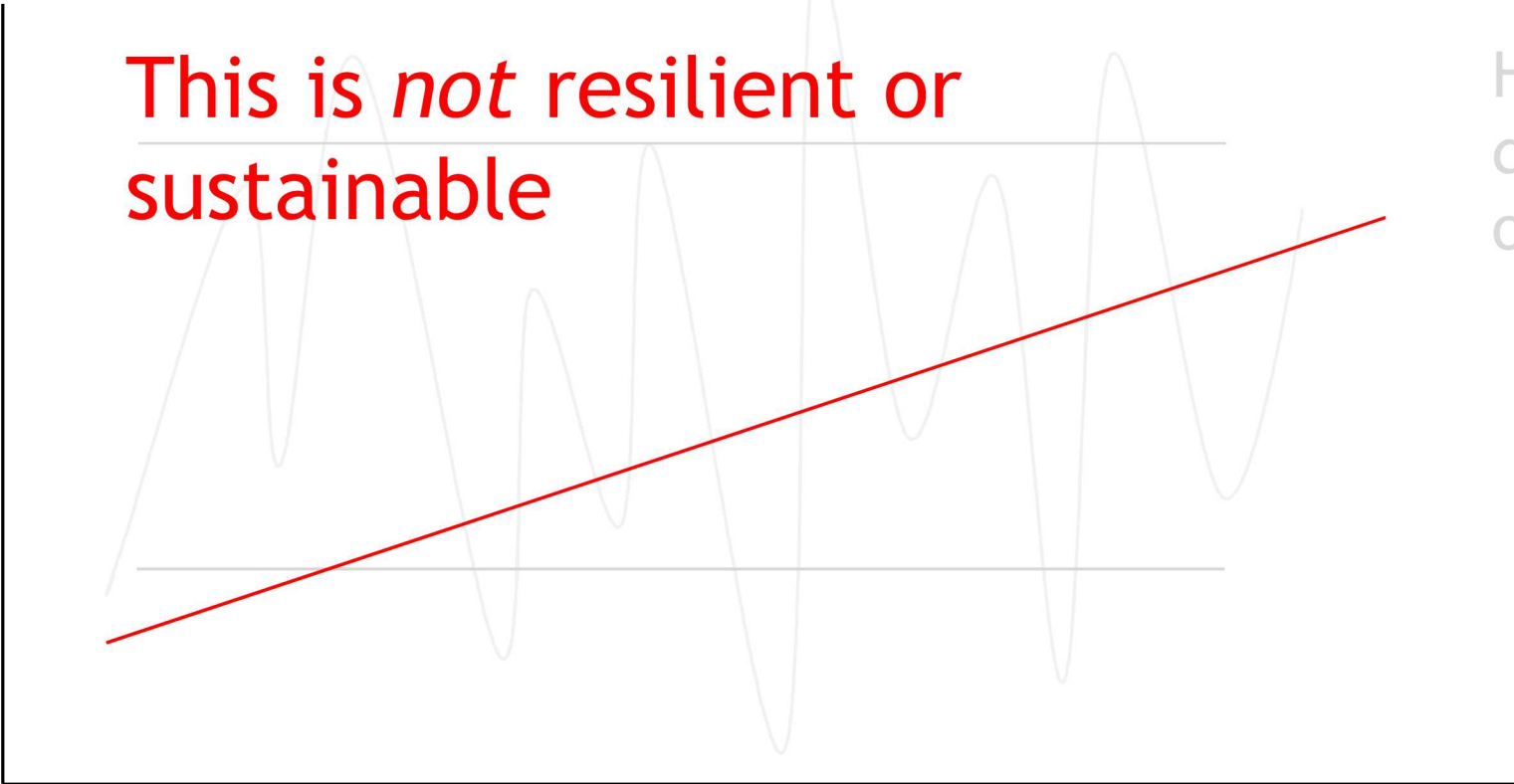


Unintended consequences occur

Resilience confers sustainability

Complex systems oscillate

This is *not* resilient or sustainable

A graph with a vertical y-axis and a horizontal x-axis. A red line starts at a low point on the left and trends upwards to the right. A grey line oscillates around the red line, with its amplitude increasing as it moves to the right. Two horizontal grey lines are drawn, one above and one below the oscillating line, representing a range of values.

Humans want to dampen the oscillations



Resource systems, economic boom and bust cycles, social and political norms, all behave the same way

Humans want to dampen the oscillations

So what?

- Anticipate oscillations, and rates of change
- Dampen ('manage') peaks and troughs
- Eschew constant increase
- Anticipate unintended consequences

Rare Earth Elements

- 17 metals not really rare but widely distributed in small reserves
- Toxic mining
- Many uses - wind turbine generators, PV, batteries, cell phones, fuel rods, missile guidance
- Poor substitutability
- China is leading source with 80-90%
- Poor recycling (<1%)

Scandium, Yttrium, Lanthanum, Cerium, Praseodymium, Neodymium, Promethium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Lutetium

Optimal PV, wind, and energy storage capacity required for meeting NM's 100% carbon free goal

