JISEA Joint Institute for Strategic Energy Analysis

Energy Issues and Implications for Macrostability Workshop: Technology Futures

April 2016

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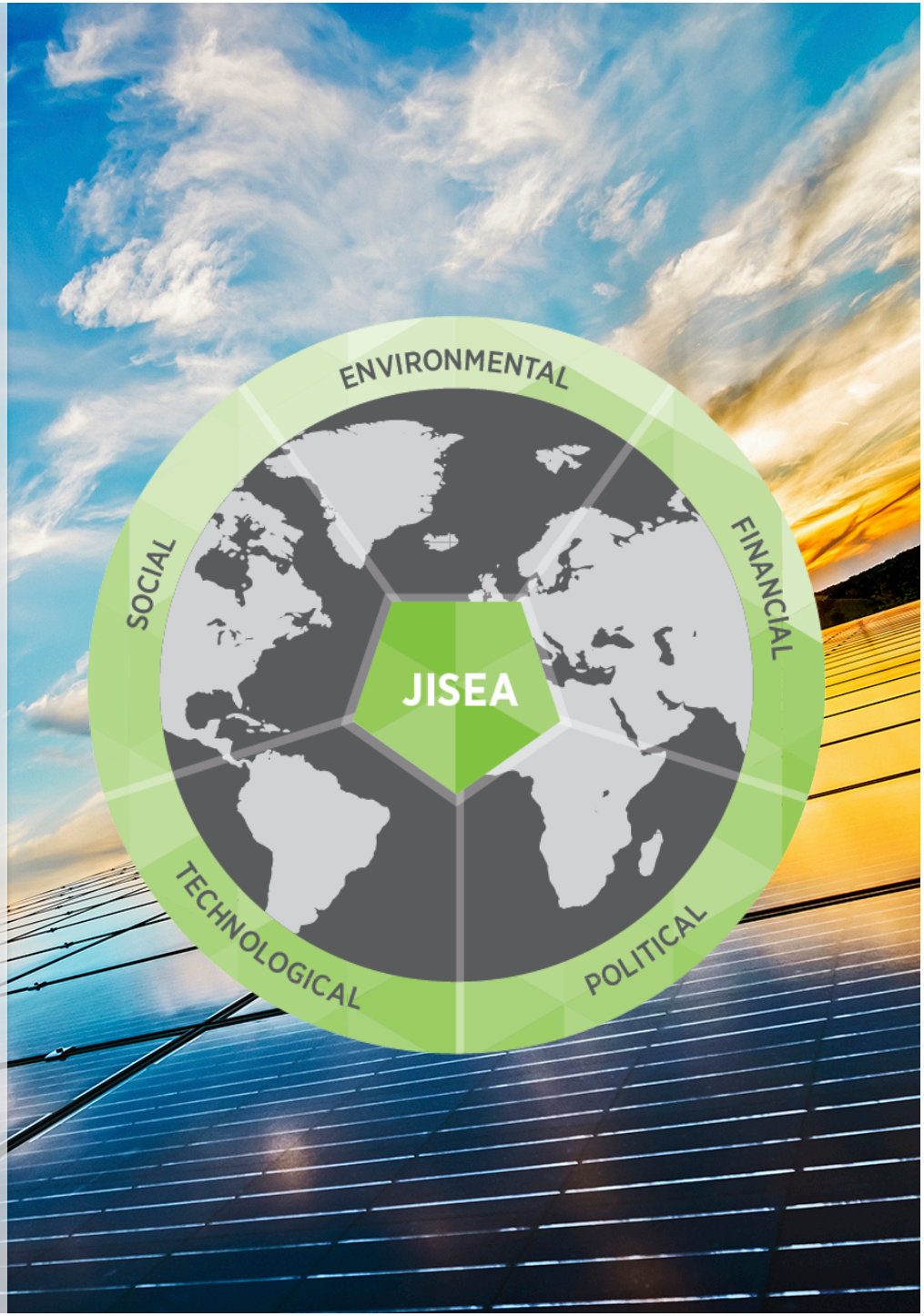
Executive Director

NREL NATIONAL RENEWABLE ENERGY LABORATORY · COLORADOSCHOOLOFMINES · Colorado State University · Massachusetts Institute of Technology · STANFORD UNIVERSITY · University of Colorado Boulder

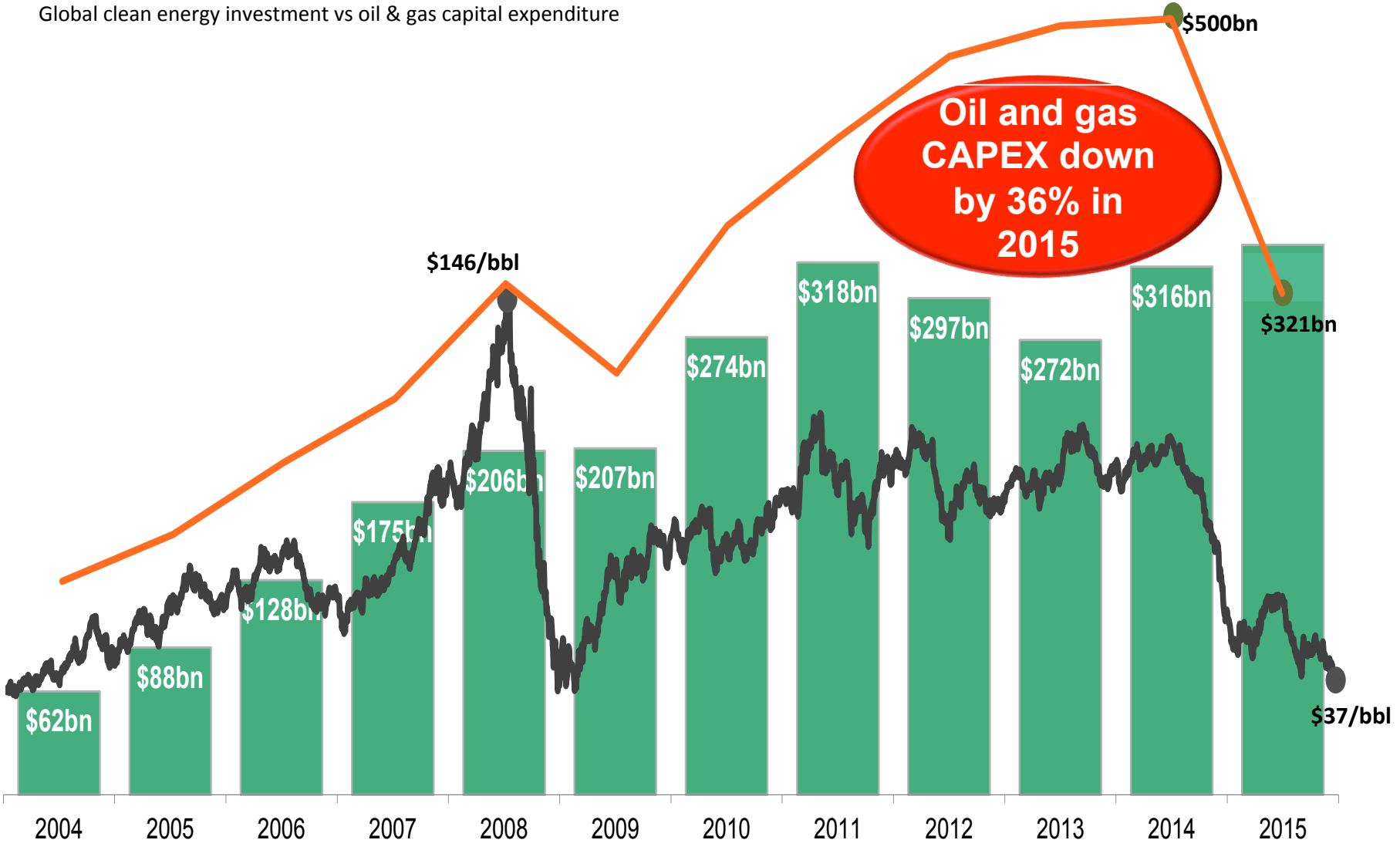
JISEA's MISSION

JISEA research focuses on the intersections of energy, finance, and society. JISEA provides critical clarity and insights to inform decision making through leading-edge interdisciplinary research and objective, credible, cross-functional analysis.



Clean energy investment rose while oil & gas CAPEX fell

Global clean energy investment vs oil & gas capital expenditure



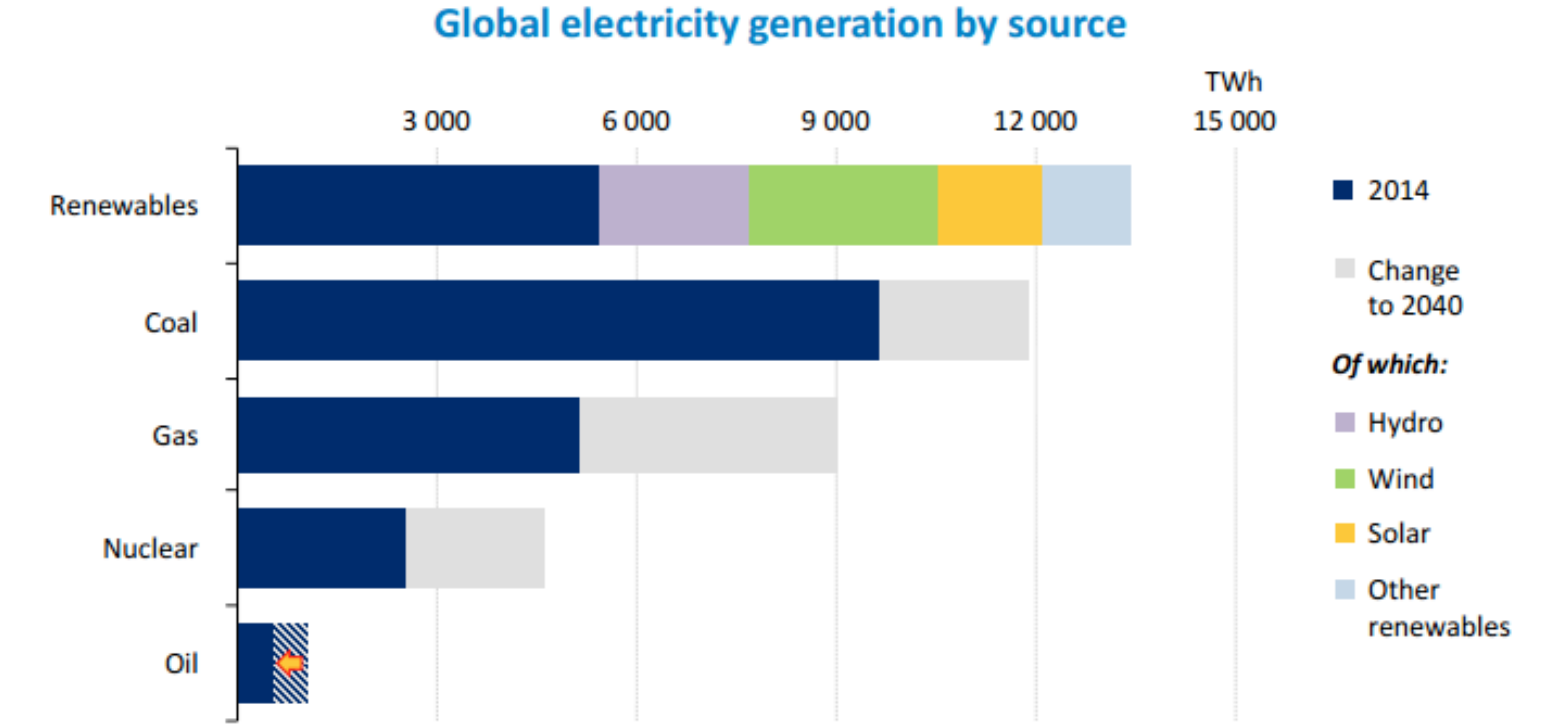
Source: Bloomberg Intelligence, Bloomberg New Energy Finance

Note: Oil and gas CAPEX data refers to total capital spending by integrated global oil firms and US independent E&Ps. Excludes NOCs.

Implications of Paris

Power is leading the transformation of the energy system

World Energy Outlook 2015



Driven by continued policy support, renewables account for half of additional global generation, overtaking coal around 2030 to become the largest power source

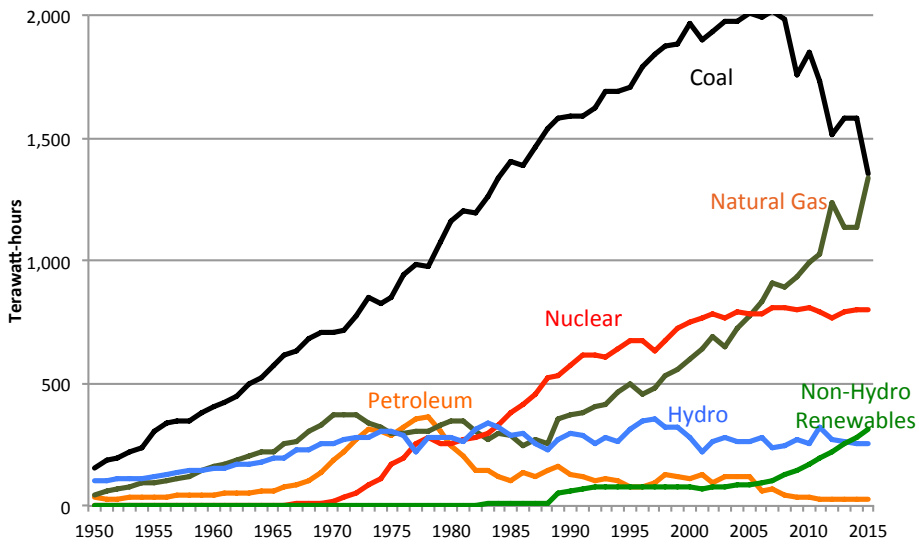
© OECD/IEA 2015

PATHWAYS
TO DECARBONIZATION

- *Natural Gas*
- *Renewables*
- *Nuclear*
- *Efficiency*
- *CCUS*
- *EVs*
- *Energy Services*
- *Human-System Optimization*

- *Synergies*
- *Competition*
- *Integrated Systems*

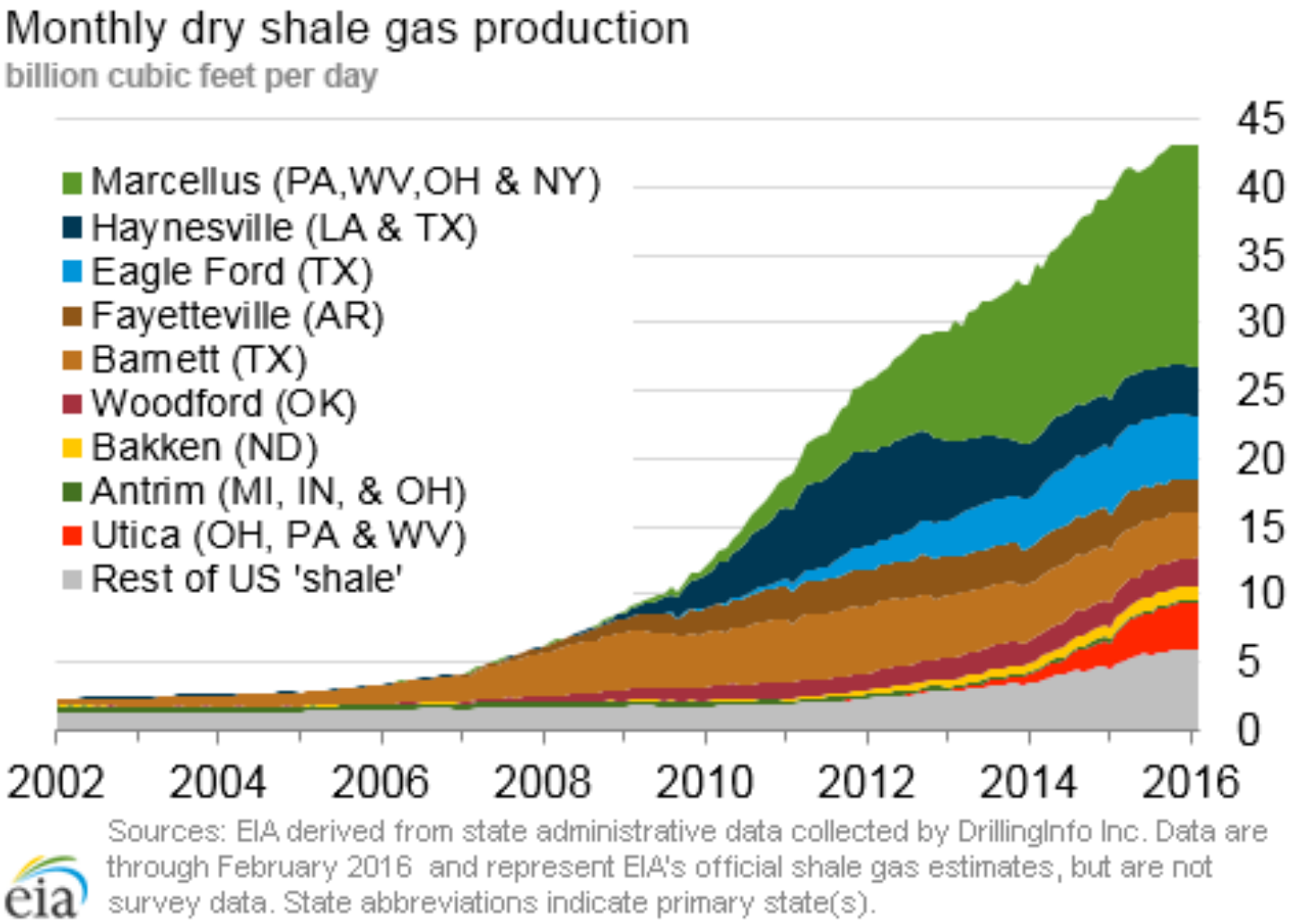
U.S. Generation by Fuel Type



The U.S. Power Sector Is Undergoing Profound Transformation

Source: Electric Power Monthly, EIA.

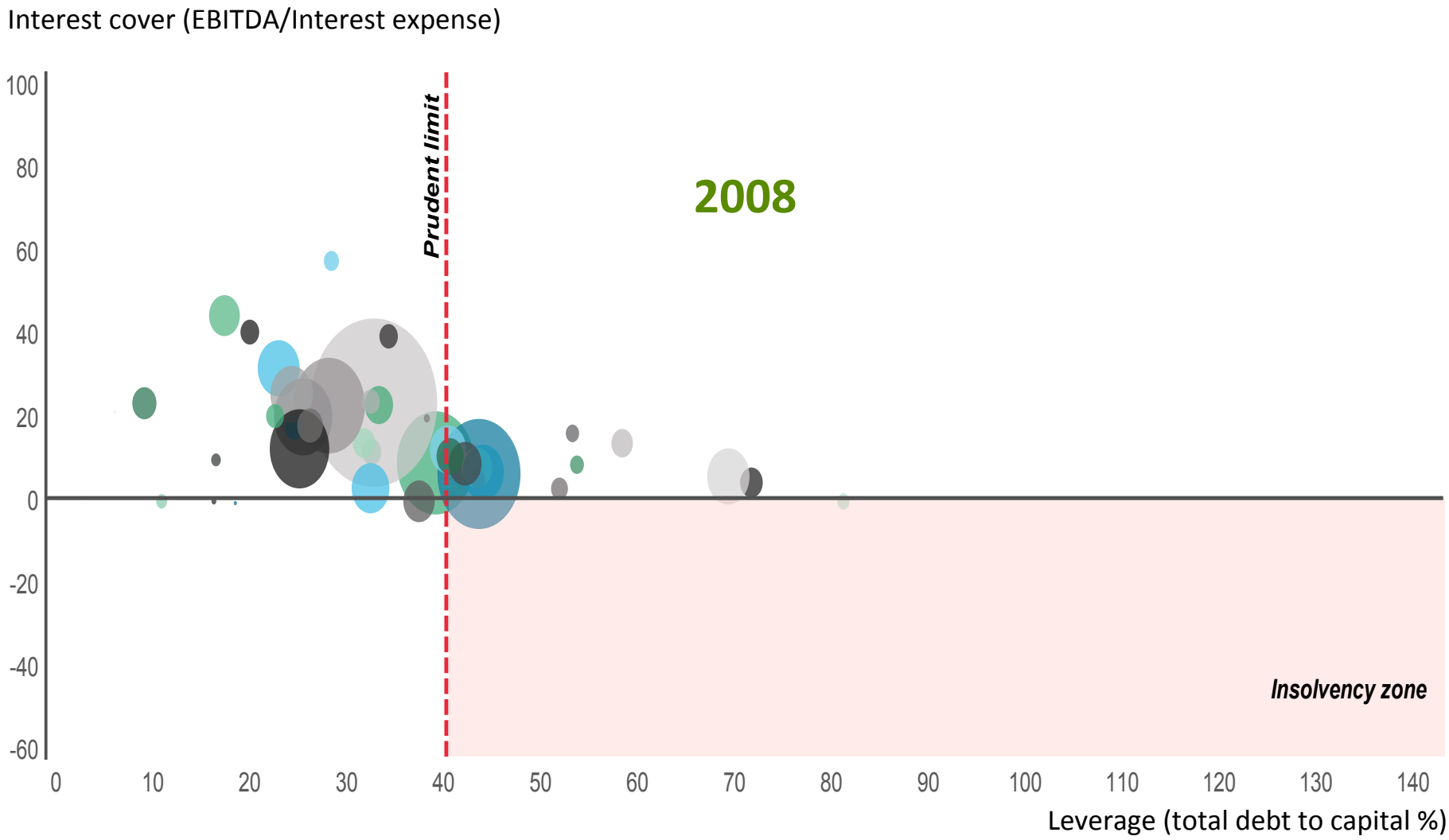
U.S. Shale Production



Shale Gas Supplied 58% of Total Dry Natural Gas Production in 2015

Source: Natural Gas Weekly Update, EIA.

