Trends, Boundary Conditions that Affect the Pathways and Pace of Transformation

Overarching Trends in – and Affecting – Energy Systems

- changes in the U.S energy supply profile
- shift from resource- to technology -based energy systems
- digitalization, big data analytics and smart systems
- electrification and electricity-dependence
- demographics, urbanization, and the emergence of smart cities; and
- Decarbonization of the electricity sector due to flat demand and changing fuel mix

Boundary Conditions of Energy Systems

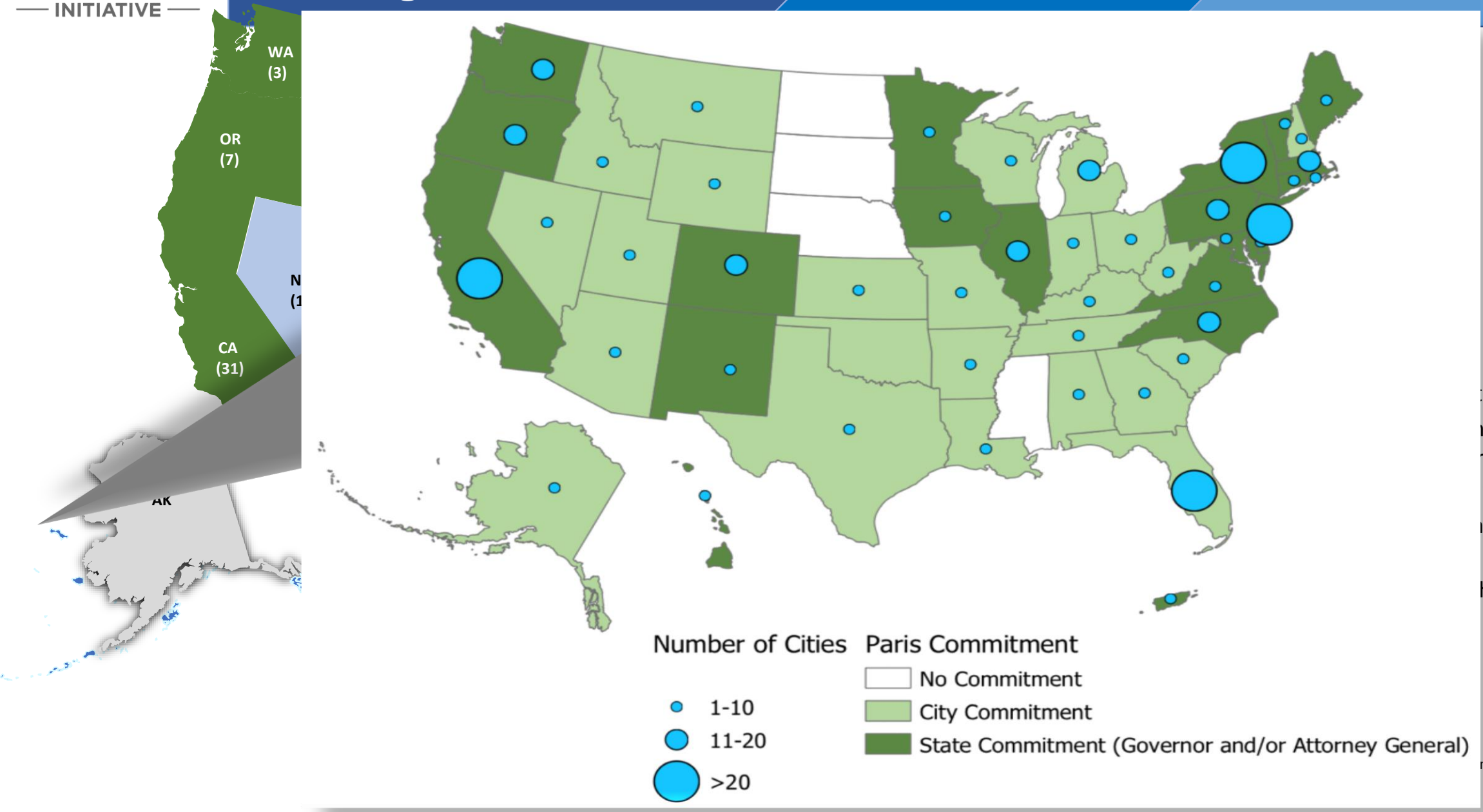
The energy industry is –

- …a multi-trillion dollar per year, highly capitalized, commodity business…
- …with exquisite supply chains,,,
- … and established customer bases…
- … providing essential services at all levels of society.