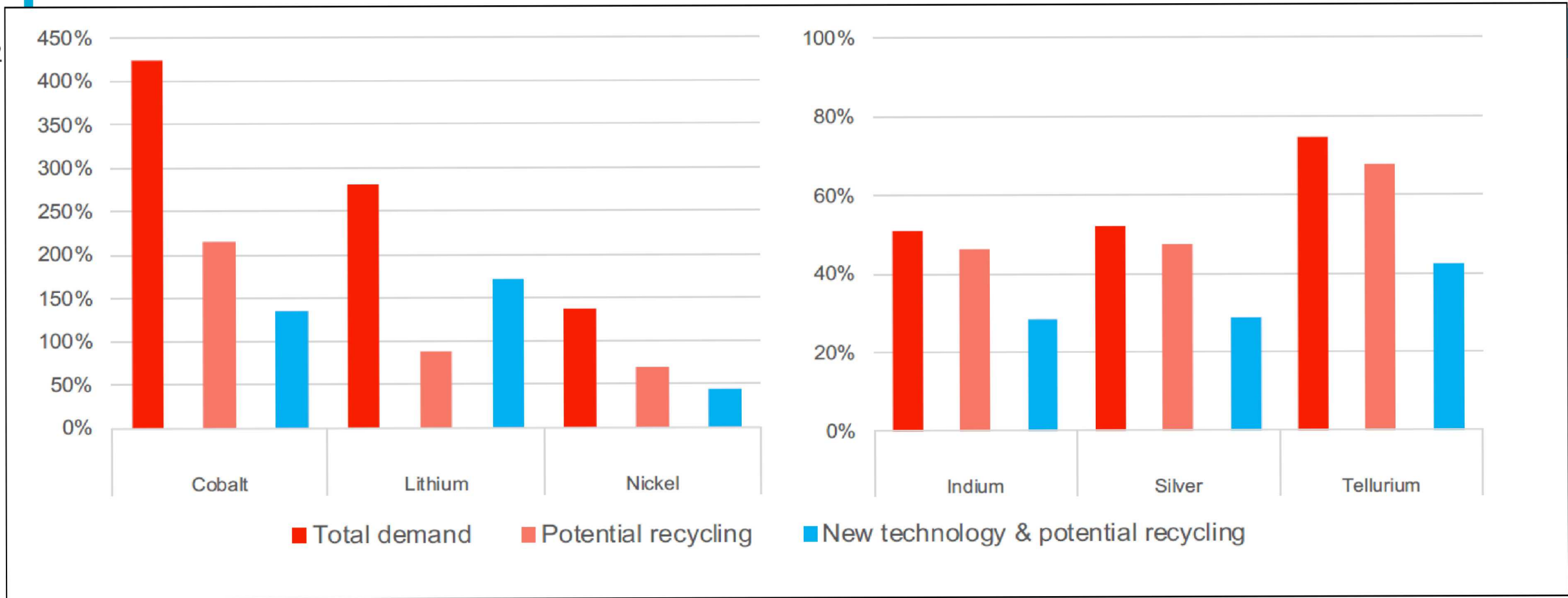
	<u>Now</u>	<u>Needed⁴</u>
Energy Storage	3.75 MW ¹ (0.00375 GW or 0.08%)	5 GW/25 GWh
Solar PV	818 MW ² (0.818 GW or 8%)	10 GW
Wind	1,953 MW ³ (1.953 GW or 40%)	5 GW
¹ Global Energy Storage Database 2019; ² Solar Energy Industries Association 2019 ³ American Wind Energy Assoc. 2019; ⁴ Copp et al., in press		

Optimal Sizing of Distributed Energy Resources for 100% Renewable Planning

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Cumulative demand from renewable energy and storage by 2050 relative to known, economically extractable reserves for selected battery metals (left) and solar PV metals (right).

Supply Chain Bottlenecks for Li, Co, etc.

- Toxic mining
- Toxic post consumer waste
- Insufficient LCA
- Child labor
- Inadequate recycling
- Inadequate substitutes
- Inadequate cradle-to-cradle design and production

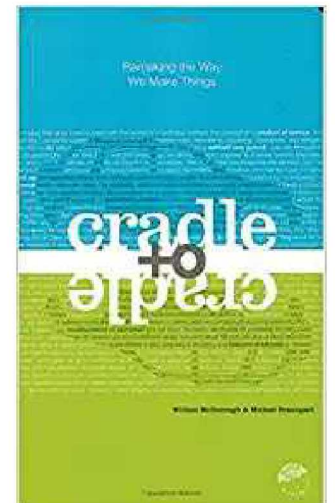
The Linear Economy -- Extract resources (metals, wood, fiber, water, nutrients, energy), use once, throw it away . . .

- Works ok with low human population, low consumption, and resource abundance

The Circular Economy -- Design and manufacture products so that they can be disassembled at end-of-life and used again, and again.

- Recycling is a subcategory. . .

2002, William
McDonough and
Michael Braungart



The Circular Economy . . .

- Reduces future extraction, conserving energy and materials and reducing pollution
- Reduces waste stream, relieving pressure on landfills and relieving pollution
- Reduces future supply chain bottlenecks and increasing costs due to scarcity
- Enhances resilience, sustainability, reliability
- In a world of increasing demand and decreasing supply for use in critical infrastructure, it is a national security issue

But, the Circular Economy requires . . .

- Greater ingenuity and expense in design and manufacturing
- Better life cycle analysis (LCA) and techno-economic analysis, and “systems” solutions
- R&D for substitutes
- Greater investment into end-of-life tracking, collection, transport, disassembly, and reassembly
- An economic or resilience incentive
- Legislation & policy, rebates, tax credits, incentives, standards & codes, public/private R&D and partnerships
- A paradigm change in the way humans deal with materials and production

Unintended consequences

If you were in a shipwreck and a piano top came floating by, you might climb up on top of it and use it as a life preserver. But if you were in the business of designing life preservers, you probably would not make one in the shape of a piano top.

Buckminster Fuller, Operating Manual for Spaceship Earth, 1969

The “energy transition” is happening now

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Climate crisis

Declining costs for renewables

Public Health

Geopolitics

Ecosystem Health



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