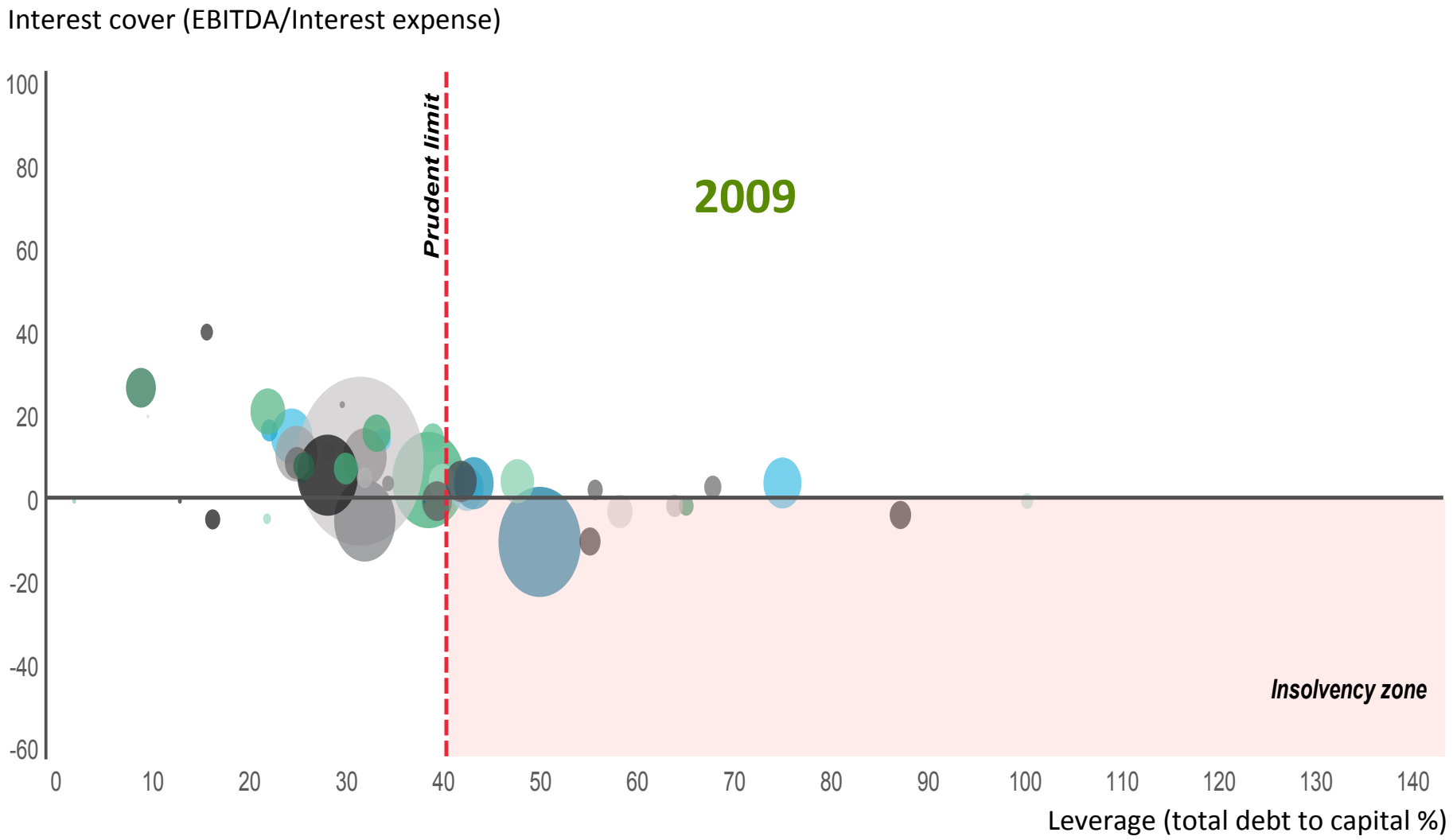
US independent oil & gas producer solvency ratios



Note: size of bubbles represents net debt position for each company

Source: Bloomberg Intelligence; Bloomberg New Energy Finance

US independent oil & gas producer solvency ratios



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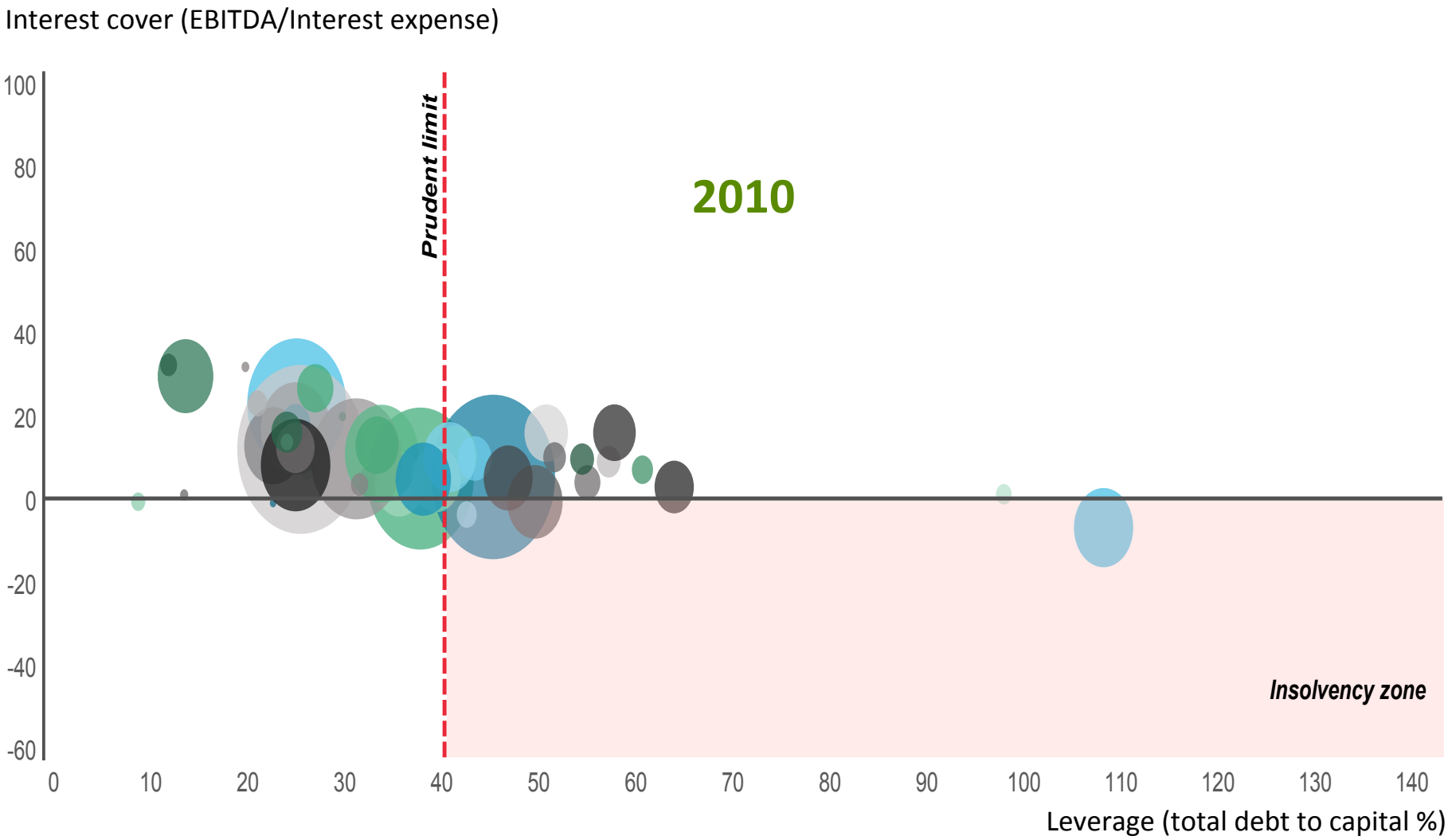
US independent oil & gas producer solvency ratios



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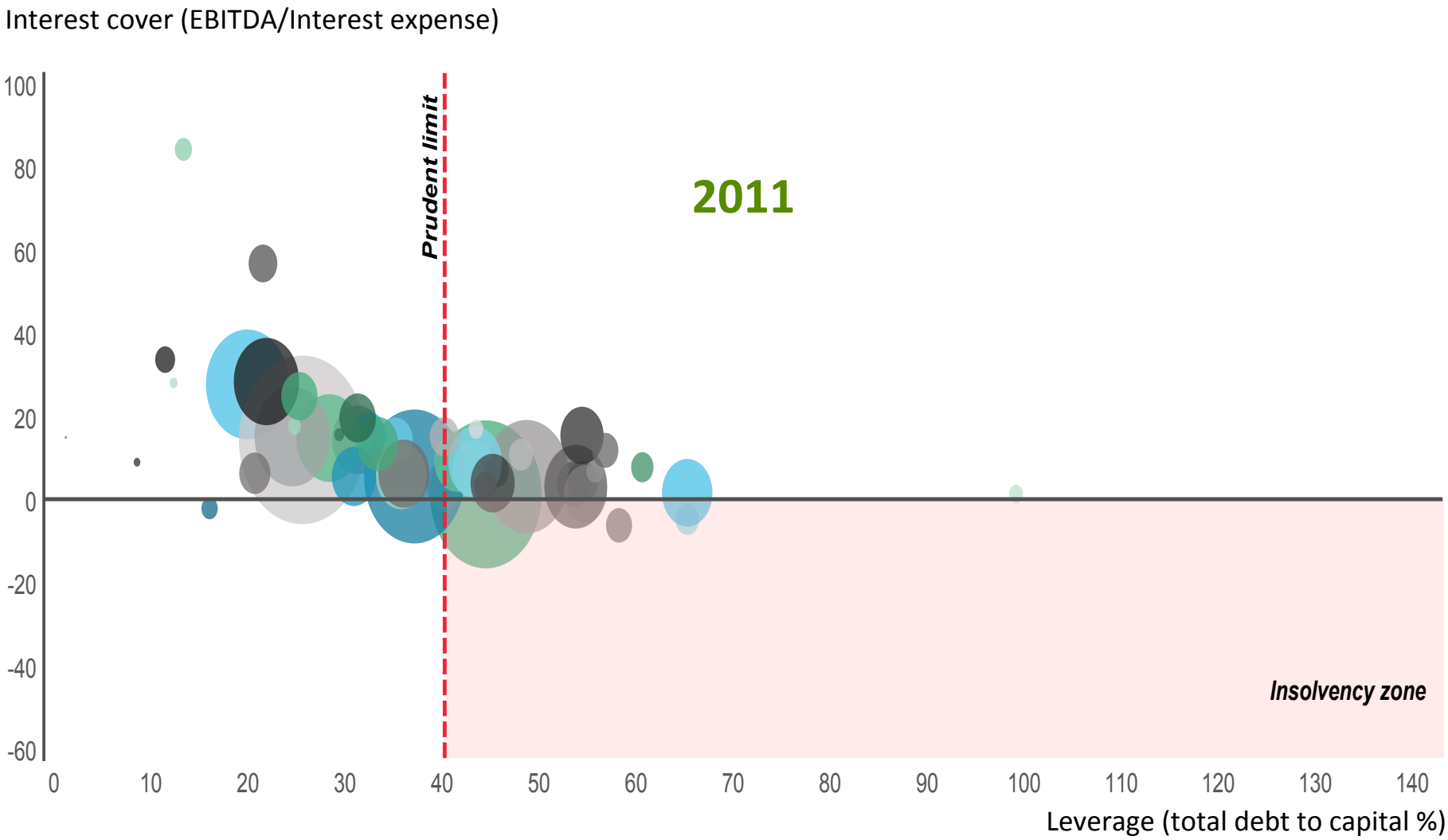
Source: Bloomberg Intelligence; Bloomberg New Energy Finance

US independent oil & gas producer solvency ratios



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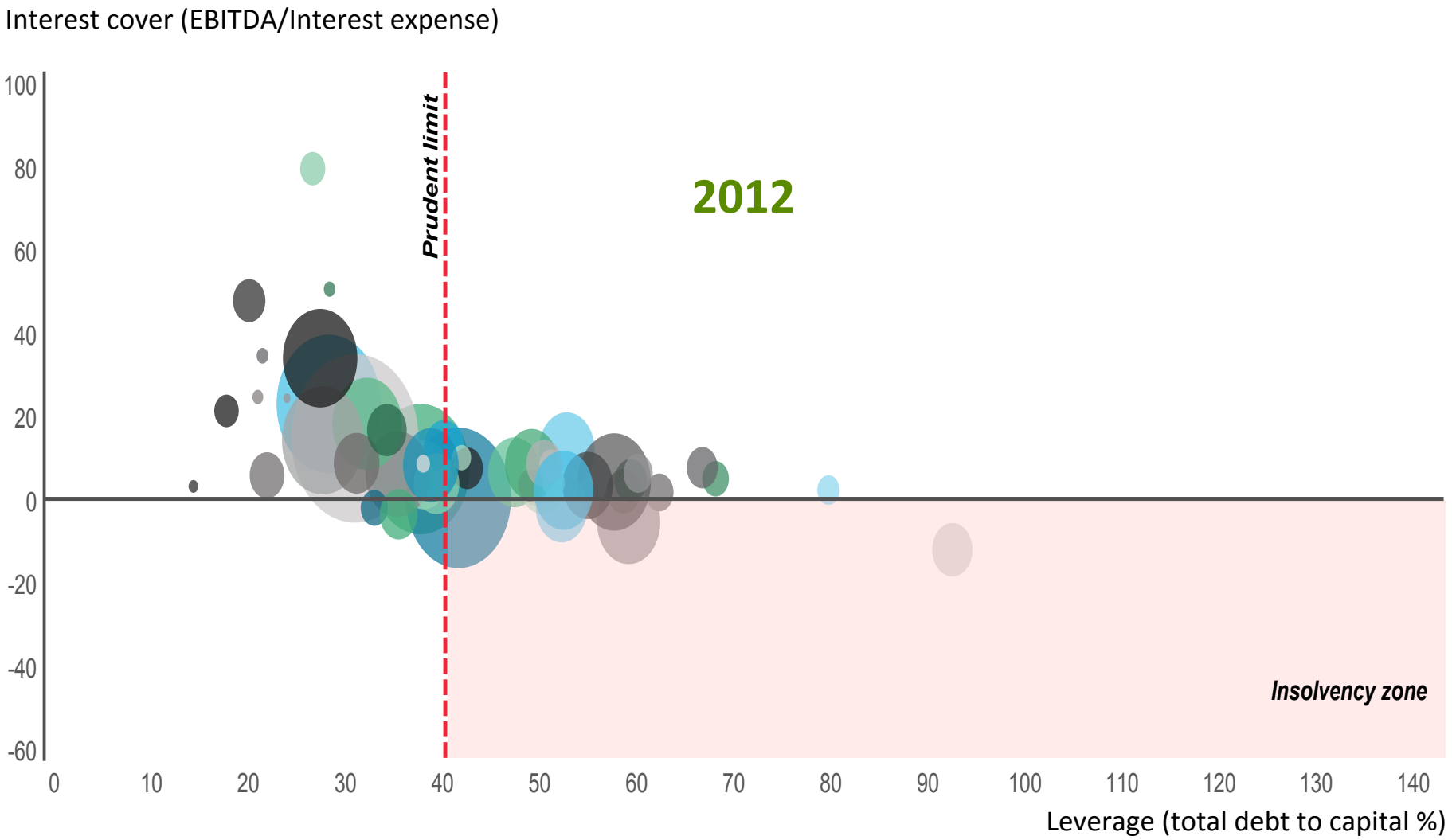
US independent oil & gas producer solvency ratios



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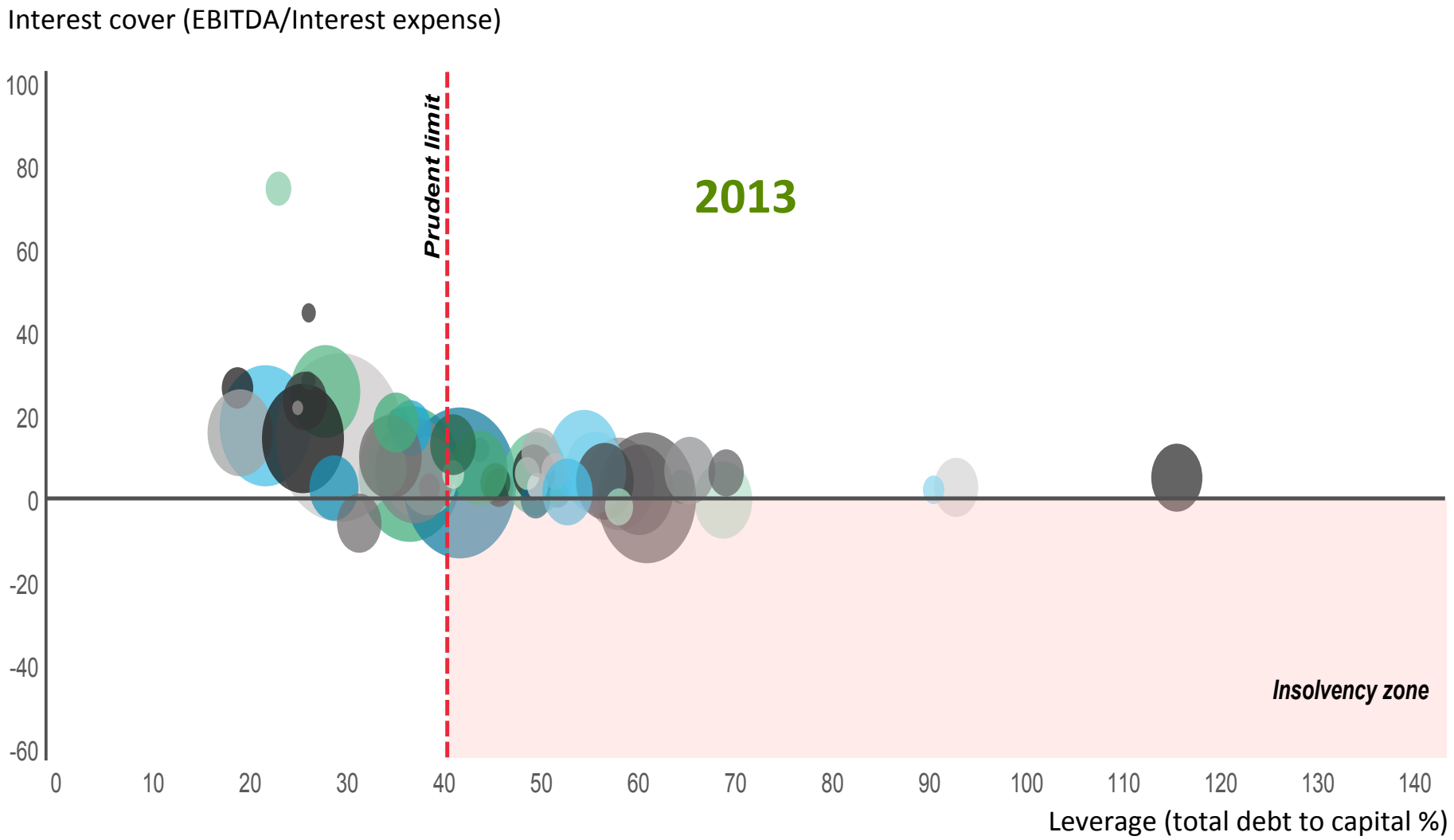
US independent oil & gas producer solvency ratios



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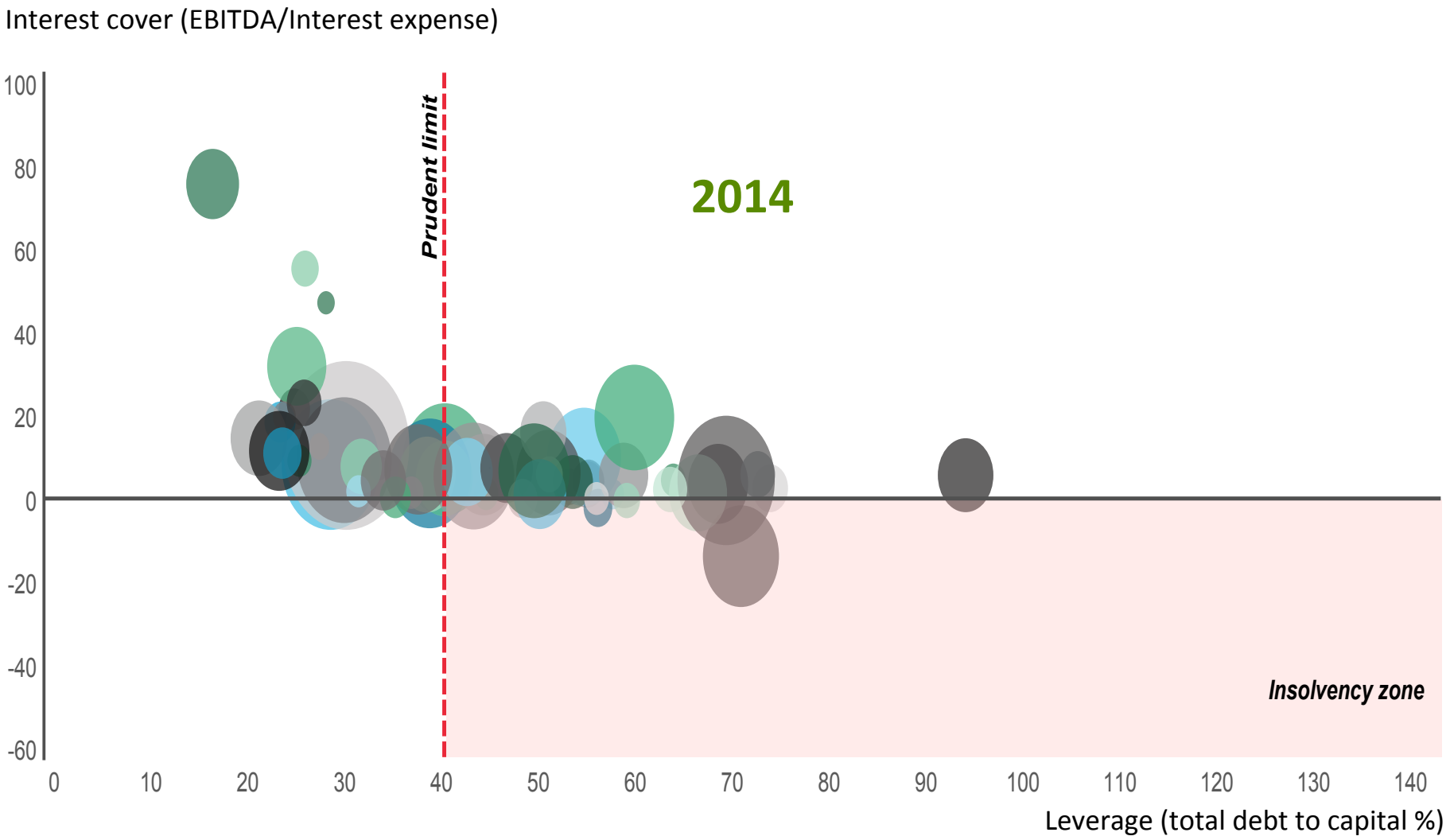
US independent oil & gas producer solvency ratios