This leads to a system with considerable inertia, aversion to risk, extensive regulation, and complex politics

ENERGY FUTURES INITIATIVE

Initial Commitments to Meeting US NDC under Paris Agreement*



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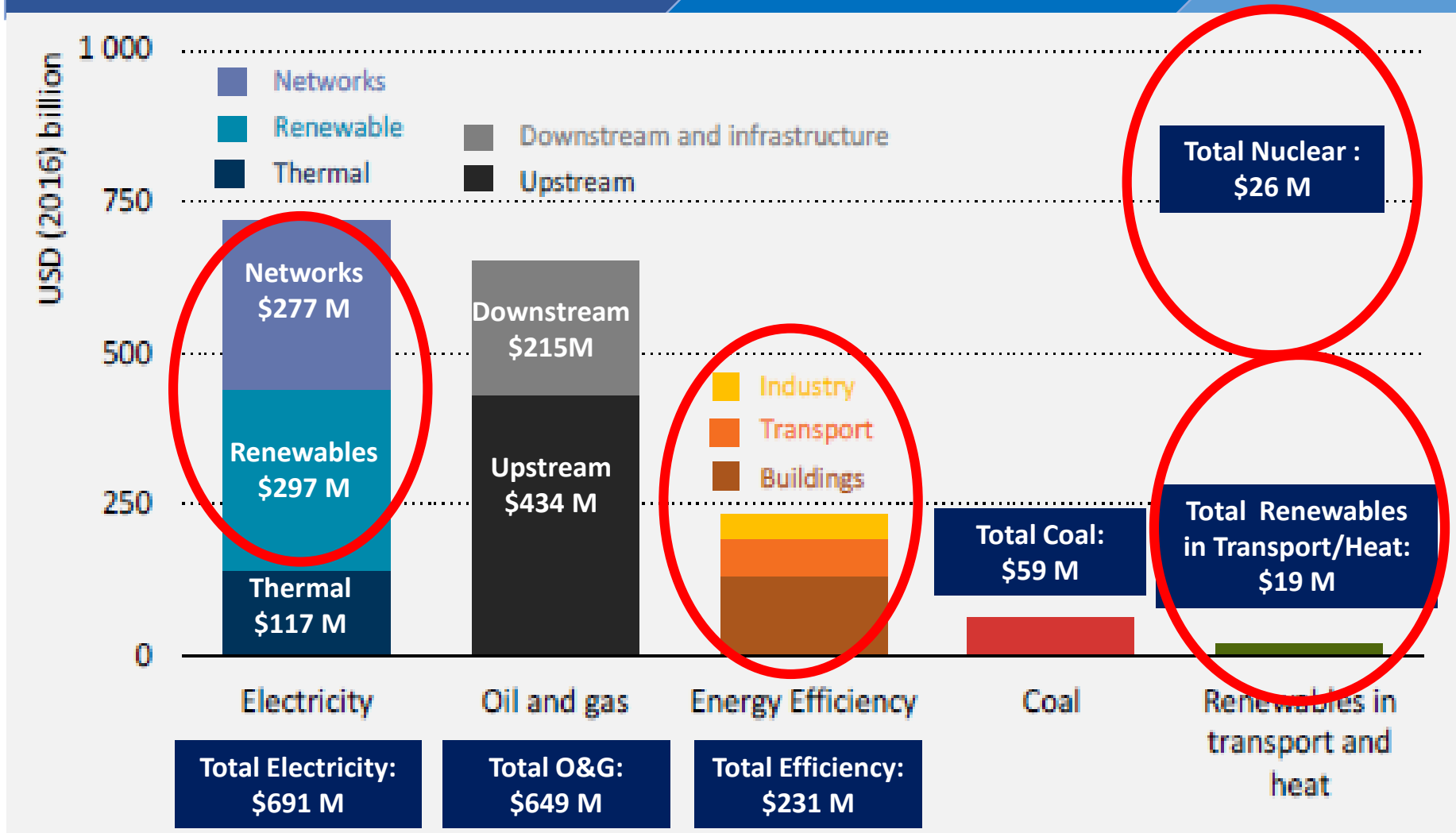
Global Energy Investment



Global energy investment totalled USD 1.7 trillion in 2016, 12% down on 2015 due mainly to a fall of over one-quarter in oil and gas investment.