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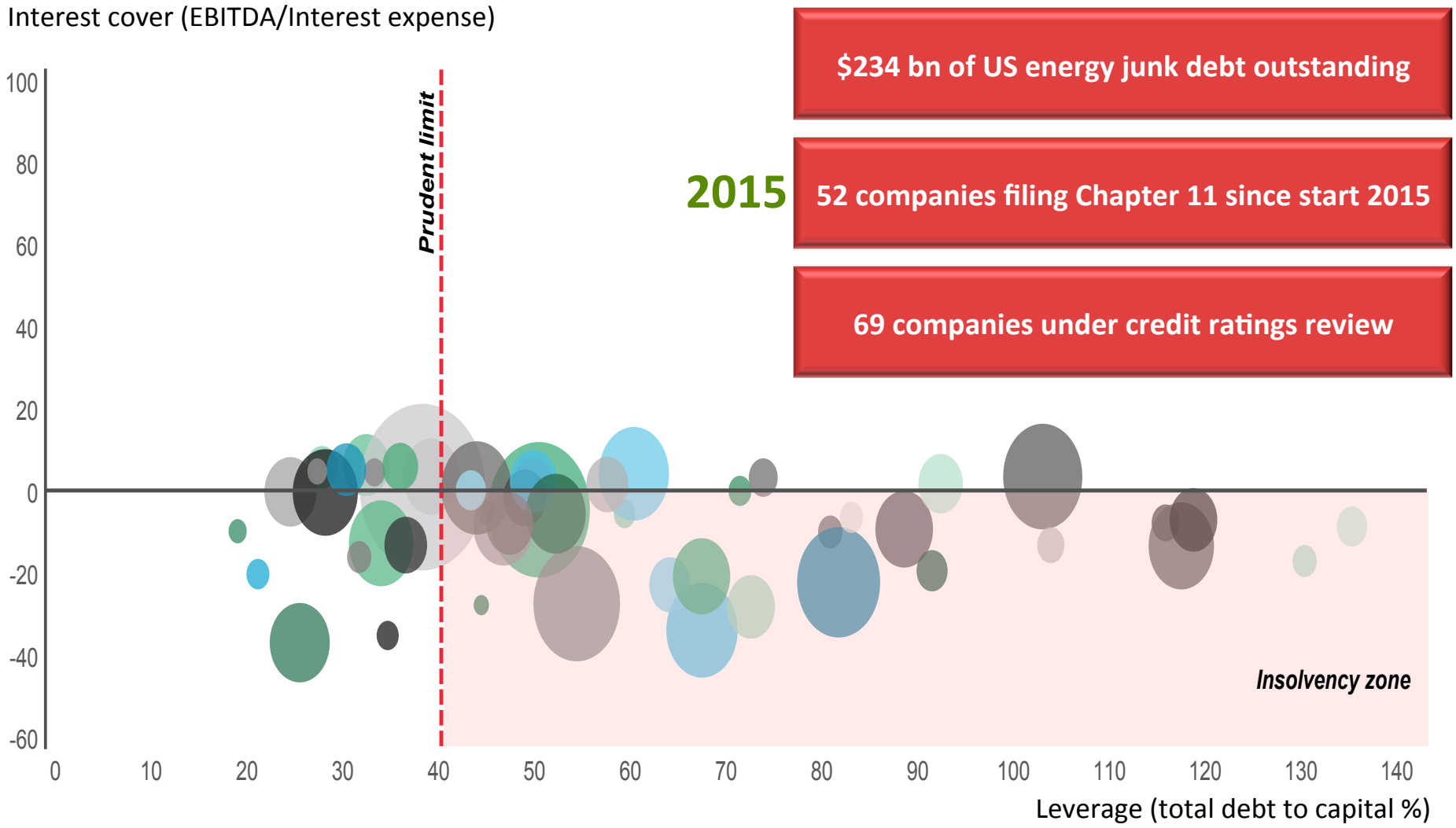
Source: Bloomberg Intelligence; Bloomberg New Energy Finance

US independent oil & gas producer solvency ratios



2015

$234 bn of US energy junk debt outstanding

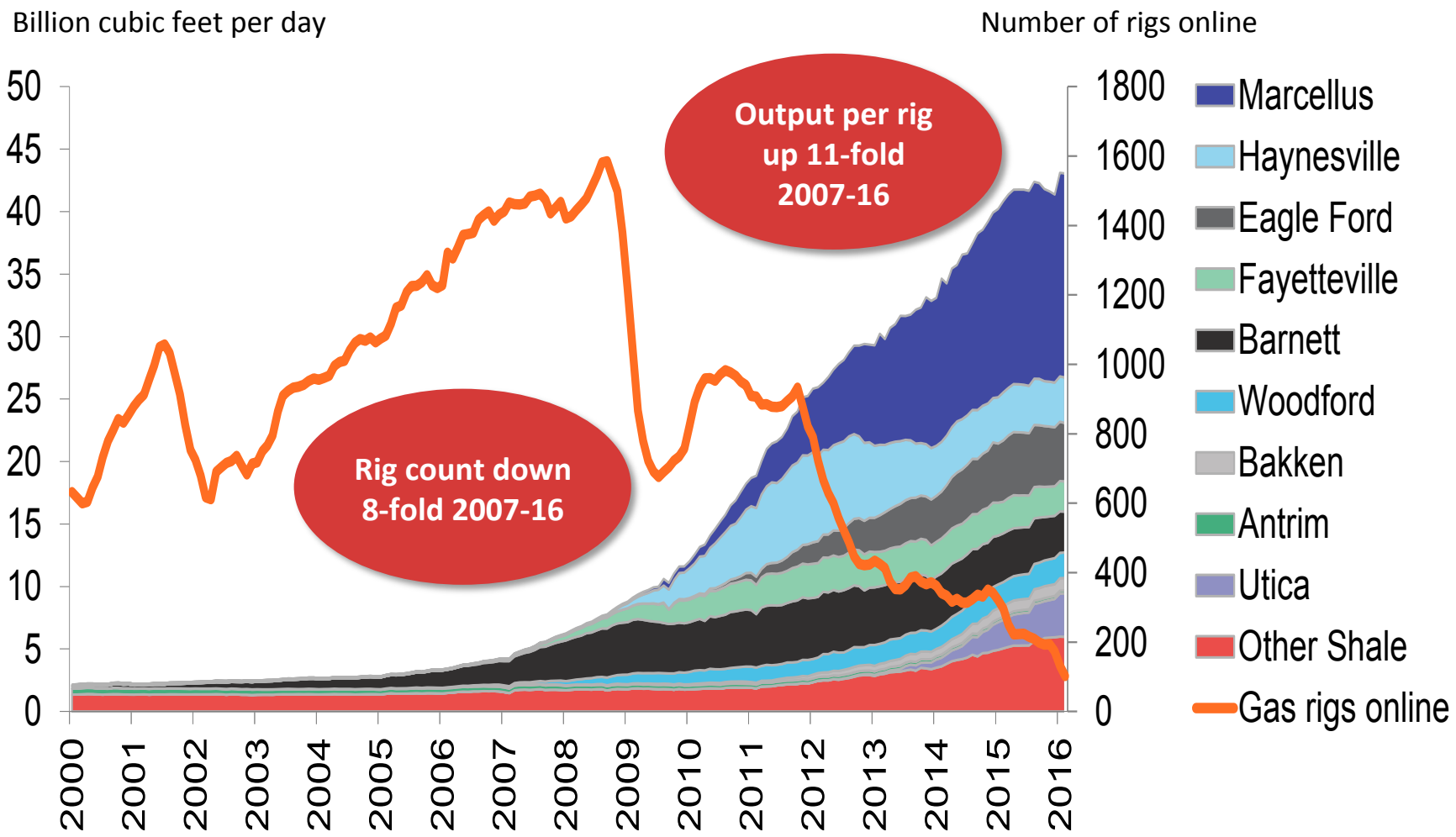
52 companies filing Chapter 11 since start 2015

69 companies under credit ratings review

Note: size of bubbles represents net debt position for each company

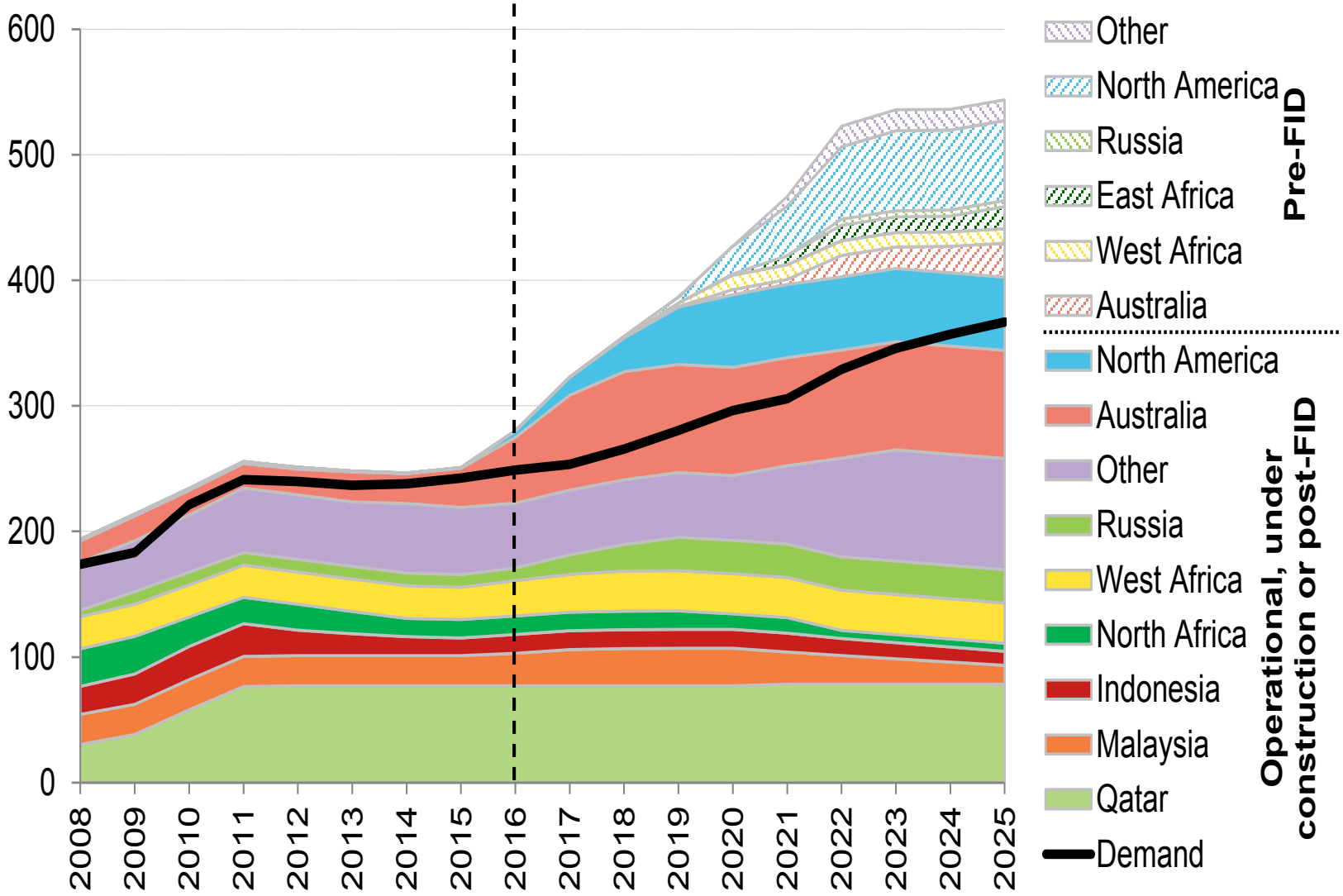
Source: Bloomberg Intelligence; Bloomberg New Energy Finance

US dry shale gas production by play vs rig count



Source: EIA, Bloomberg New Energy Finance

LNG export capacity by country/region
(MMtpa)



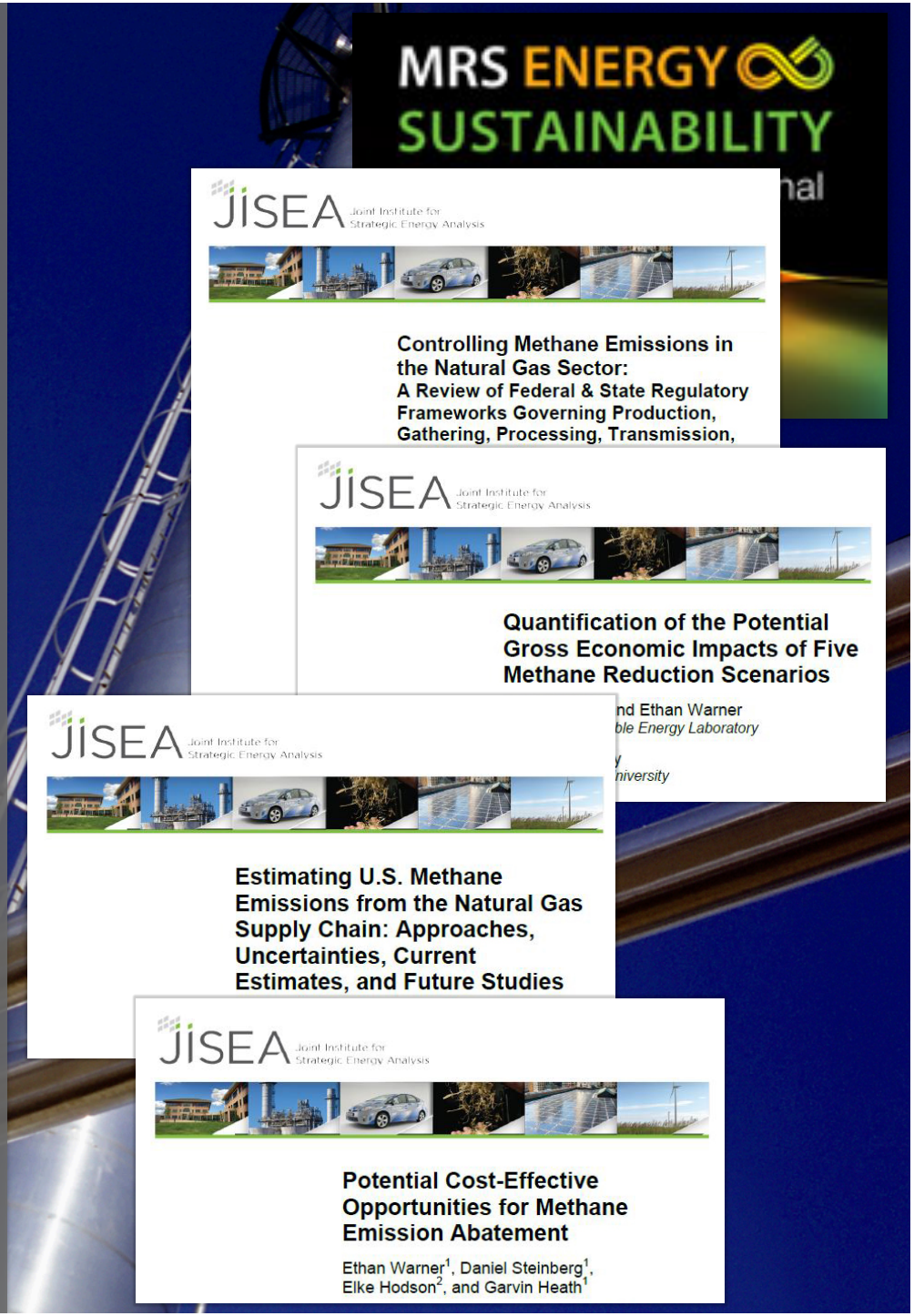
Note: Pre final investment decision (Pre-FID) projects with <50% chance of success are excluded.

Source: Bloomberg New Energy Finance

METHANE
EMISSIONS & ABATEMENT

Key Issues:

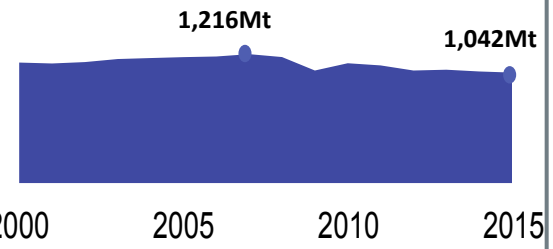
- Federal Framework
- Economics
  - Corporate
  - Stakeholder & Local
  - State
  - Federal
  - United States.
- Environment
  - Water
  - Emissions
- Society
  - Social License…



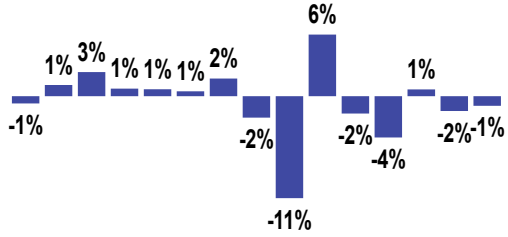
COAL CONSUMPTION BY REGION (MTOE)

OECD - DECLINING

Coal consumption (Mt/yr)

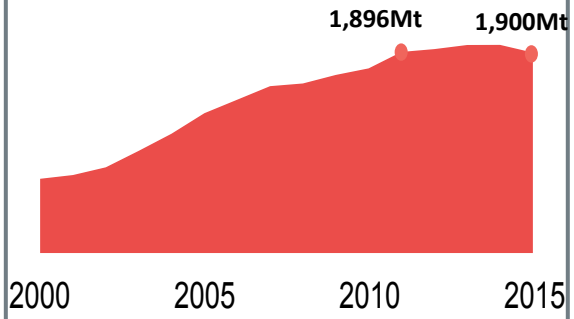


Year on year % change

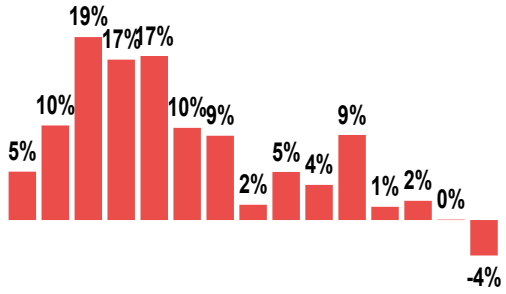


CHINA - FLATTENING

Coal consumption (Mt/yr)

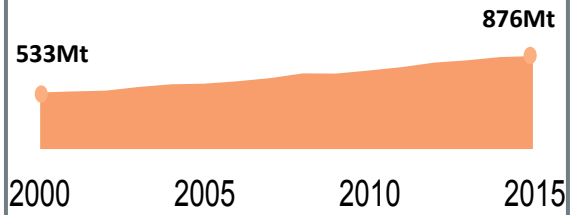


Year on year % change

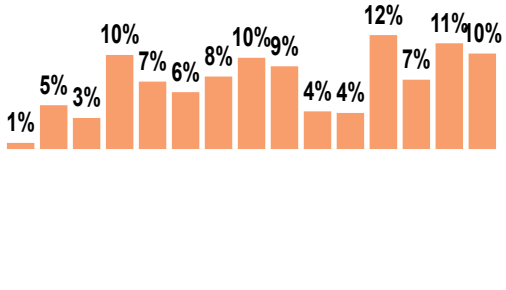


NON-OECD EX CHINA - SLOWING

Coal consumption (Mt/yr)