Technology-based Energy Systems Bring New Players into the Market: Illustrative Companies

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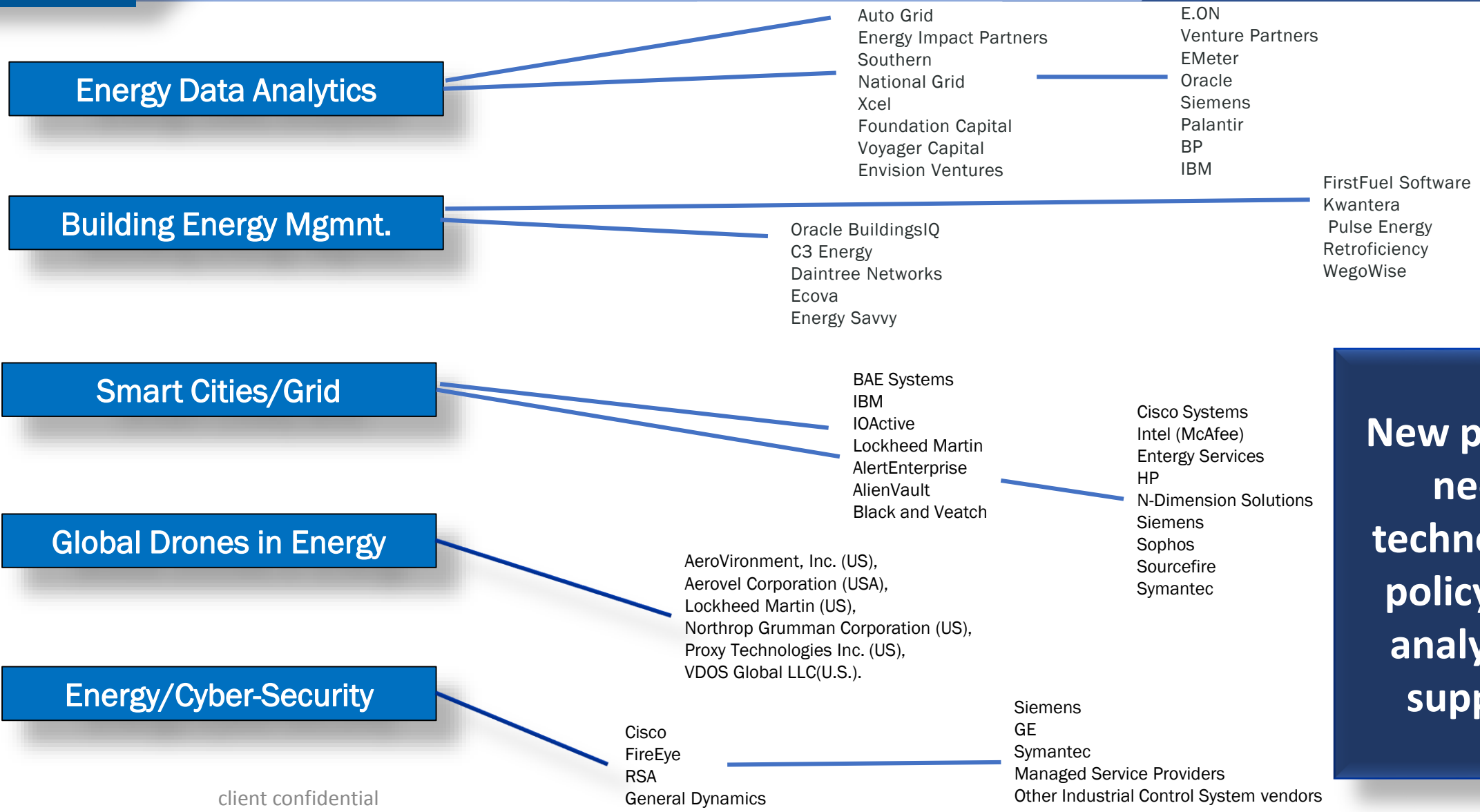

New players need technology, policy and analytical support

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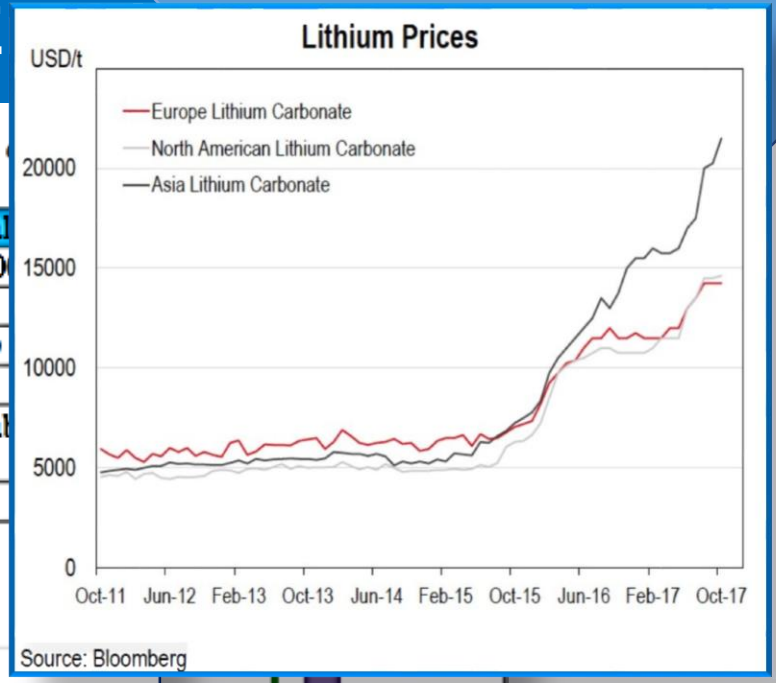
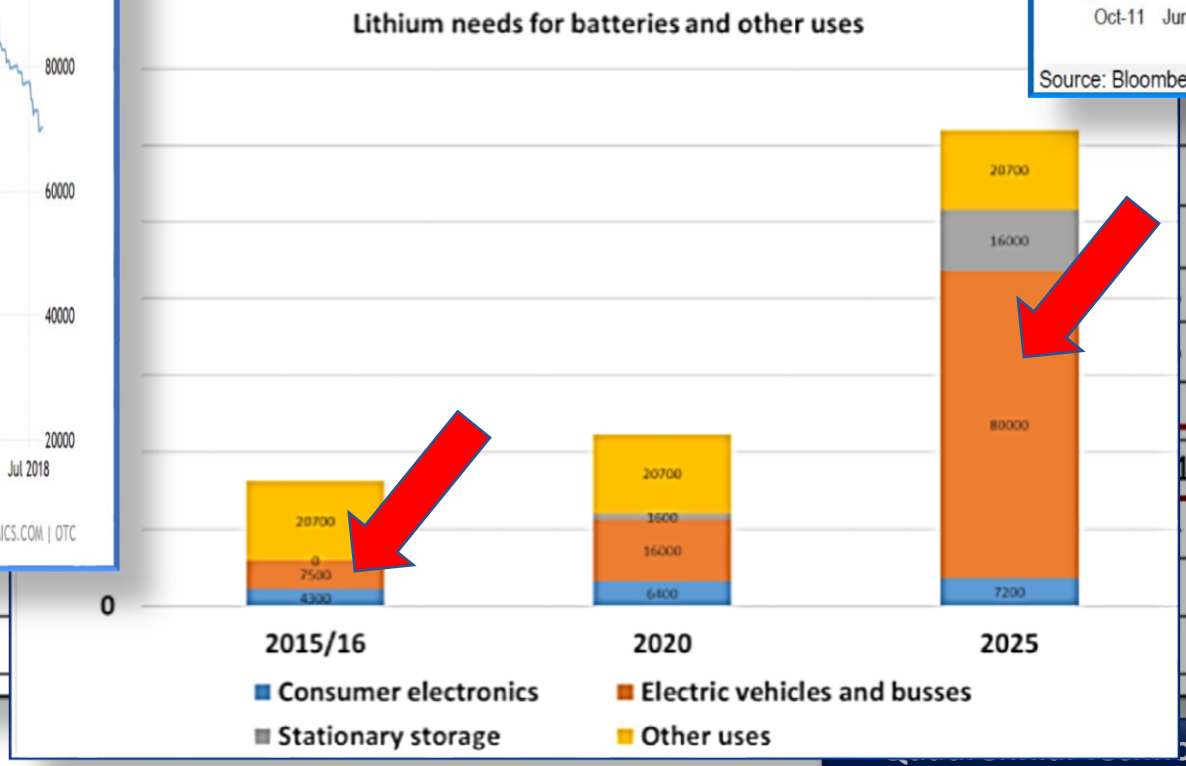
Batteries: Key Clean Energy E

Table 1. Production, reserves, share of battery use and recycling rate of lithium and (Jaskula, 2016) (CDI, 2016) (UNEP, 2011).

	Lithium	Cobal
Annual production (Ton/a)	32.500	99.00
Useful reserves (million tons)	14	7.1
Global resources (million tons)	34	120
Share of battery use (%)	35	42
Main reserves	Chile, Argentina, Bolivia China, Australia	Democratic Repul
%)	< 1	68





	2014	2015	2016
	600	470	25
1	35016	145470	430
	1100	6100	
	100	1270	
		48	

Flow Battery

Electro-chemical

ology Review

Source: DOE Global Energy Storage Database (energystorageexchange.org), April 6, 2016.