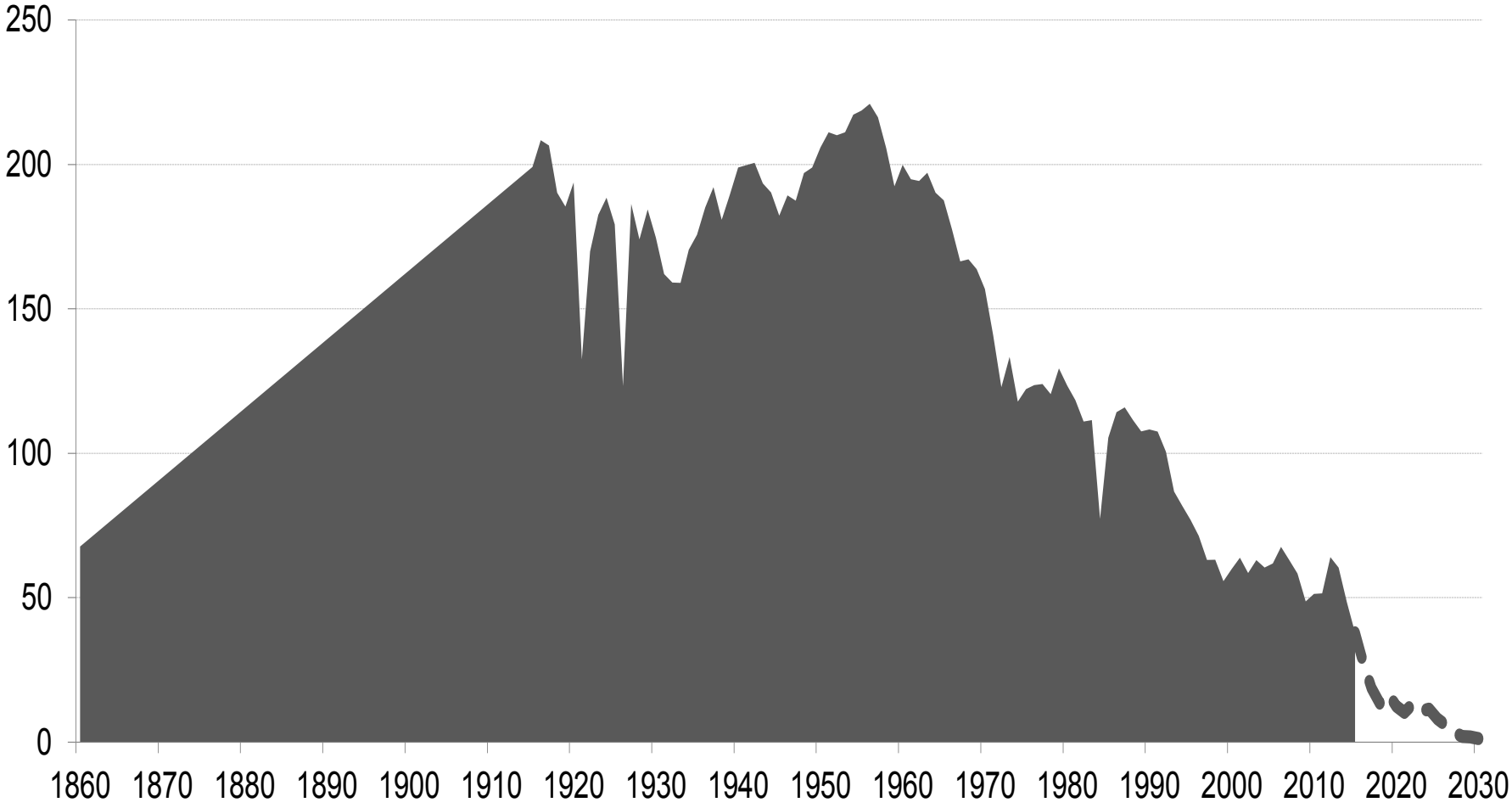
Year on year % change



Source: Bloomberg New Energy Finance

UK coal demand, 1860–2015

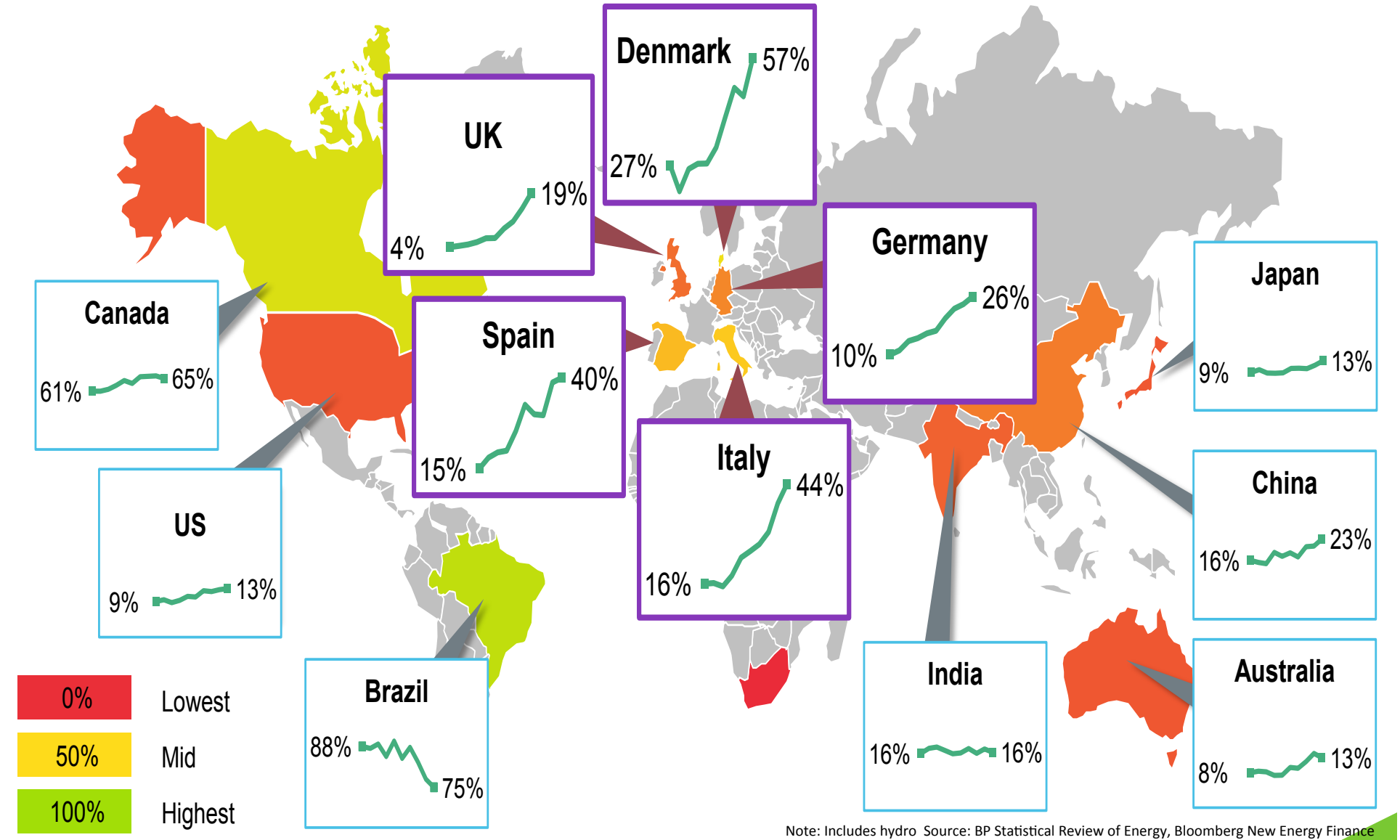
(Mt/yr)



Note: Pre-1913, data is available only for 10-year average annual consumption

Source: UK DECC, Bloomberg New Energy Finance

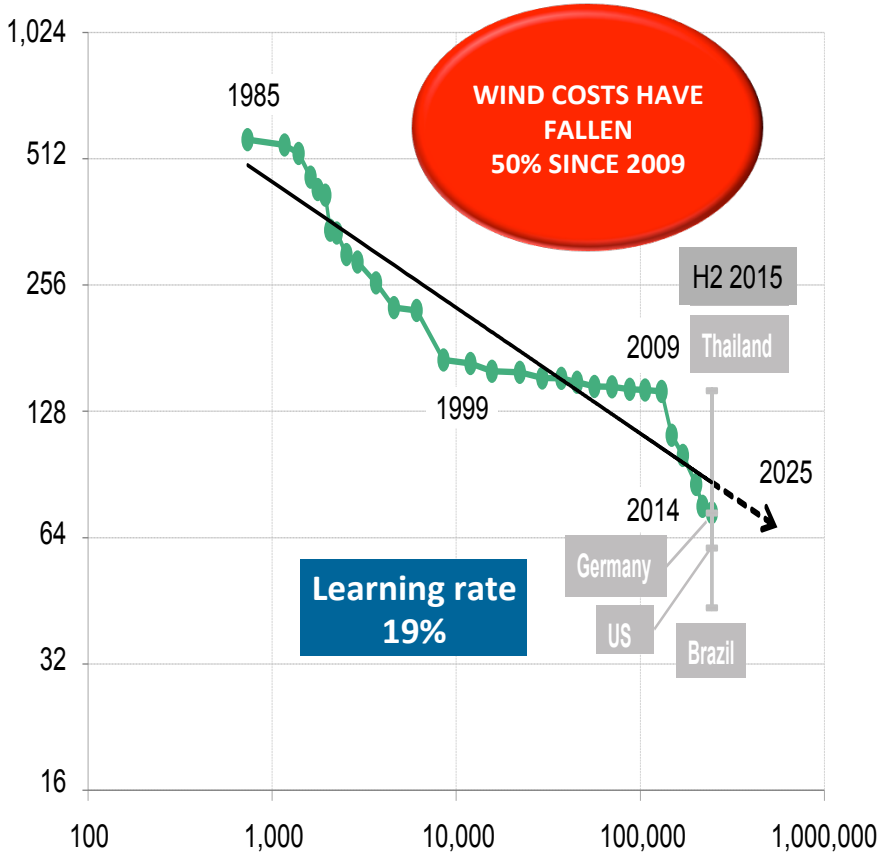
Renewable energy proportion of power generation, 10 years to 2014 (%)



Note: Includes hydro Source: BP Statistical Review of Energy, Bloomberg New Energy Finance

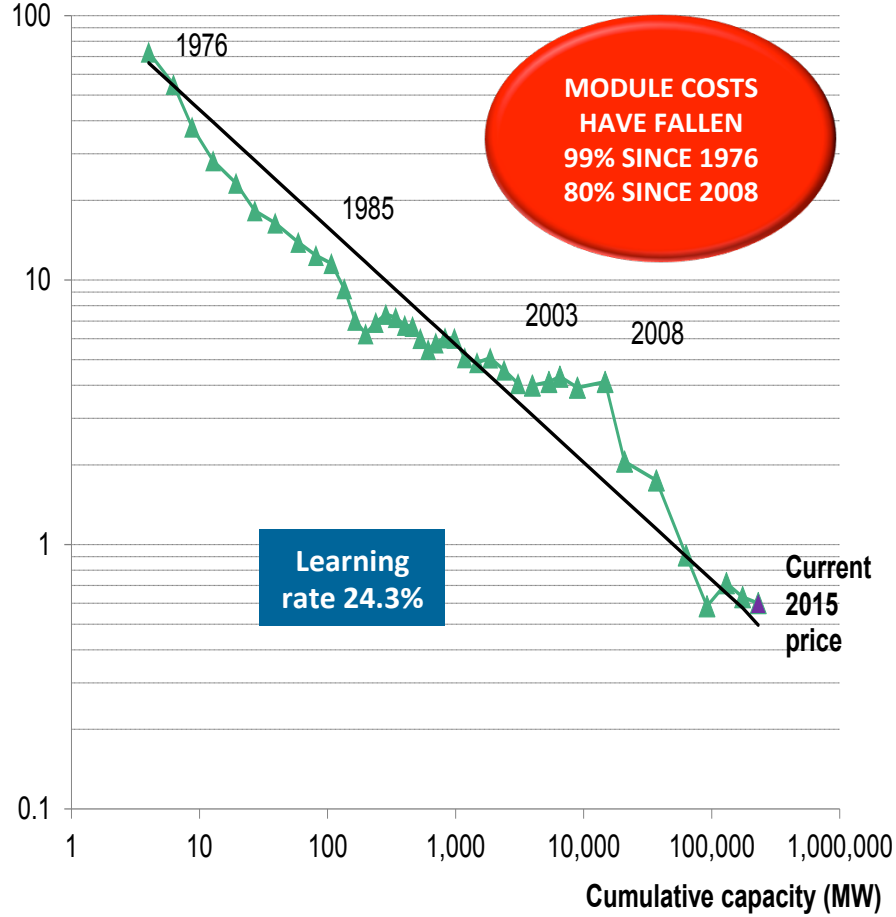
Wind and solar experience curves

ONSHORE WIND LEVELISED COST ($/MWh)



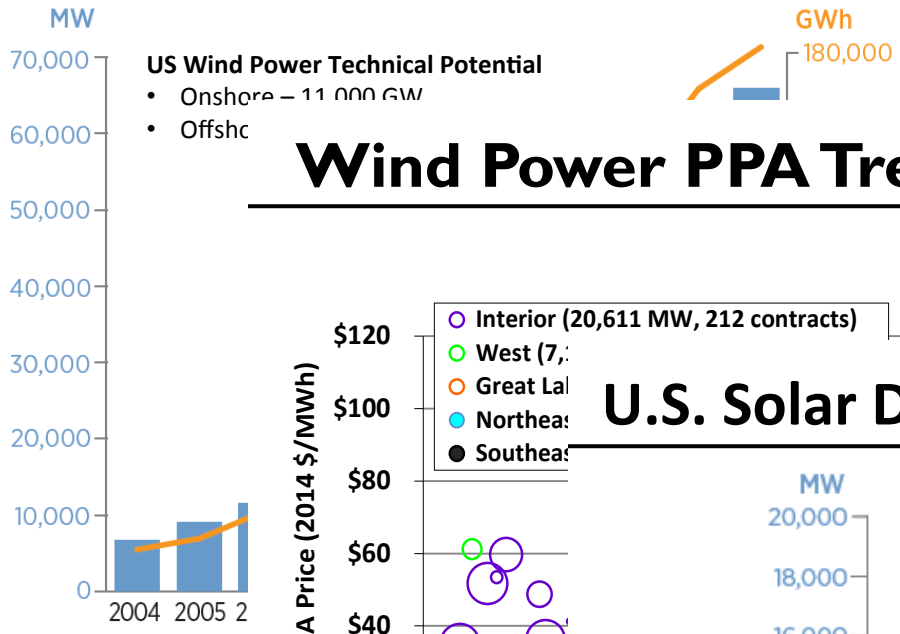
Note: Pricing data has been inflation corrected to 2014. We assume the debt ratio of 70%, cost of debt (bps to LIBOR) of 175, cost of equity of 8% Source: Bloomberg New Energy Finance

SOLAR PV MODULE COST ($/W)



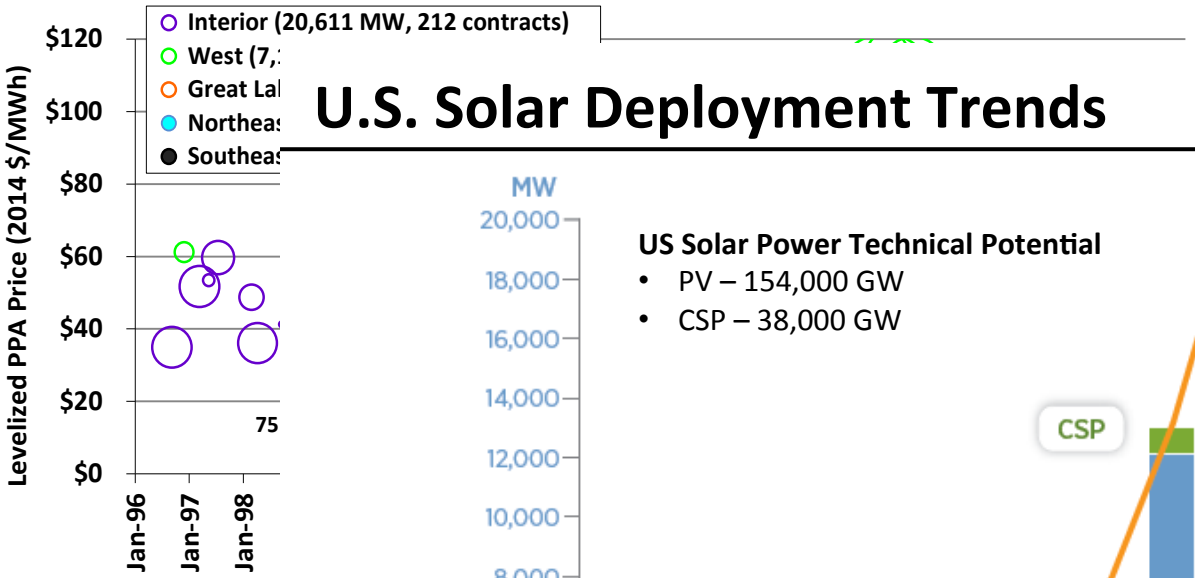
Note: Prices are in real (2015) USD. 'Current price' is $0.61/W Source: Bloomberg New Energy Finance, Maycock

US Wind Generation Trends

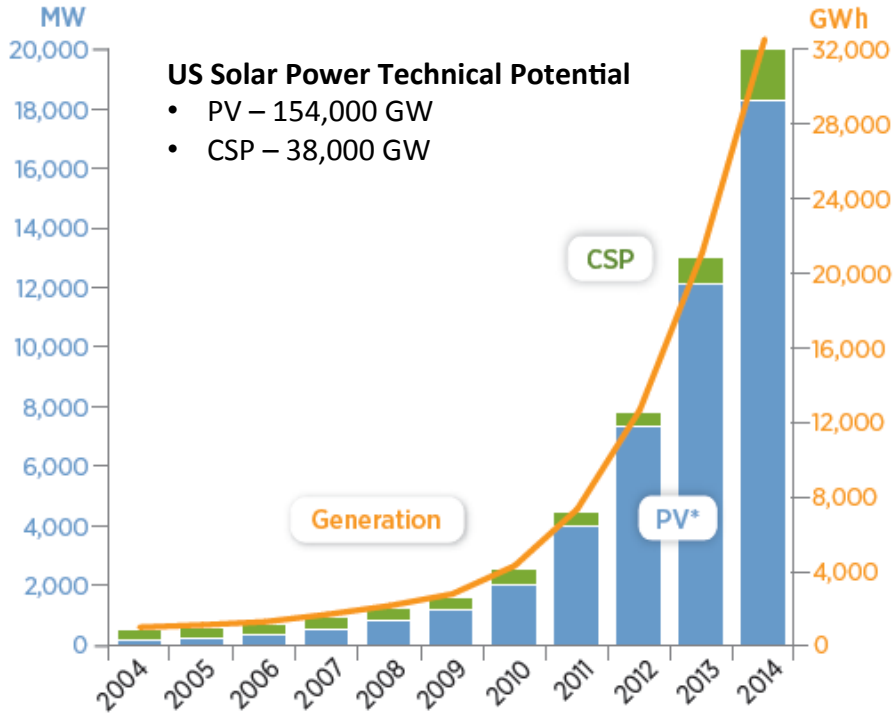


Source: EIA and LBNL

Wind Power PPA Trends



U.S. Solar Deployment Trends



Sources: SEIA/GTM, Larry Sherwood/IREC

World record: 3-cent wind, sub-4-cent solar (Unsubsidised)

ONSHORE WIND

Location:	Morocco
Bidder:	Enel Green Power
Signed:	January 2016
Price:	US$ 3.0 c/kWh

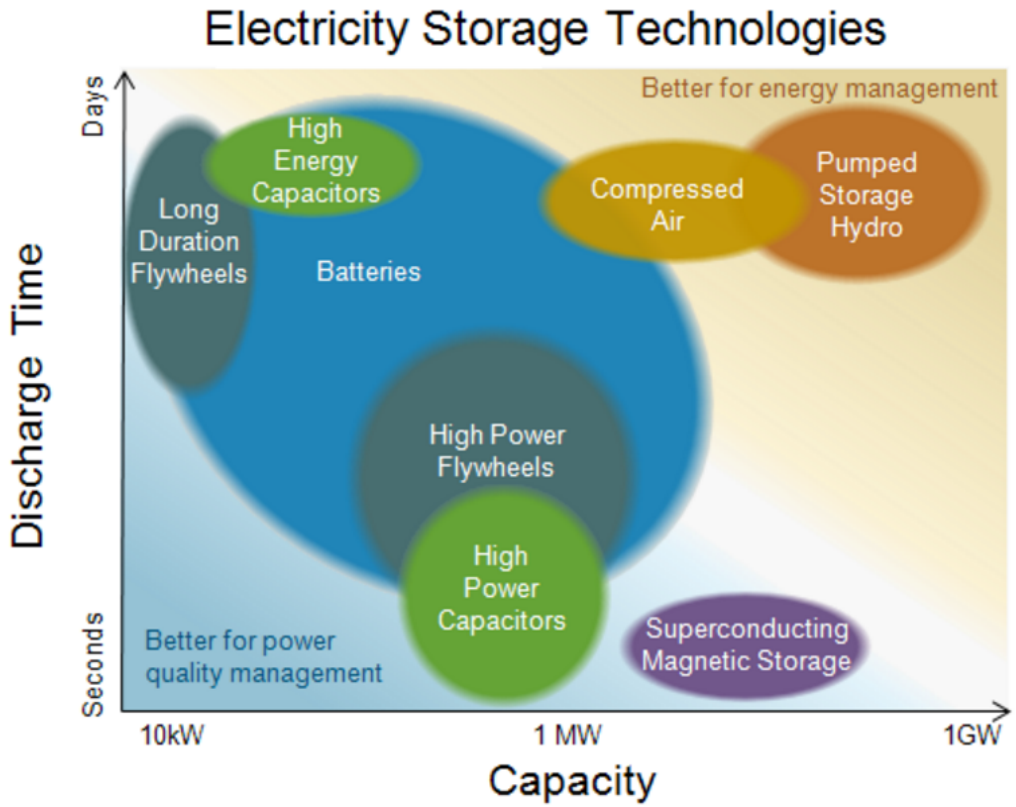
SOLAR PV

Location:	Coahuila, Mexico
Bidder:	Enel Green Power
Signed:	March 2016
Price:	**US$ 3.6 c/kWh**

Source: Bloomberg New Energy Finance; ImagesSiemens; Wikimedia Commons

Planning Considerations for Storage

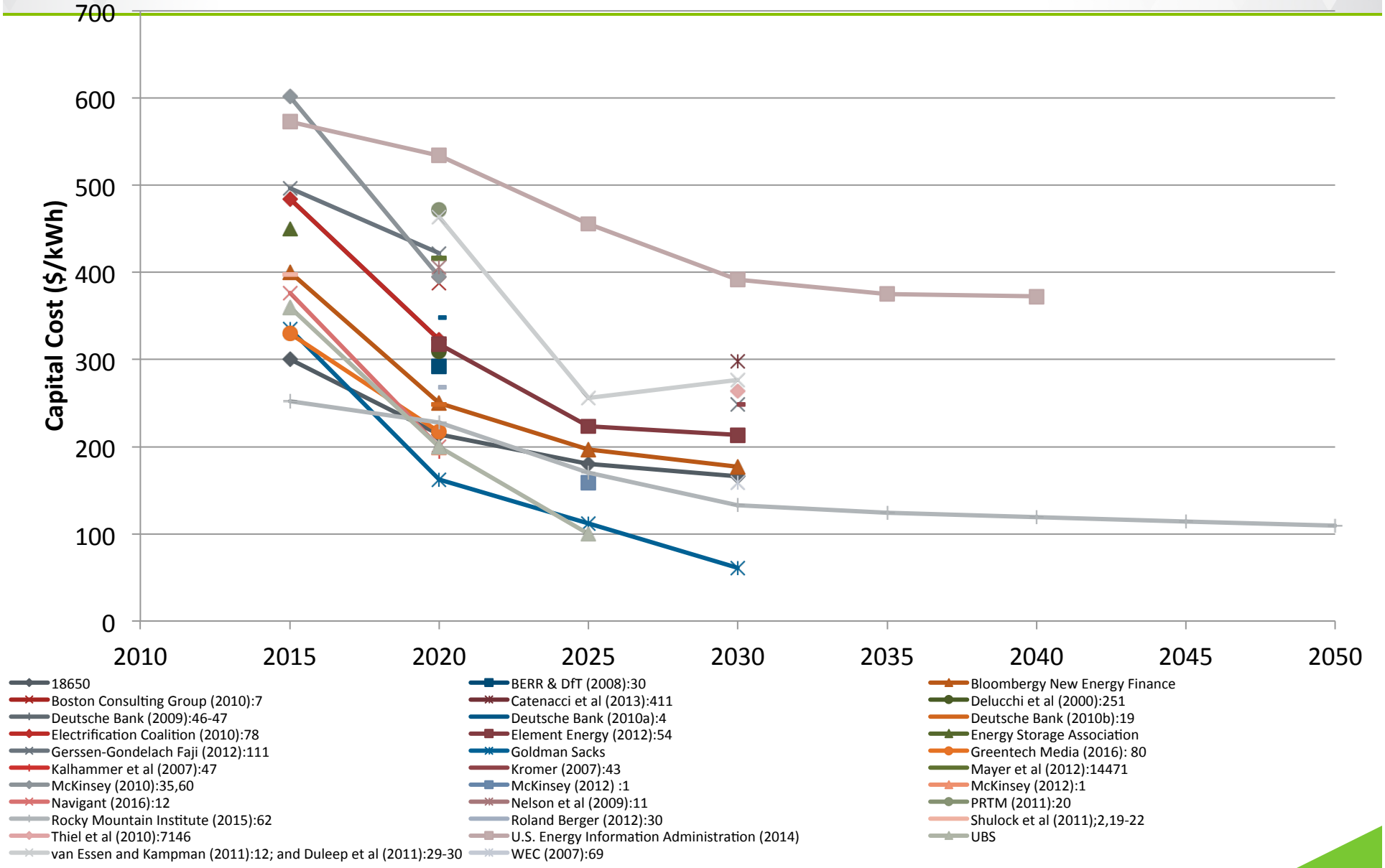
21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems



Source: U.S. Energy Information Administration, based on Energy Storage Association.

Shipping containers filled with lithium batteries on Kauai, Hawaii USA
(Source: *Technology Review* 2015)

Literature review – battery pack costs



Tech cost Trends

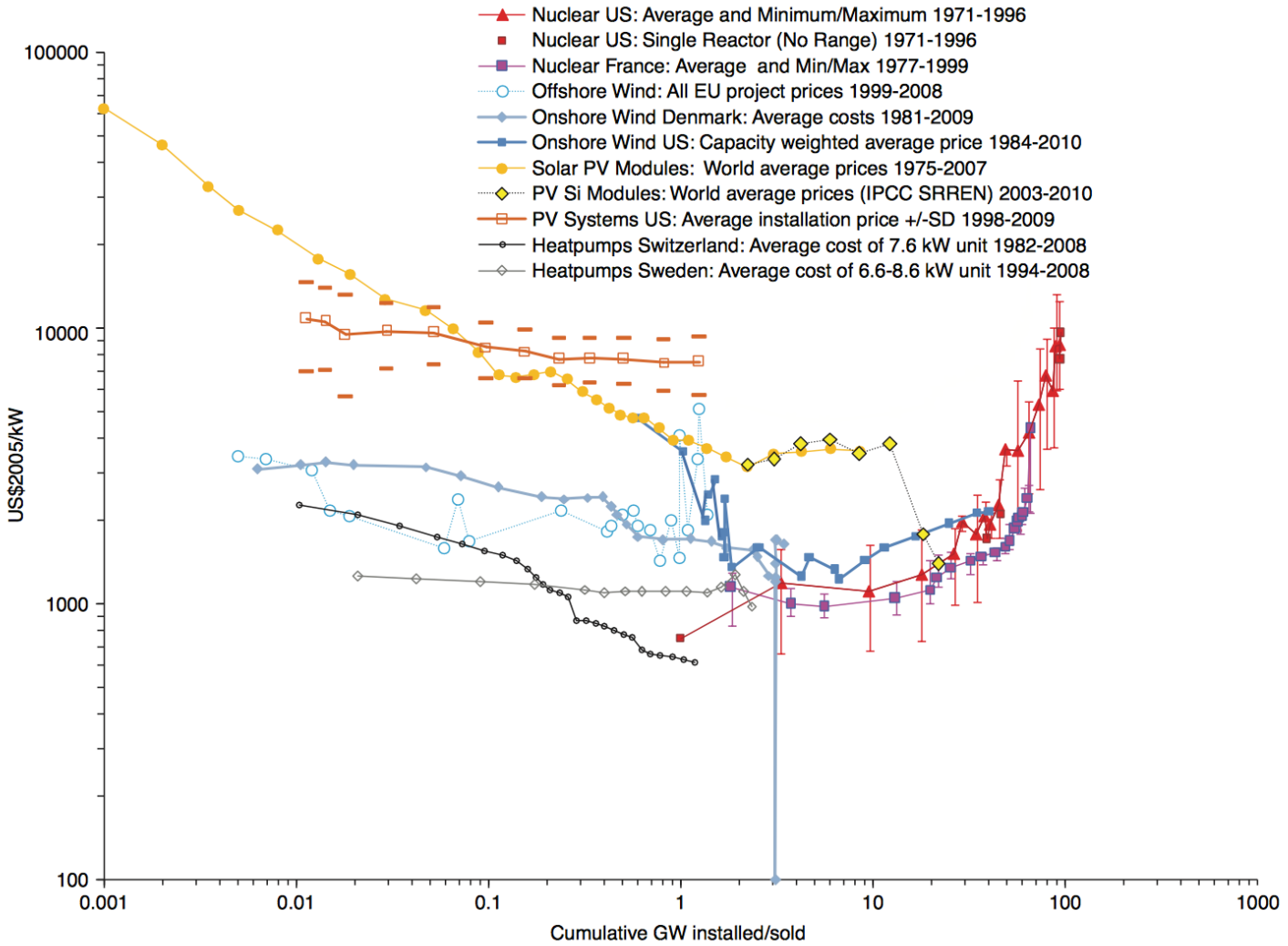


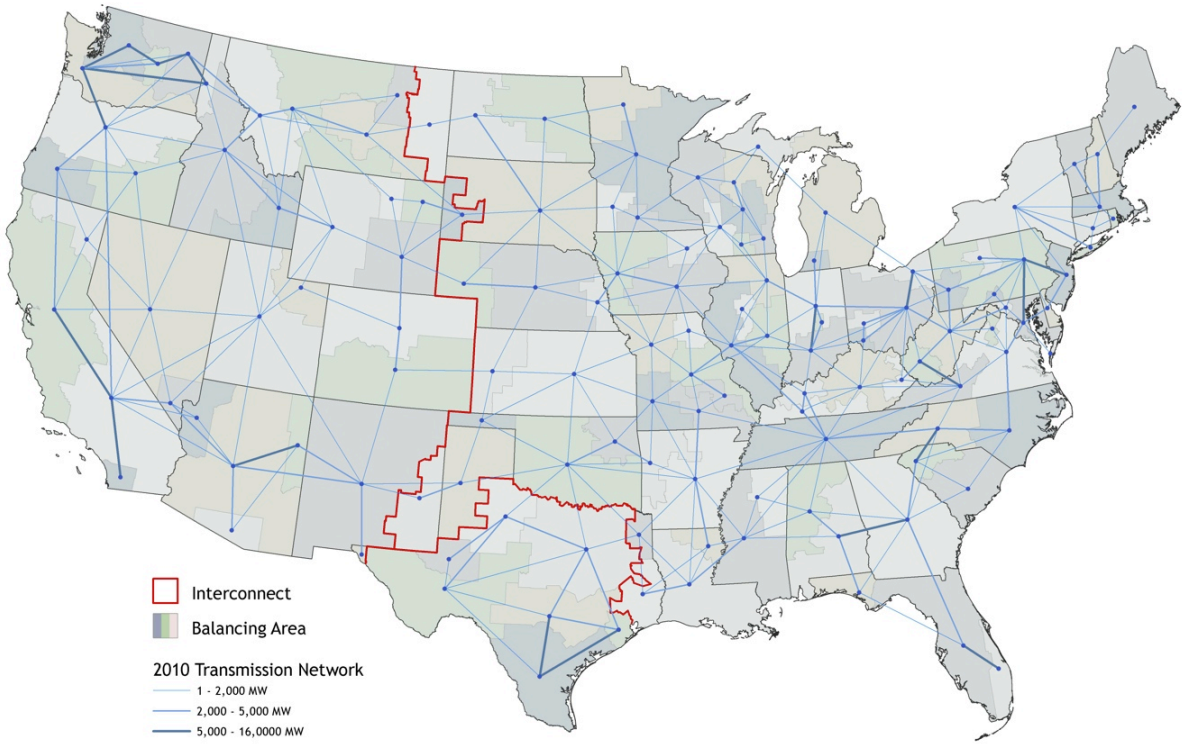
Figure 24.11 | Chapter 24 Case Studies summarized: Cost trends of selected non-fossil energy technologies (US_{2005}/KW installed capacity) versus cumulative deployment (cumulative GW installed). Source: Chapter 24 case studies.

Exploring Technology/Policy/Finance Scenarios

- 20% Wind Energy by 2030 (2008)
- Evaluating a Proposed 20% National Renewable Portfolio Standard (2009)
- SunShot Vision Study (2012)
- Renewable Electricity Futures Study – Exploration of High-Penetration Renewable Electricity Futures (2012)
- Beyond Renewable Portfolio Standards (2013)
- Integrated Canada-US Power Sector Modeling with ReEDS (2013)
- ReEDS Modeling of the President's 2020 U.S. Renewable Electricity Generation Goal (2014)
- Wind Vision Report (2015)

- Active Projects
  - Hydropower Vision
  - Geothermal Vision
  - On the Path to SunShot

Regional Energy Deployment System (ReEDS) Model

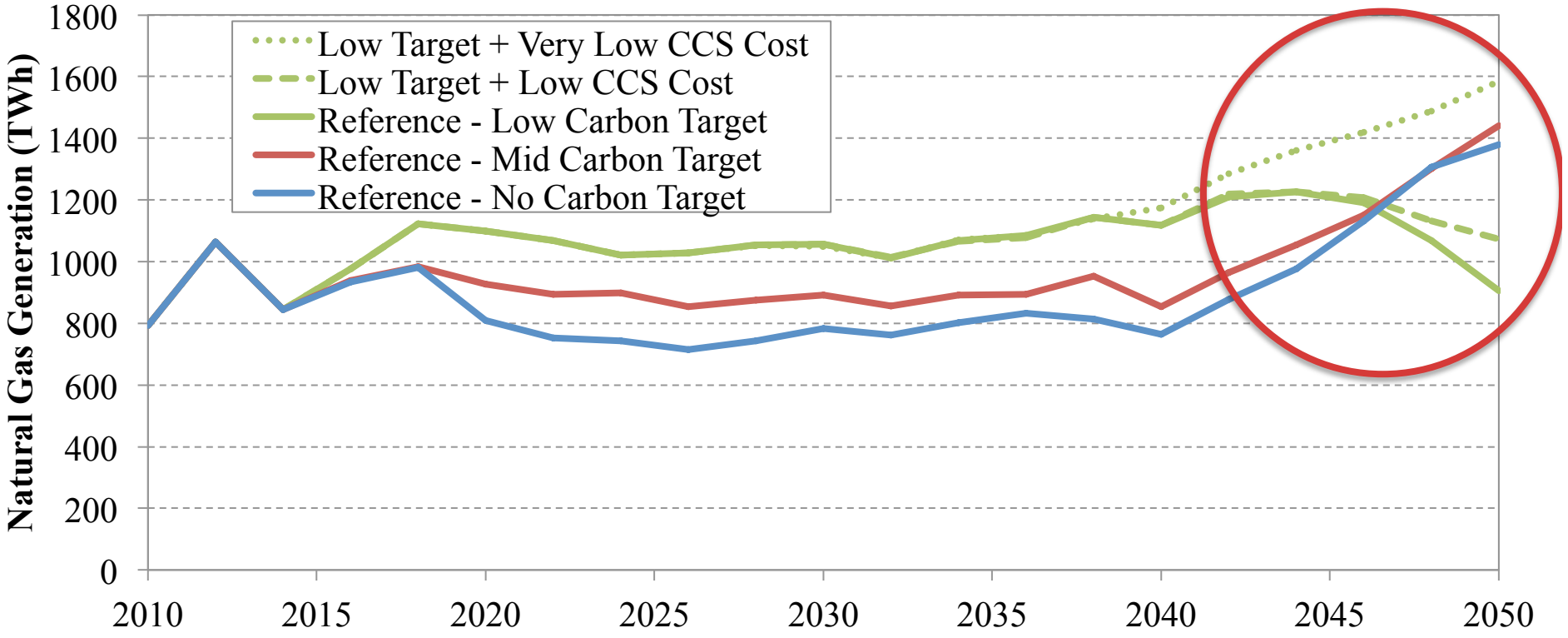


- Optimization model of U.S. Electricity Sector
- 134 Balancing Areas
- 356 Wind/CSP regions
- Explicit consideration of RE integration issues

- Solves combined capacity expansion and dispatch out to 2050 under different assumptions
  - Economic
  - Technology
  - Policy

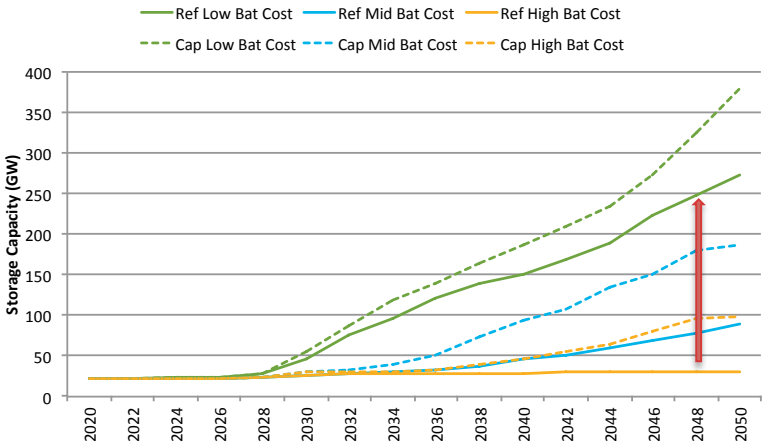
NG can be useful in lowering emissions in the near & Medium term, but low cost CCS important for Deep Decarbonization

- Under a low carbon target, NG usage increases over time with competitive CCS



ReEDS initial results – storage capacity

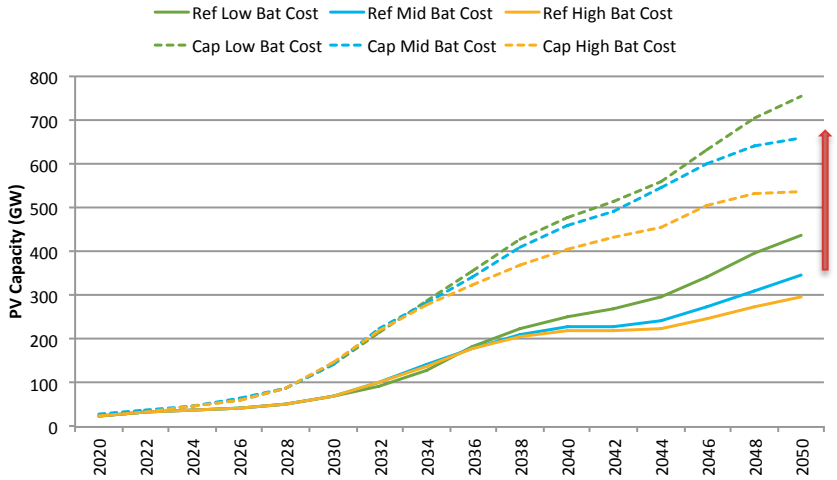
In all scenarios very little storage is deployed until after 2028. The high cost storage trajectory does not result in any additional storage capacity in the reference scenario, but does in the carbon cap scenario.



- Cost Decreases Dominate for Storage
- Carbon Budget drives RETs

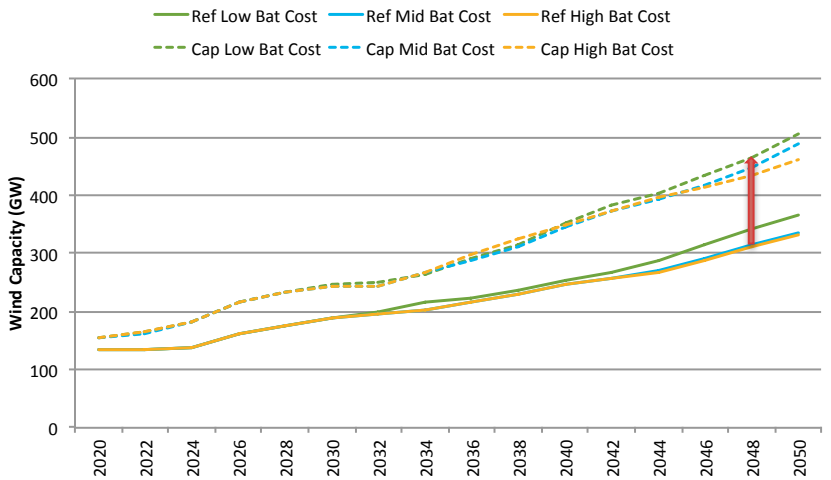
ReEDS initial results – PV capacity

PV capacity is strongly influenced by low cost storage (more than 130 GW of additional PV capacity between the low and high battery cost scenarios). CSP capacity (not shown) is reduced due to low cost storage.

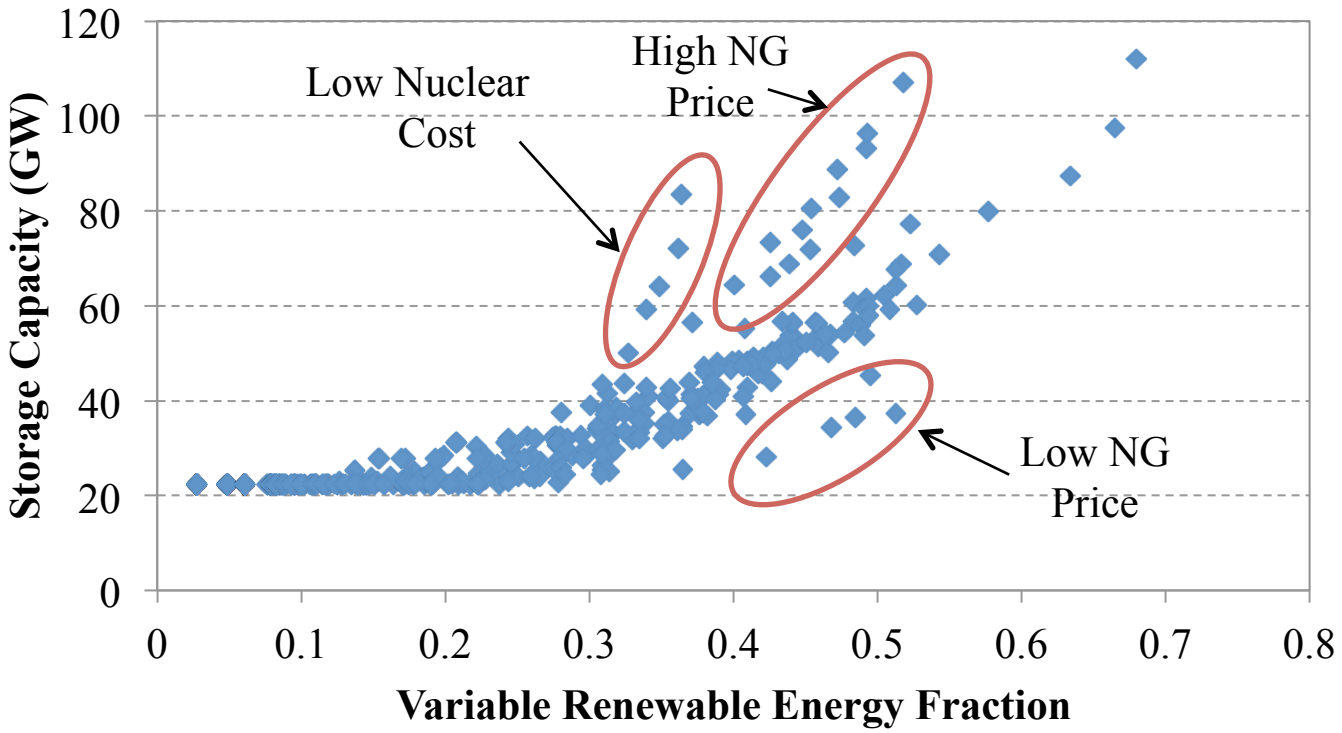


ReEDS initial results – wind capacity

Wind capacity is not as significantly impacted by low cost storage.

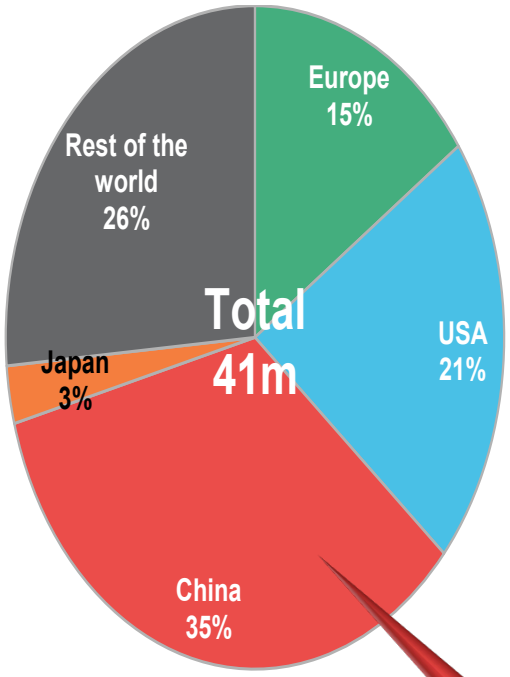


Gas and Storage Compete for Providing Flexibility.