ENERGY FUTURES INITIATIVE

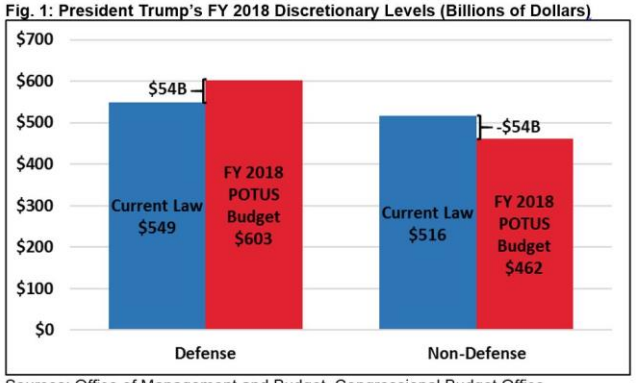
Critical (often invisible) Role of Federal Government

An article, *EOR: Past, Present and What the Next 25 Years May Bring*, highlighted the key role of technology in oil production….it noted that at the 30th anniversary of the Offshore Technology Conference, there was "a display of technology that would have seemed like science fiction a decade earlier." The article highlighted among others, these technologies: conversion of Star Wars laser defense technology to drilling; a downhole factory that combined fiber optics, artificial intelligence and robotics; and cross-borehole seismic tomography.

Supercomputing, a related and enabling technology of all of these. The federal government has expressed a long-standing commitment to the development of supercomputing. One of the first industry developments resulted from a partnership between Harvard and IBM with the ASCC project. Cray and the iterations of Seymour Cray's many companies competed in parallel to the IBM/Harvard partnership, and still competes with other prominent companies such as Intel, Hewlett Packard, and AMD, among others. DOE has long pushed the frontiers of supercomputer development for its science, energy, and nuclear weapons missions.

Implications of Current Fiscal Policy/Status

Budget Caps (now next year)



Sources: Office of Management and Budget, Congressional Budget Office

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Tax Cuts

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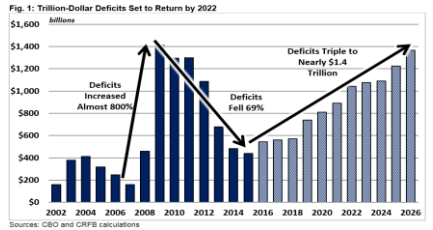
Increased Deficits of $1-$1.5 Trillion



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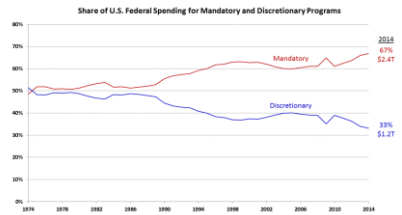
Less Federal $ for Energy Innovation



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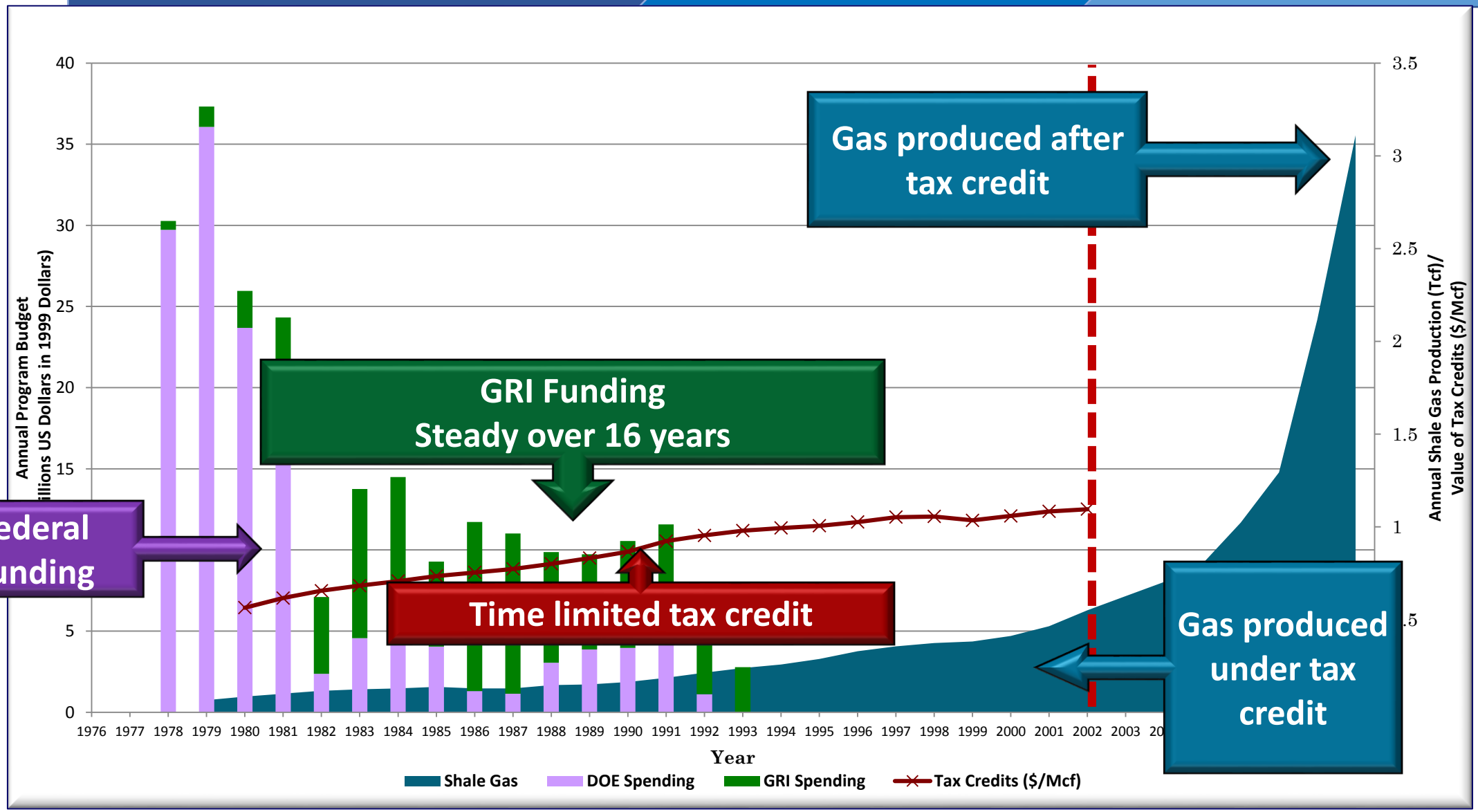
$1-$1.5 Trillion over 10 years to Corporations for increased capital investment