Electrification of transportation - impacts

EV SALES BY REGION IN 2040 (MILLION VEHICLES)

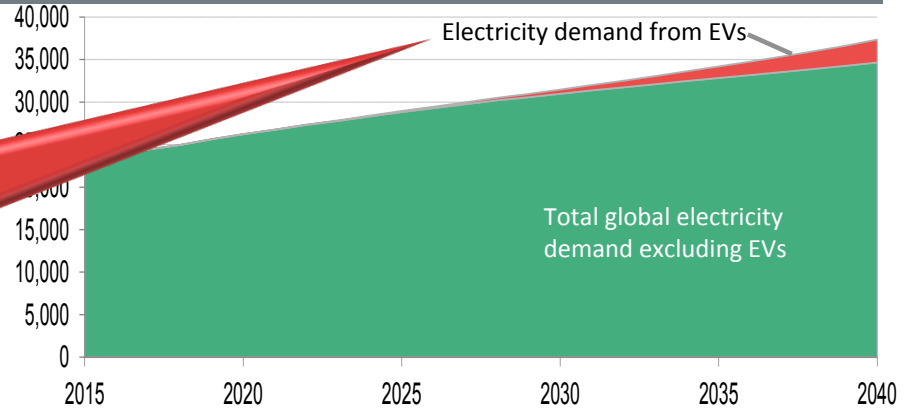


Around 10% additional power demand

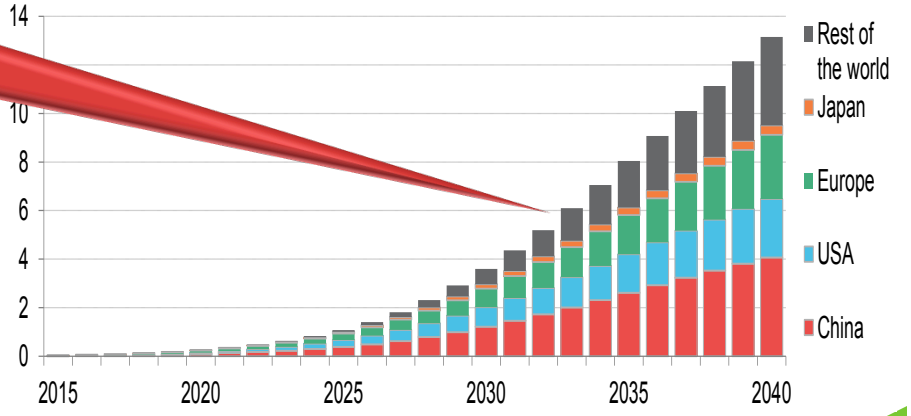
Destruction of 13m bbl/day oil demand

Chinese car industry leadership

ELECTRICITY DEMAND FROM EVS (TWH/YR)



OIL DEMAND DISPLACED BY EVS (MILLION BARRELS / DAY)

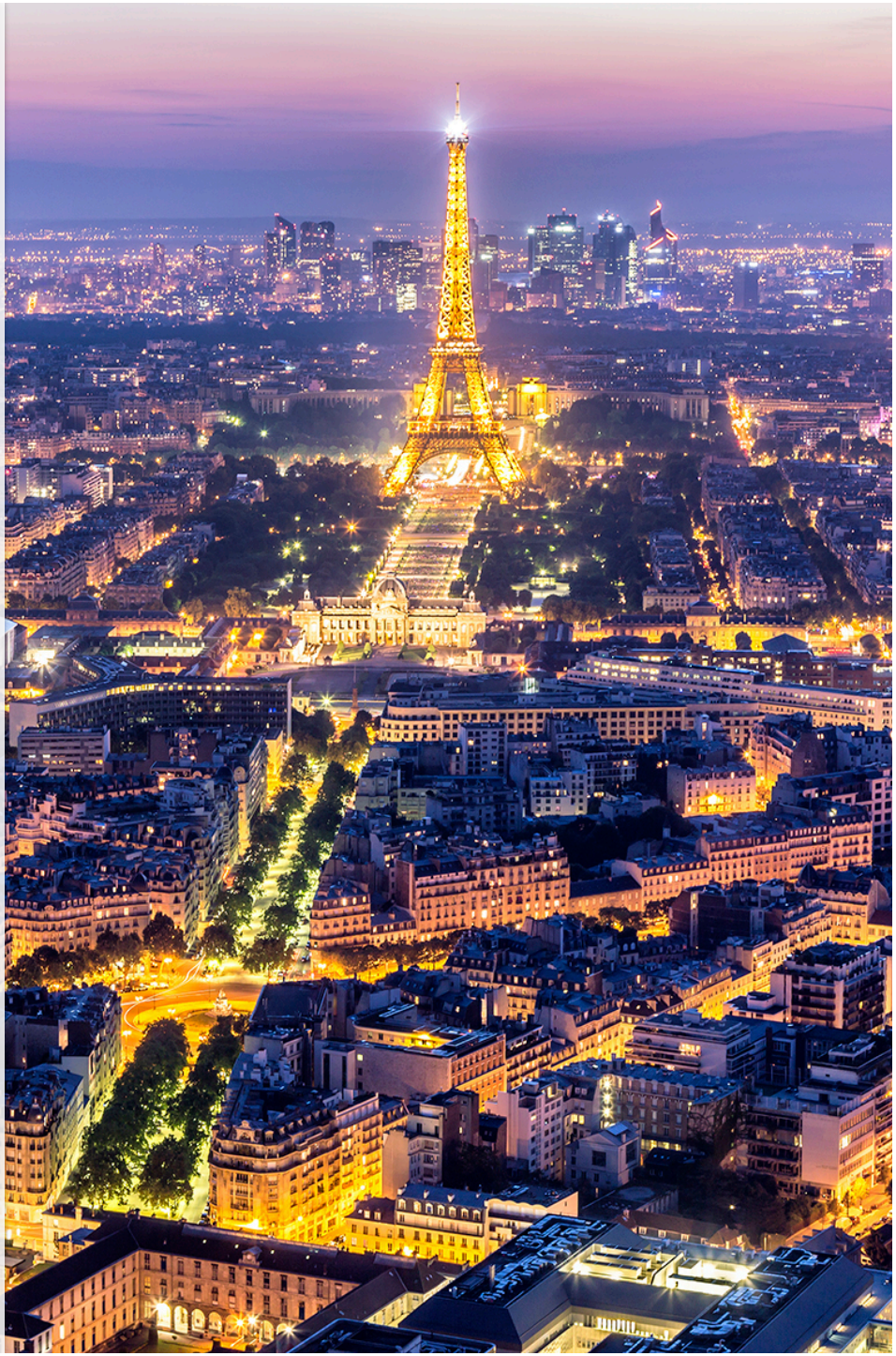


Source: Bloomberg New Energy Finance

THE ROAD FROM PARIS

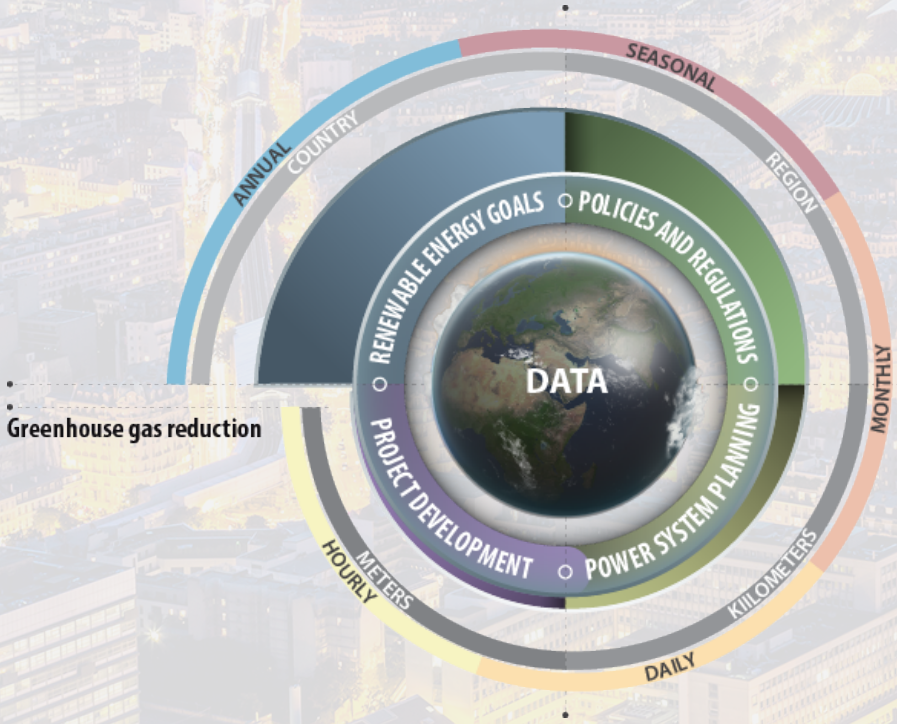
Aspirations…

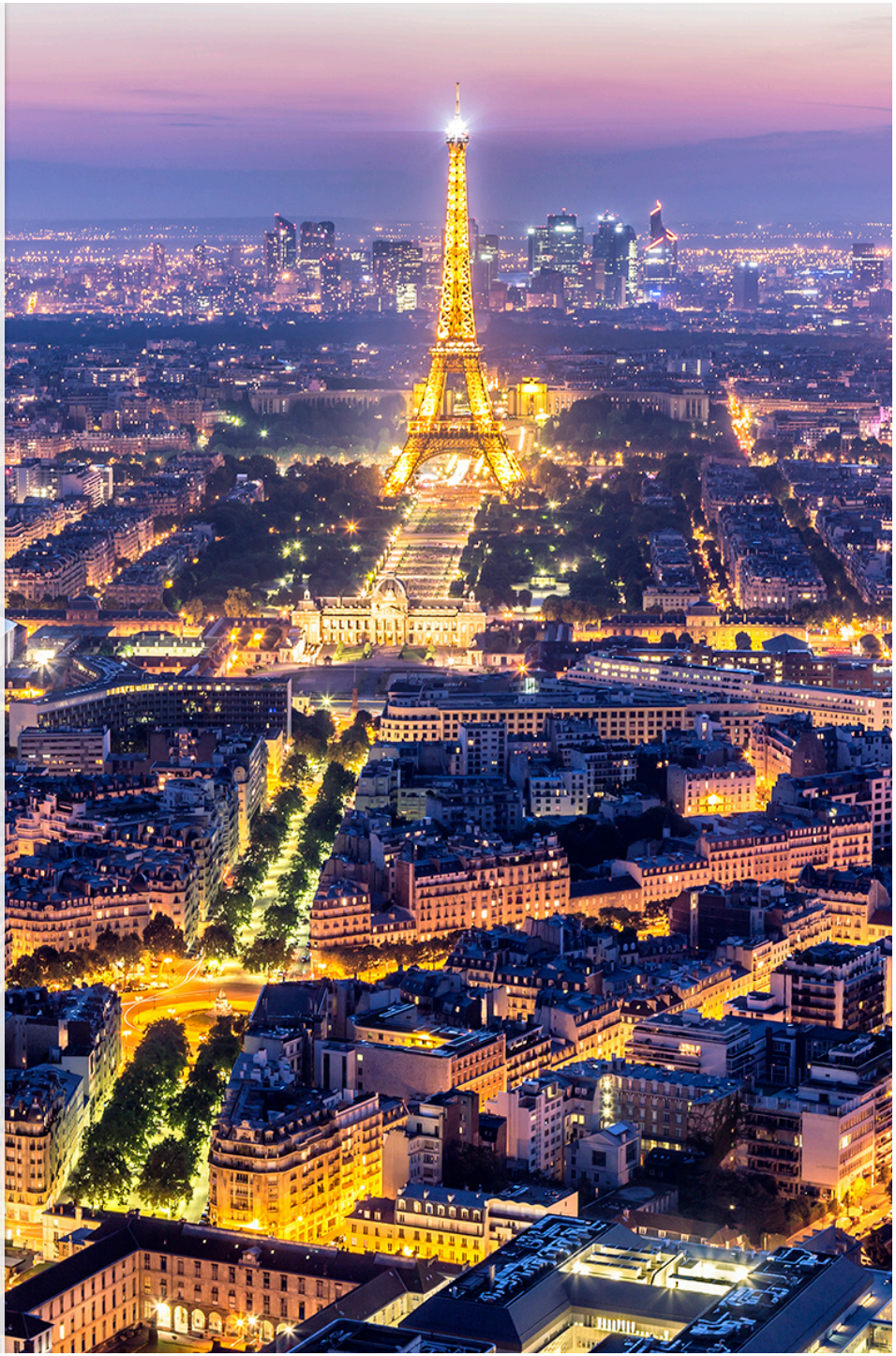
Realization…



THE ROAD FROM PARIS

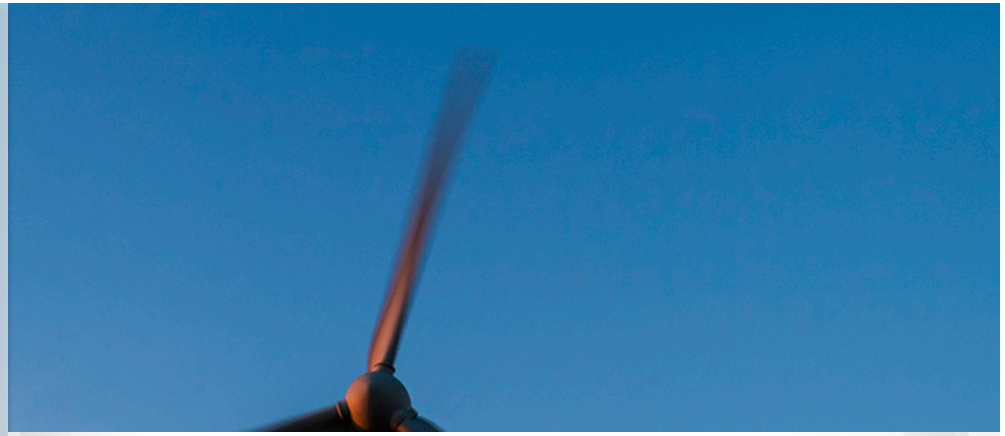
Science Informed Decisions...



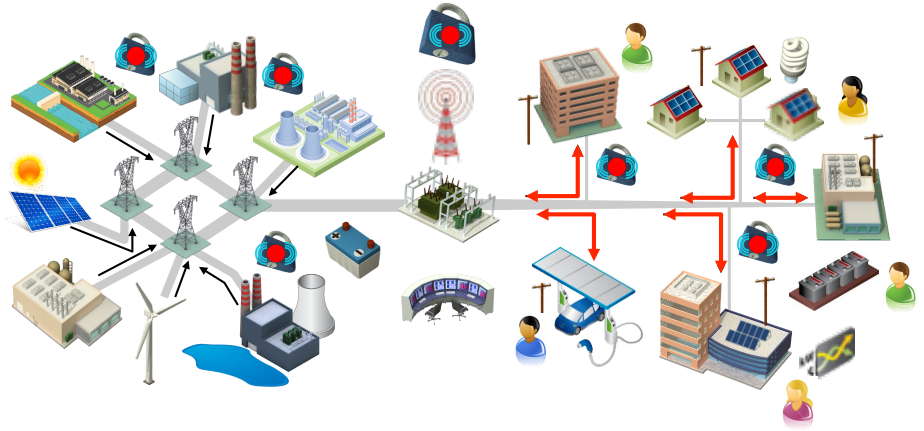


THE EVOLVING POWER SECTOR

- *NG & RE*
- *Gas/Electric Coordination/ Dependencies*
- *DER*
- *Intelligence*
- *State, CPP +…*
- *Flexibility*
- *PSOF: e.g. "Utility 2.0"*



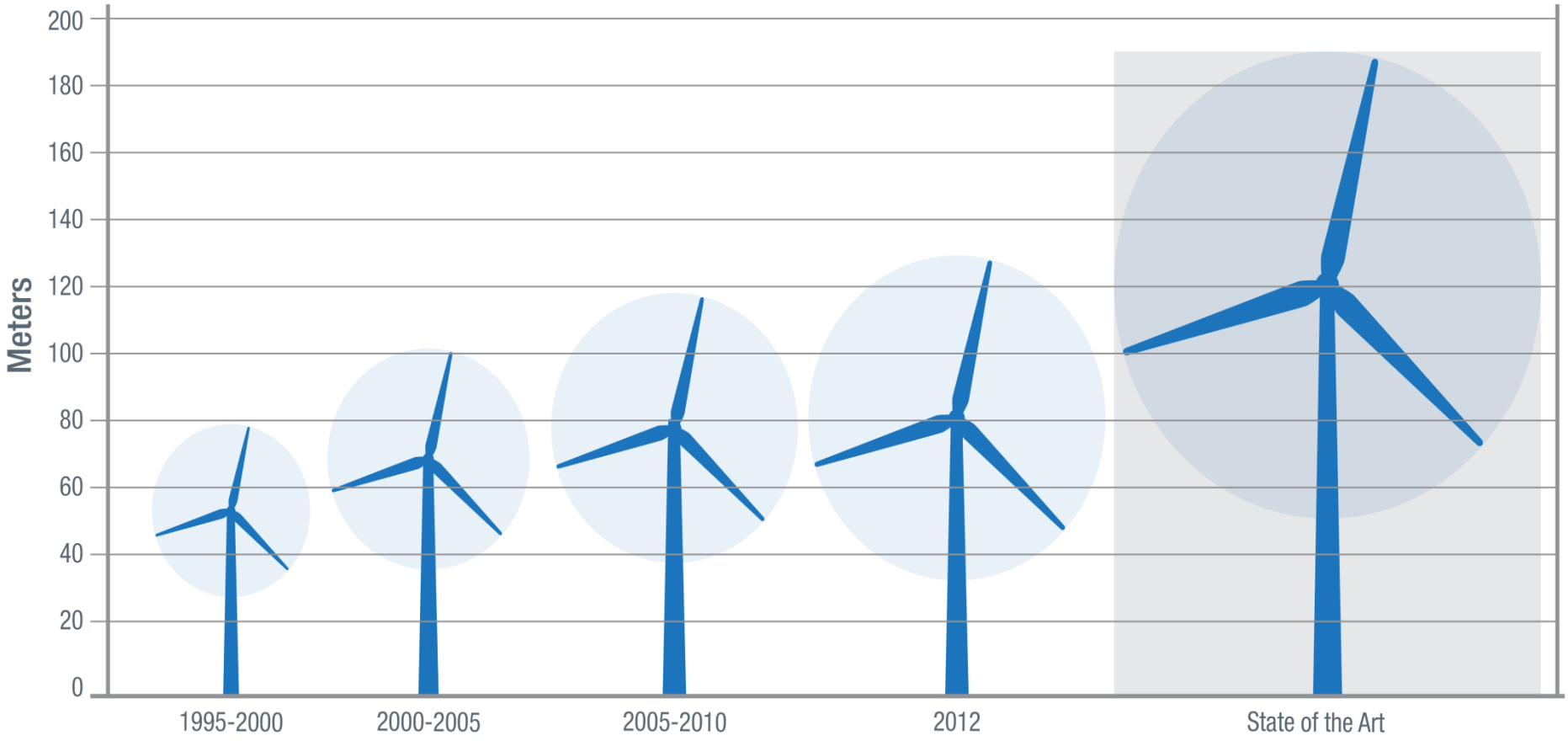
The Evolving Power System …



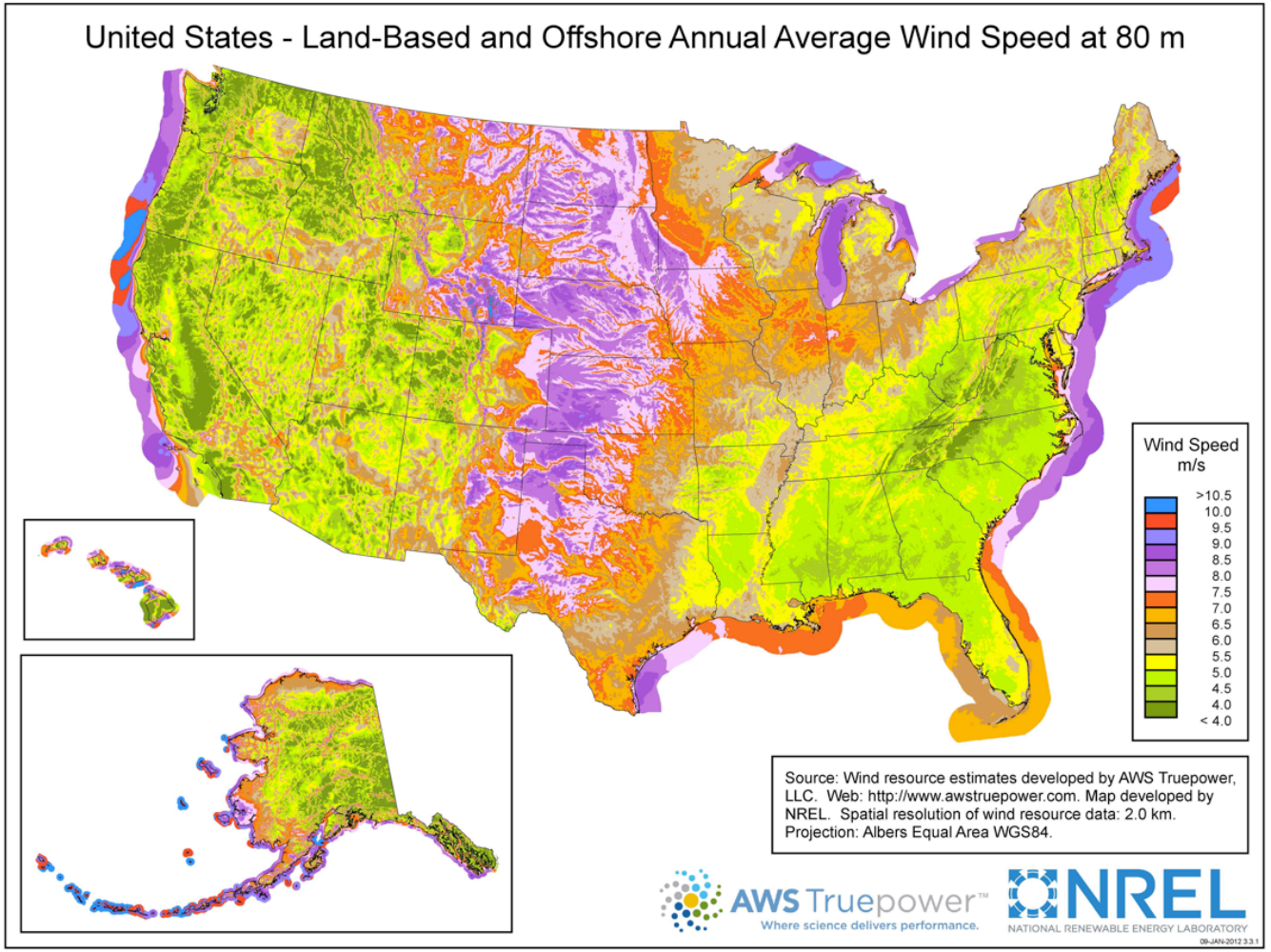
Transitioning today: Restructuring, New Business Models, New Technologies

Technology is Accelerating Faster than Ever

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems



US Wind Resources



US Wind Power Technical Potential

- Onshore – 11,000 GW
- Offshore – 4,200 GW

Technology Evolution Unleashes New Opportunities and Challenges

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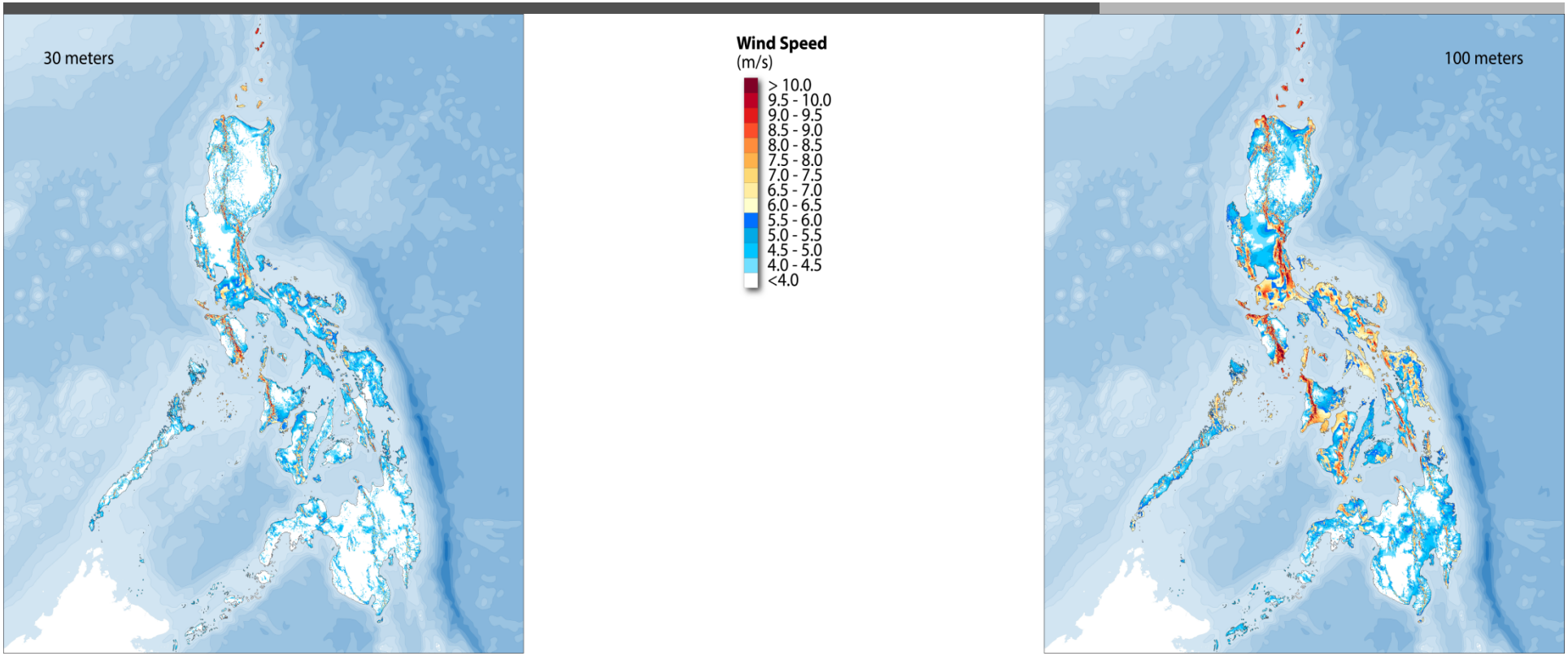
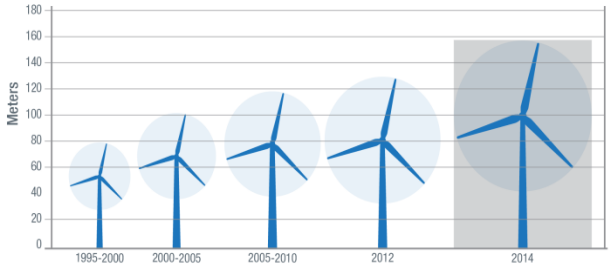
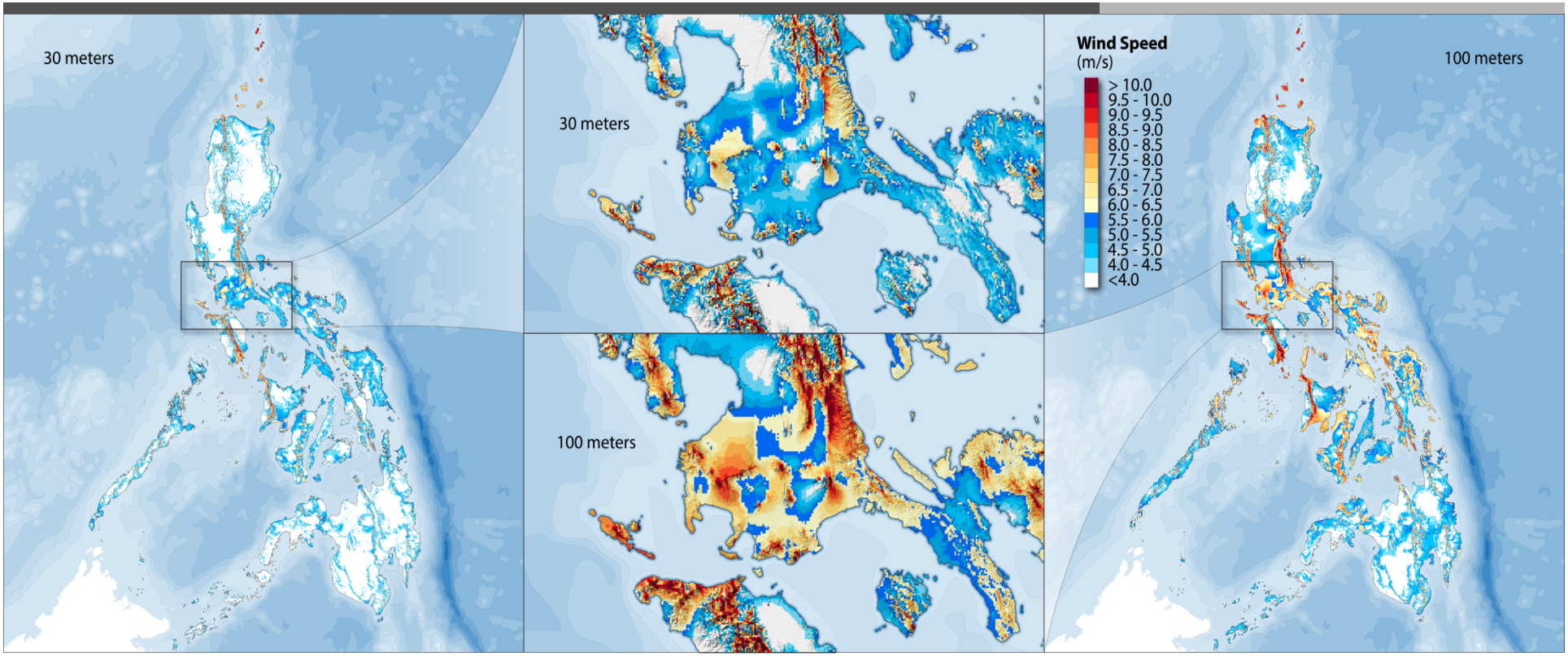
Accelerating the transformation of power systems

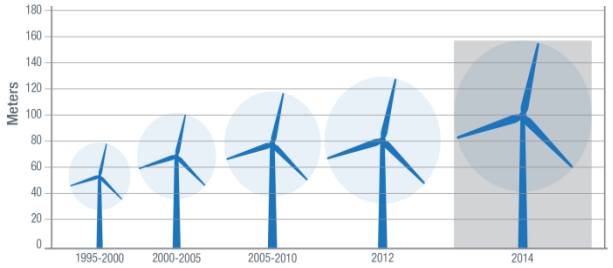




Technology Evolution Unleashes New Opportunities and Challenges

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems





POWER SECTOR TRANSFORMATION

Driving Change …

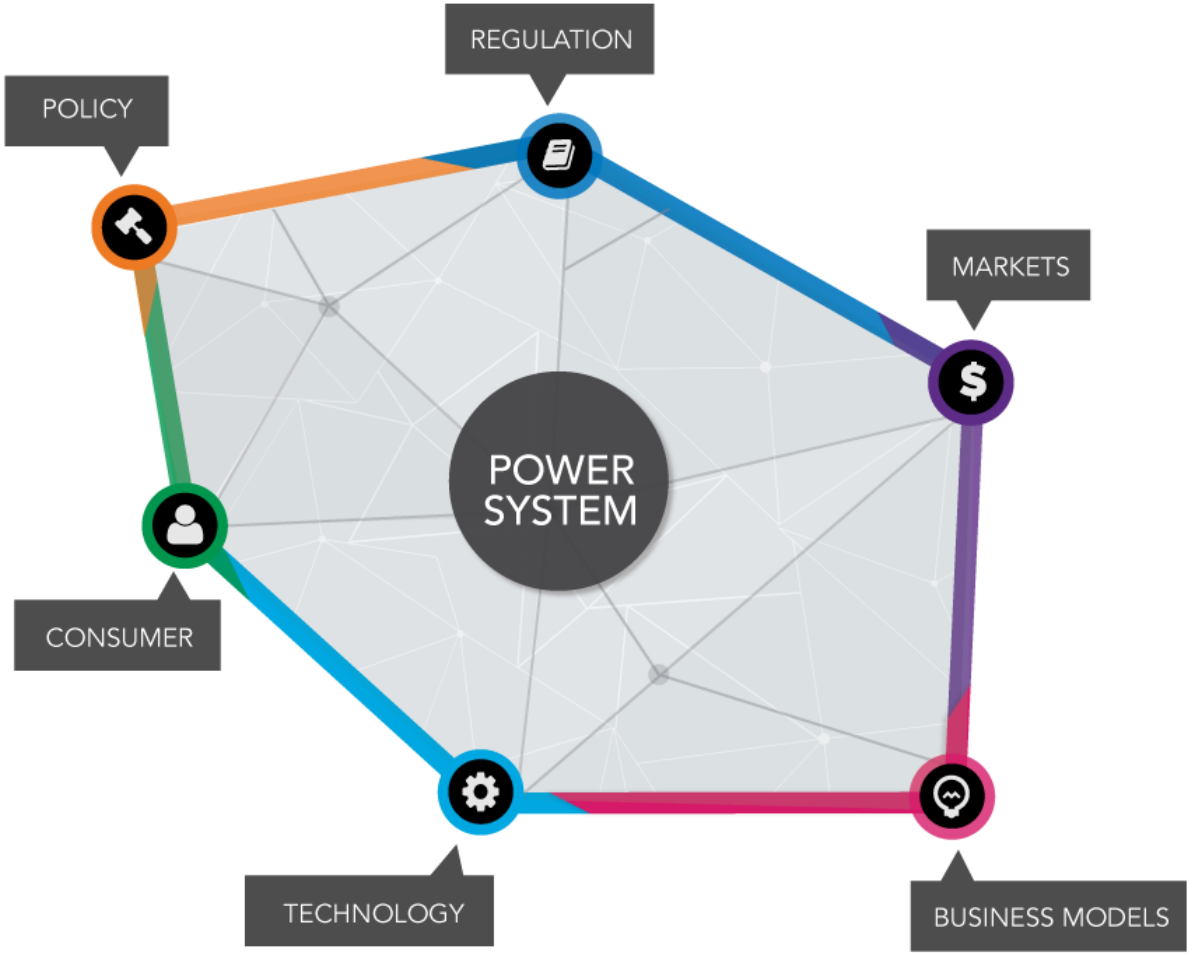
Measuring Progress…

- Degree of innovation
- Engagement
- Impact

A Holistic Approach to Power System Transformation

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Power systems are *complex and dynamical…*



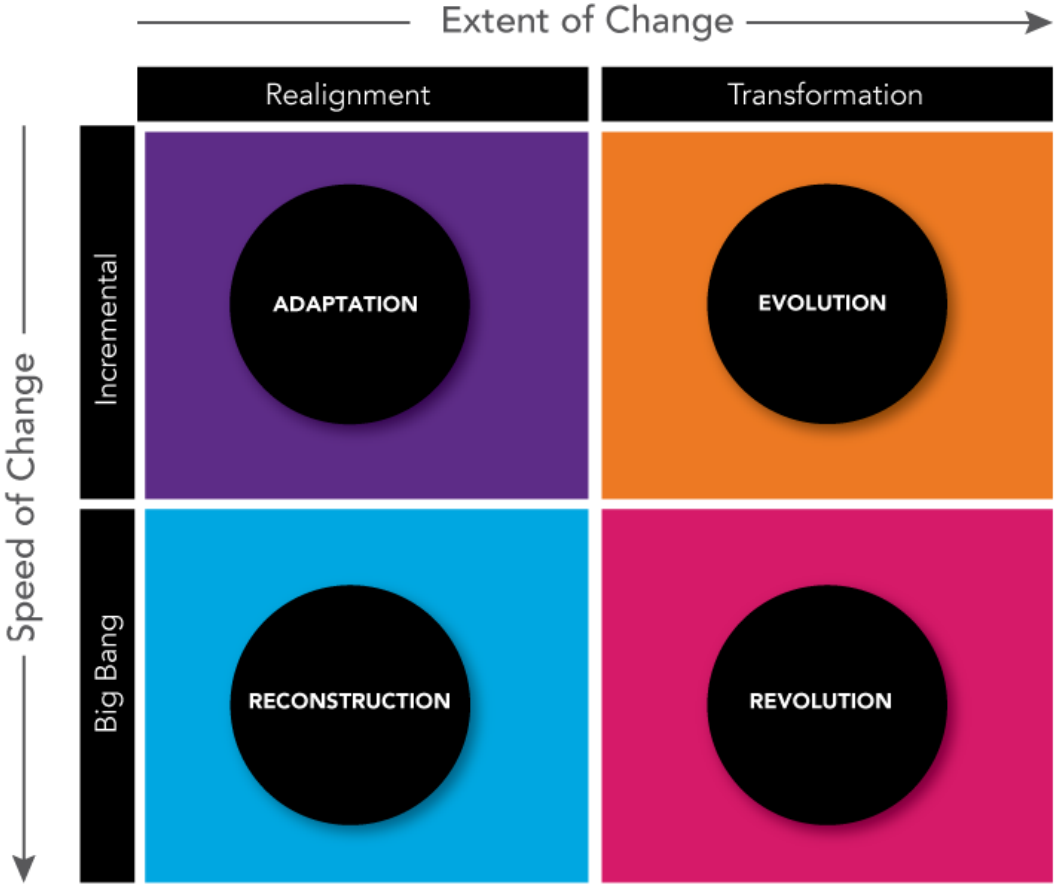
Extent and Speed of Transformation

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Different *extent* and *speed* of change implies different modes of transformation: Adaptation, Evolution, Reconstruction, and Revolution.

Transformation is path-dependent

- Technological, financial and institutional legacies have important bearing on the rate and extent of change
- *Heavier legacies*: cautious incrementalism
- *Light legacies*: more rapid change.



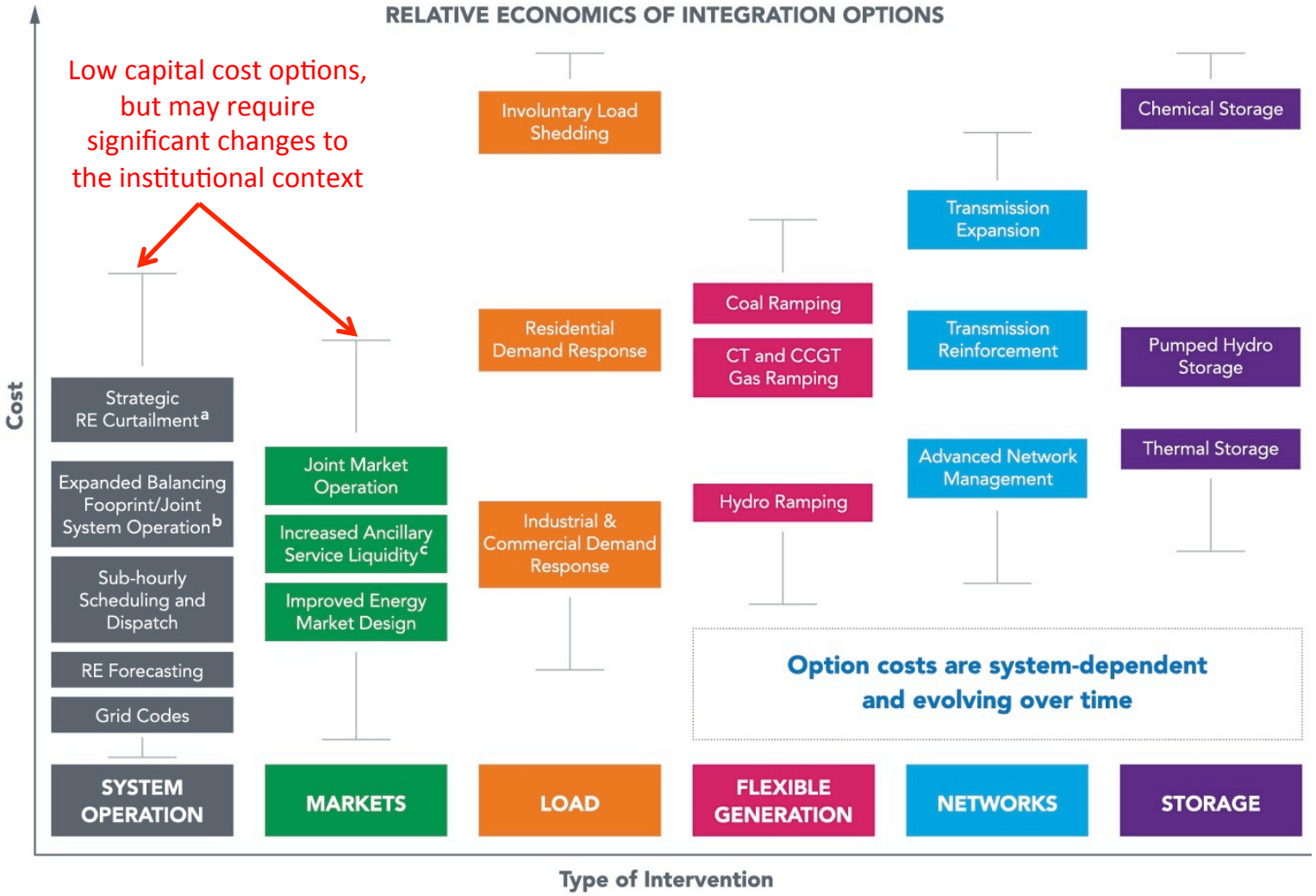
Source: Power Systems of the Future (2015). A 21st Century Power Partnership Report: http://www.nrel.gov/docs/fy15osti/62611.pdf

Key Drivers Behind Next Generation Planning Questions

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Renewable energy cost reductions	Increased interactions with other sectors
Data, intelligence, and system optimization innovations	Local and global environmental concerns over air emissions
Energy security, reliability, and resilience goals	Energy access imperatives
Evolving customer engagement	Increasingly diverse participation in power markets
A tale of two electricity demand forecasts	Revenue and investment challenges.

Transforming Power Systems



Energy Reform in Mexico Triggers Shifts In Planning

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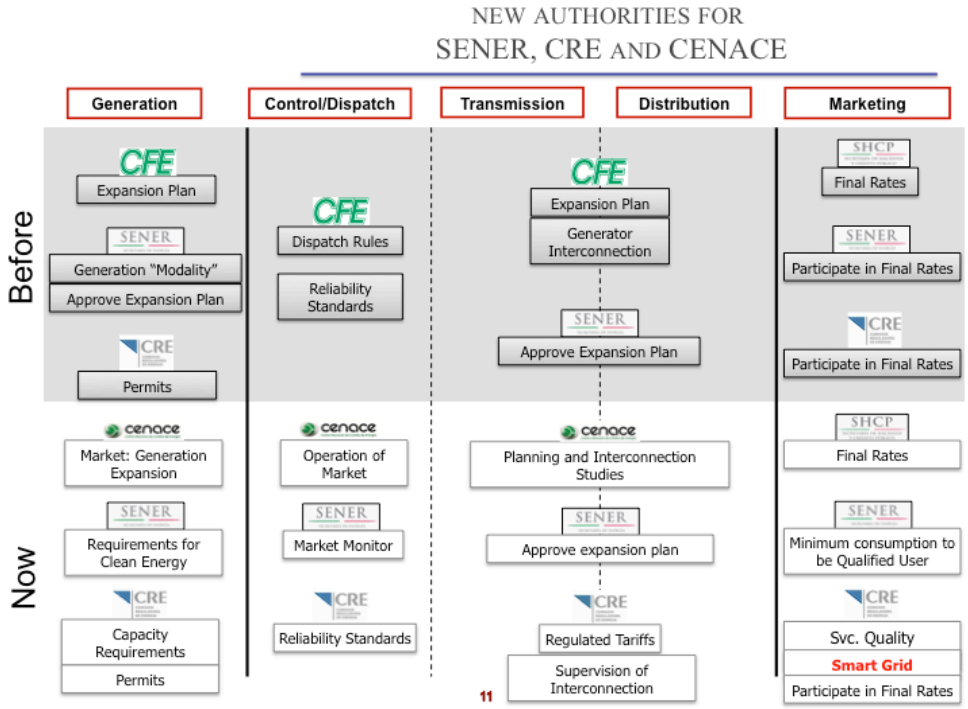
Accelerating the transformation of power systems

- Energy Sector Reform in 2014
- New independent system and market operator (CENACE)
- Creation of independent regulator (CRE)
- Retention of strong central government role for power sector planning

ENERGY REFORM IN MEXICO

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

- **Clean Restructuring**
  - ❖ Reconstructive change dynamics
  - ❖ Bulk power market restructuring, incorporating lessons learned from the past 20 years
  - ❖ Design features to facilitate clean energy integration and system optimization