Challenge: Mobilizing industry to support new partnerships in clean energy innovation and energy infrastructure

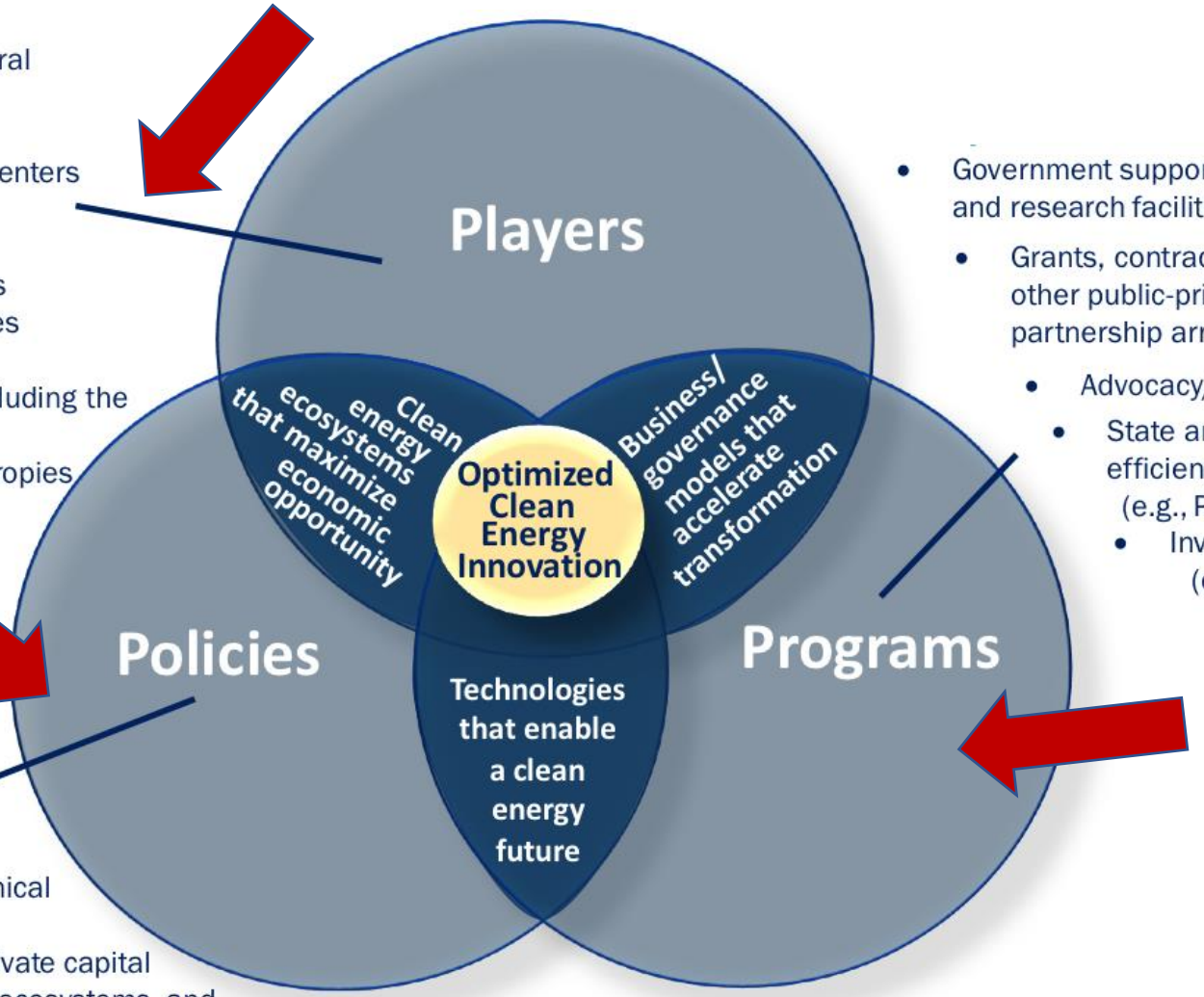
Shale Gas Success: RD&D, Public/Private Partnerships, Policy Mechanisms