India's 2022 100 GW Solar Goal Requires an Evolution in Power System Planning

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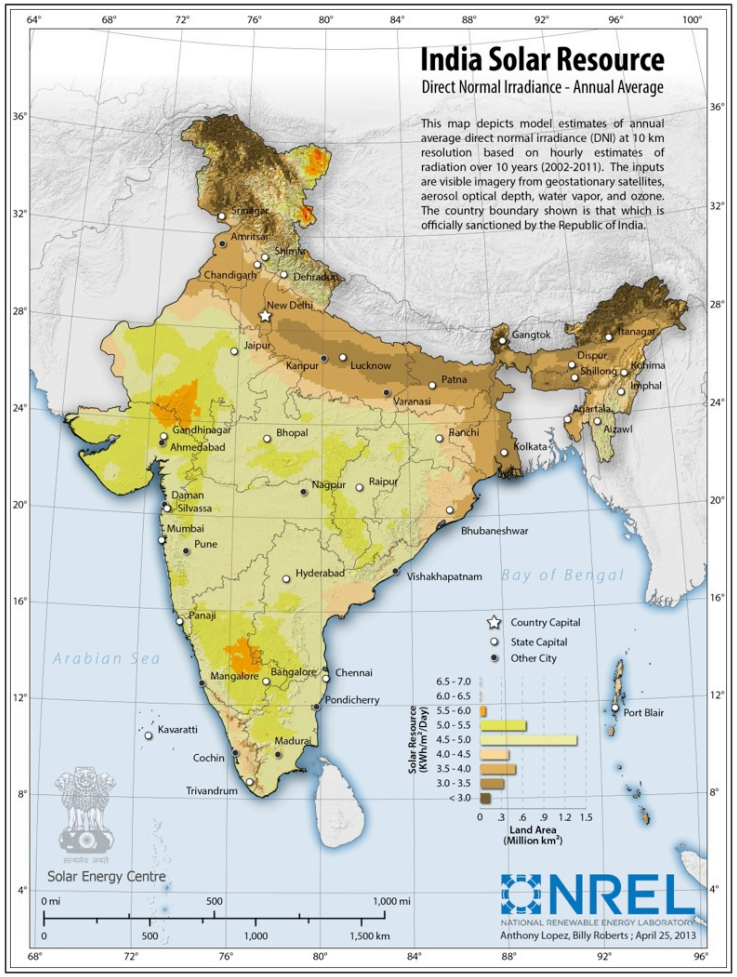
Solar (and wind) generation is variable, uncertain, and location-constrained



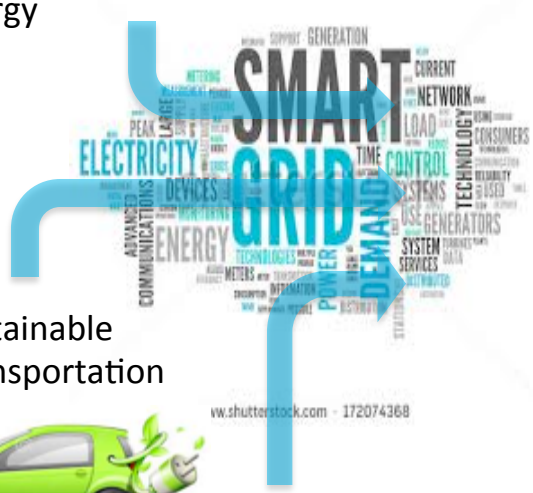
….raising new considerations for grid planning and operations

1. More flexibility is needed to balance supply and demand
2. More transmission might be necessary
3. Grid services (e.g. inertial response) from wind/solar or other equipment come at additional cost
4. Existing conventional generators are needed, but run less, affecting cost recovery

Grid Modernization Components

Technologies

Renewable Energy



Sustainable Transportation

Energy Efficiency

Scales and Challenges

Consumer

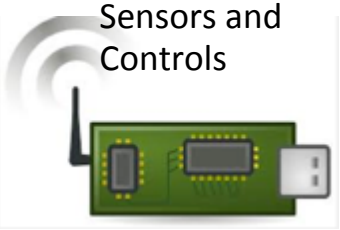
City

Regional

- More Variable Supply and Demand
- Limited Grid Flexibility
- Aging Infrastructure
- Vulnerability to Extreme Events
- Challenges to Reliability
- Increasing Costs

Solutions

Sensors and Controls

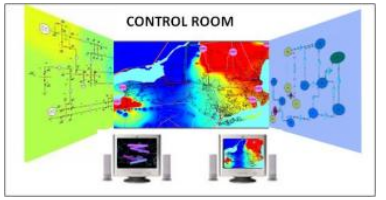


Energy Storage

Interconnection

Interoperability

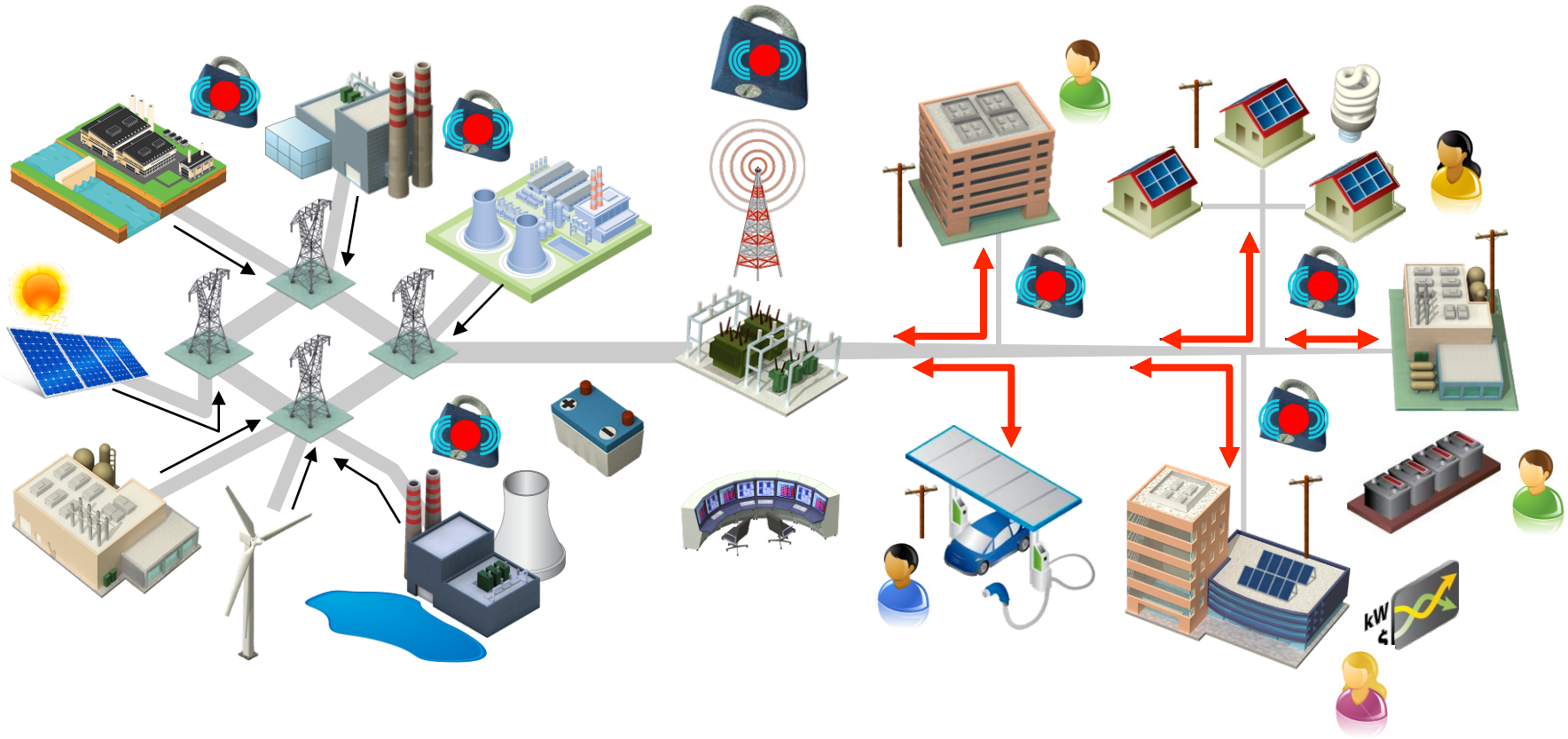
Analysis, Modeling and Simulation



Markets and Business Models

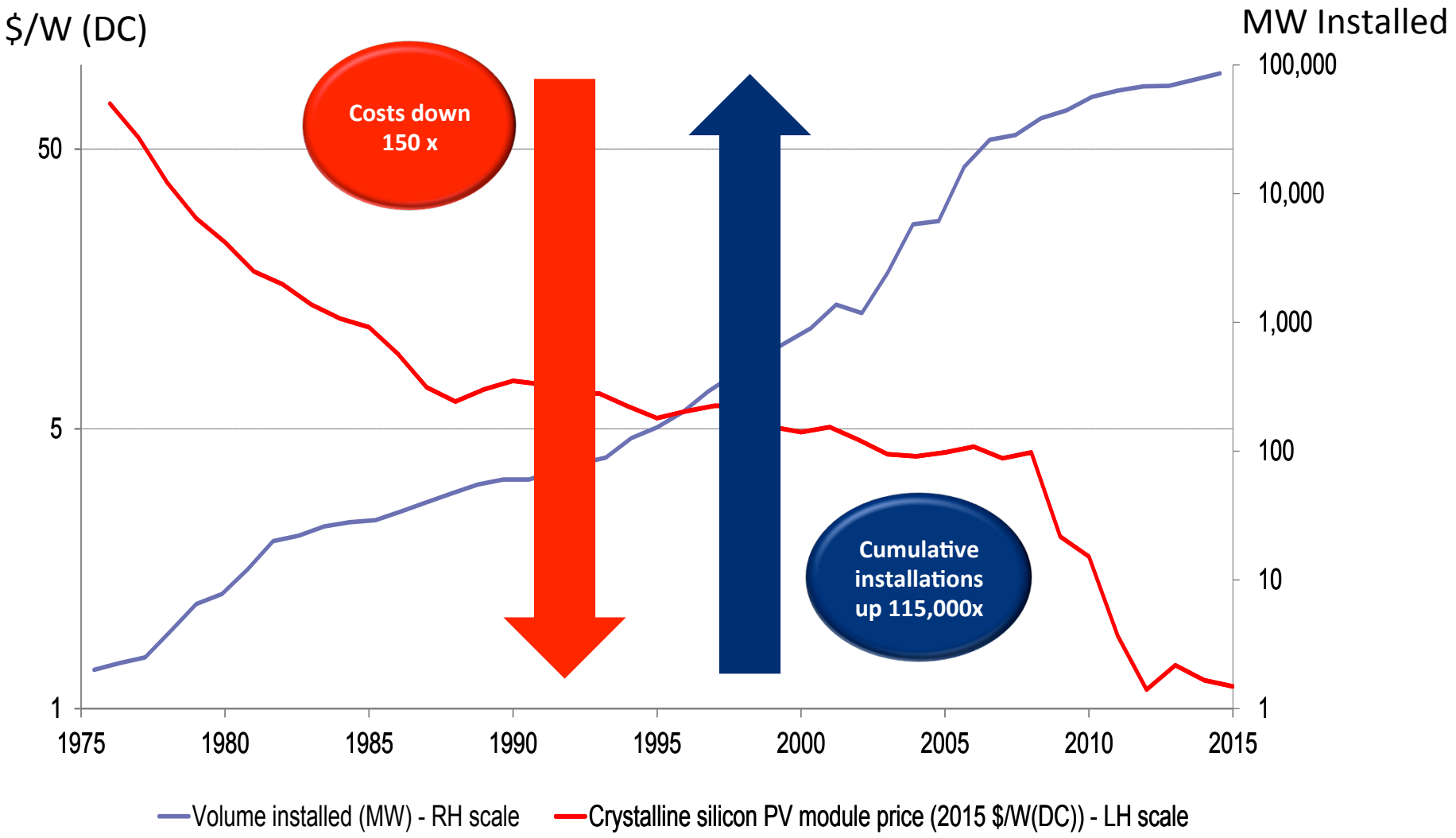
Policy and Regulation

The Evolving Power System …



Transitioning today: Restructuring, New Business Models, New Technologies

Rethinking the Future: Solar



Source: Maycock, Bloomberg New Energy Finance

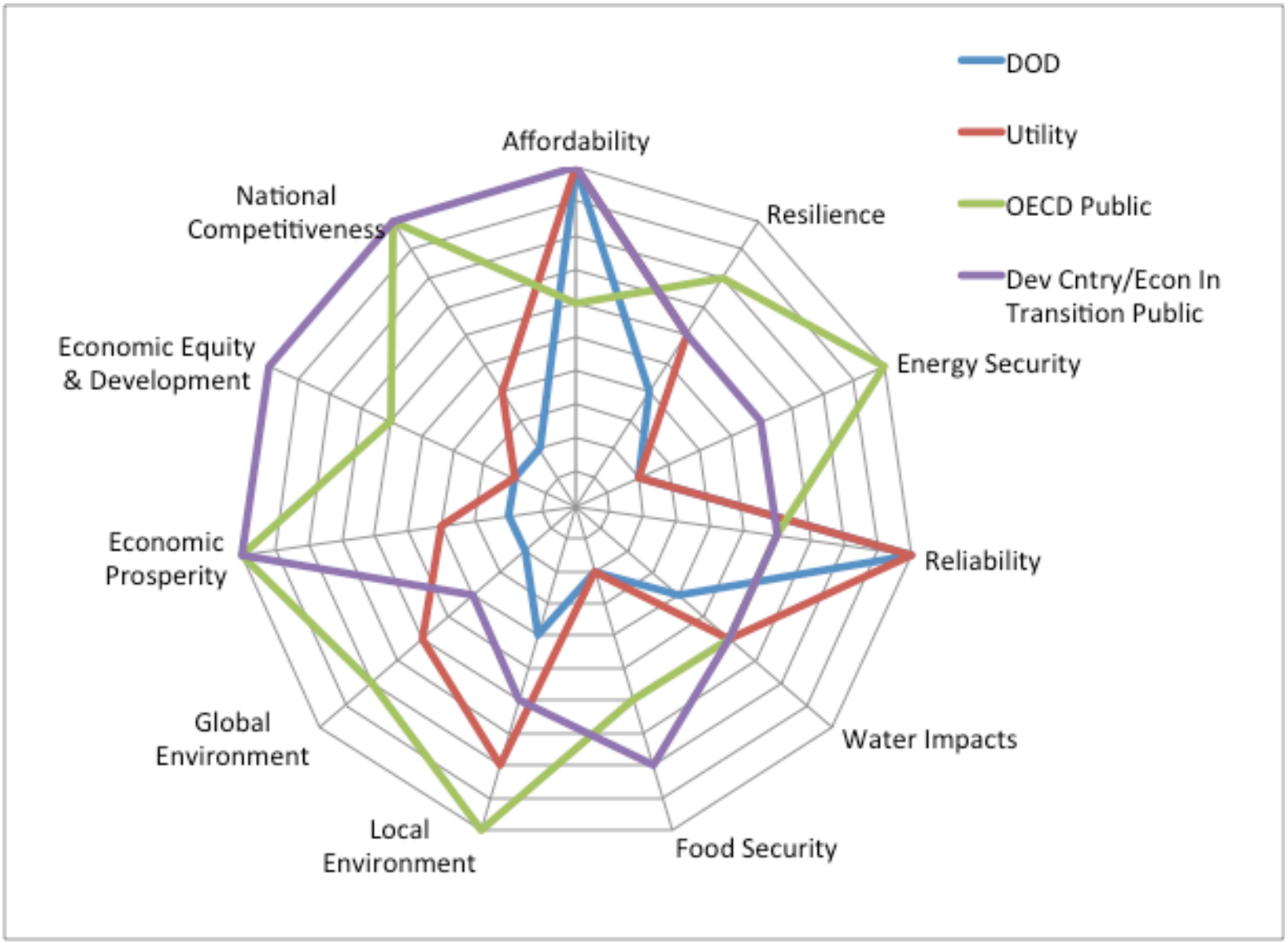
Good Data Informs Good Policy: Long-term Scenario Planning

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

NREL Renewable Electricity Futures Study
Capacity Expansion Scenario Model – 80% RETs

http://www.nrel.gov/analysis/re_futures/data_viewer/

Energy Policy Dynamics Increasingly Complex



A Few Take Aways

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

- Technology advances are changing the landscape
  - Low carbon, smart, least cost solutions
  - Renewables offer domestic advantages with potential economy wide benefits:
    - Price certainty, trade, water/food, health…
- Policy, Finance/business models enable or hinder change
- Power Sector Structural reforms underway across the globe
  - Least cost structures
- Innovation in Financing and Financial reforms underway “in an era of lower growth”.

Support for Power System Planning: Technical and Policy Assistance

21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Provides **technical assistance** to countries – modelling, road-mapping, integration

Knowledge development & sharing – report publication and dissemination

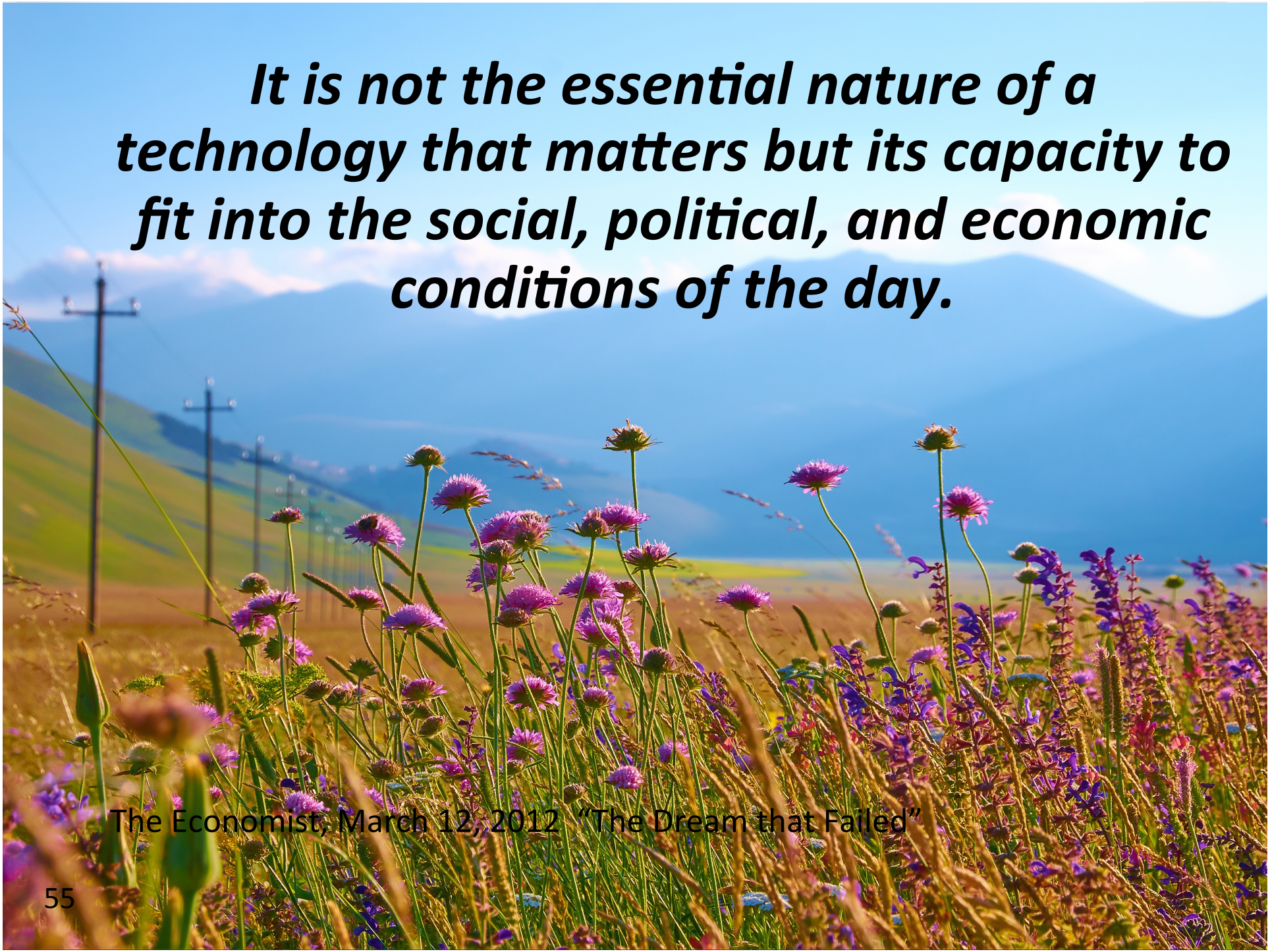
Organizes **global networks of expertise** – such as today's program

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Supports governments in developing **policy, program and finance solutions** for clean energy deployment

Ask-an-Expert – **no-cost, tailored assistance** from global experts

PowerAfrica partnership - **targeted support for sub-Saharan African** countries


It is not the essential nature of a technology that matters but its capacity to fit into the social, political, and economic conditions of the day.
The Economist, March 12, 2012 "The Dream that Failed"

Key Examples from different stages of VRE development

	Ambition and Confidence	Deployment and Capacity Building	Grid Infrastructure	Short-term System Flexibility	Long-term System Performance
Early Stage	Anti-nuclear groups encourage wind 1,000 roofs pilot program (expanded to 100,000) Public Goods Charge to support RE	FIT/ Soft Loan Program/ Standardized permitting FIT/Municipalities required to identify wind sites Renewable portfolio standard, Net metering	Transmission plan integrated with VRE goals Simplify interconnection protocols / Required utility interconnection for VRE	Requirements for flexible CHP Market design for flexible coal plants Wind interconnection requires voltage ride through	Liberalized wholesale market Formal grid integration and resource adequacy studies Unbundling of generation and transmission
Intermediate Stage	Integrated policy framework (Energiewende) Develop grassroots political support through distributed generation	Degression in FIT tariff Smart inverter requirements for PV Reverse Auction Mechanism, California Solar Initiative	Expanded balancing area with complementary generation mix (Nordpool) Designated renewable energy zones with transmission buildout	Bornholm grid pilot project Demand response programs Centralized VRE forecasting, fast dispatch	Long term procurement planning and Resource Adequacy (RA) payments • Thermal plants receive ancillary services and reliability payments
Advanced Stage	50% RE by 2020, 100% RE by 2050 55% RE by 2030, 85% RE by 2050 50% RE by 2030	Offshore wind tender system Incentivize VRE dispatchability	Strengthen grid interconnection ties within existing balancing areas Nodal markets (LMP)	Energy imbalance market and flexi ramp product Markets for fast responding ancillary services	Market Model 2.0: (Power market redesign to accommodate high RE penetration) EEG 3.0: (Adapt to nuclear phase-out)

Legend: Germany Denmark California Texas

21st Century Power Partnership

- RE Integration
  - Technical, Institutional, Operational, Finance, Policy & Regulation
- EE, Smart Grid, & DER Policies
- Securitization: Mobilization of Capital