Source: MIT Future of Natural Gas Study

Urgency of Climate Imperative Requires Significant Alignment of Innovationn Players, Programs and Policies

- All three branches of the Federal government
- The education system
- Government supported R&D centers (particularly DOE labs)
- State and local governments
- Standard-setting organizations
- Industry-supported laboratories
- Incubators
- A range of industry players including the investment community
- NGOs, think tanks, & philanthropies
- Consumers



- Government support for R&D and research facilities
  - Grants, contracts, CRADAs, other public-private partnership arrangements
    - Advocacy/analysis
      - State and local efficiency programs (e.g., PACE, EERS)
        - Investment vehicles (e.g., green banks)

- Energy and environmental statutes
- A transparent and flexible patent system
- Tax incentives
- Mandates
- Systems for establishing technical standards and protocols
- Flexible rules for accessing private capital
- Support for regional markets, ecosystems, and initiatives

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Breakthrough Technology Selection Criteria

Technical Merit that leads to systems level performance improvements, or innovations that support cost, risk, and performance gains across a variety of technologies or systems.

Market Viability includes manufacturability at scale with adequate and secure supply chains, a viable cost/benefit for providers, customers and the greater economy; significant market penetration; and revenue generation.

Compatibility includes interoperability, flexibility, extensibility, and the ability to minimize stranded assets.

Consumer Value consideration of customer preferences, expanding consumer choice of new or improved products and services, and the ability to compete with incumbent choices.

BREAKTHROUGH INNOVATIONS

Innovations that alter the value chain (energy system performance or design) in both qualitative and quantitative ways, enabling the exploitation of new resources and the development of new products and services.

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Illustrative Technologies were Selected with Breakthrough Potential

- ✓ Storage and Battery Technologies
- ✓ Applications for the Difficult to Decarbonize Sectors (Industry, Buildings)
  - Hydrogen
  - Advanced Manufacturing Technologies
  - Advanced Nuclear Reactors
  - Building Energy Technologies
- ✓ Systems: Electricity and Smart Cities
  - Electric Grid Modernization
  - Smart Cities
  - Transportation
- ✓ Deep Decarbonization: Large Scale Carbon Management
  - Carbon Capture, Use, and Storage (CCUS) at Scale
  - Sunlight to Fuels
  - Biological Sequestration

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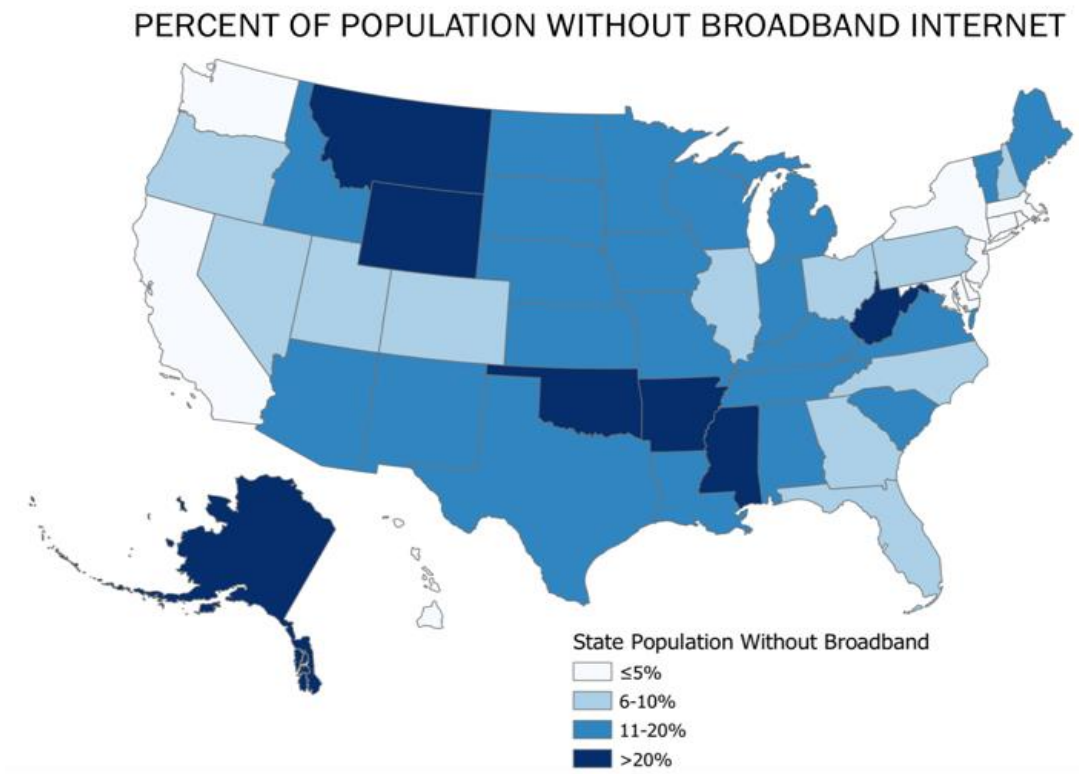
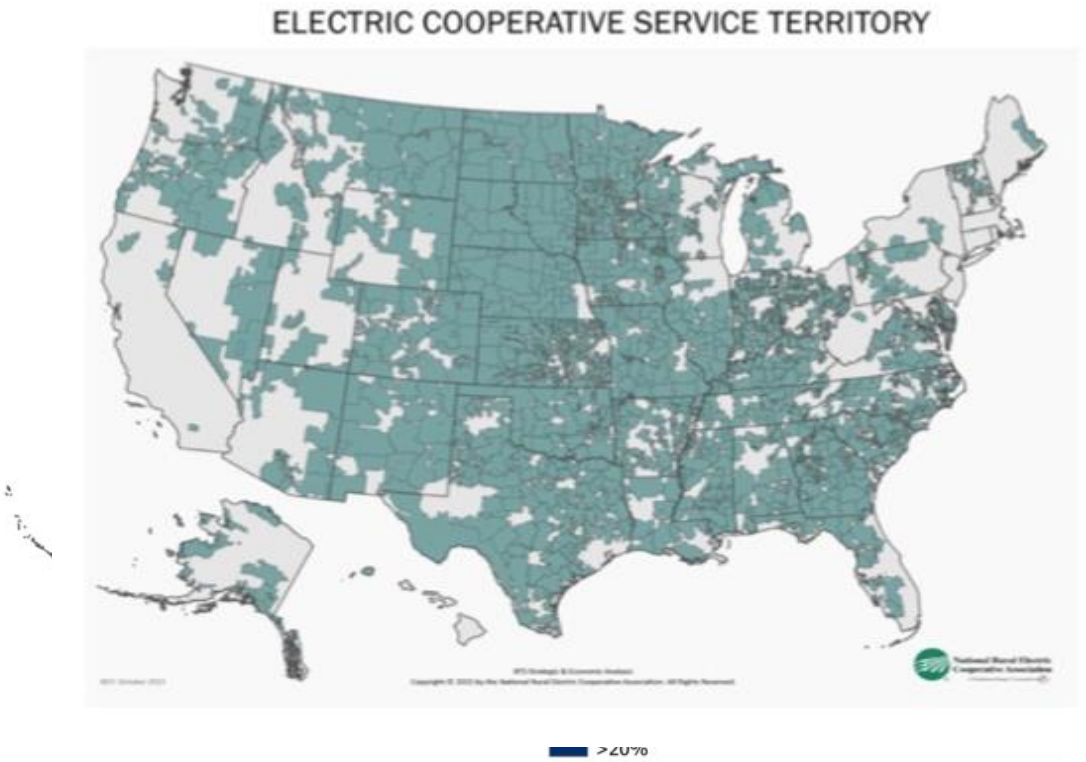
Innovation Ecosystems Not Evenly Distributed, Regional Approaches Are Needed





Broadband access and innovation ecosystems are essential for a transformed energy economy and technologies that support/enable "decentralization," e.g., distributed generation, additive manufacturing. Programs and policies should support regional ecosystems and broadband access to help provide broader access to clean energy jobs, and clean energy and economic benefits.

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- Are our investments aligned with trends?
- How are we measuring/validating the commitments to Paris?
- Are we creating global opportunities in clean energy investment for US countries?
- Are we engaging the right players in the energy transition?
- Are we paying attention to supply chains?
- Are we providing the government with adequate resources?
- Are we developing programs to help direct private sector windfall from tax cut into clean energy transition?
- Are we aligning players, programs and policies in ways that will accelerate clean energy innovation?
- Are we putting federal dollars in the right places?
- Are we leaving people behind and, if so, will they impede progress? How do we engage all Americans in the clean energy transition?