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The Scale and Scope of Deep Decarbonization

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A Global Challenge

Deep Decarbonization of the Global Energy System

- Deep decarbonization is not an option
- Scale, scope, and rapidity of the necessary changes are unprecedented, all-encompassing, and truly daunting
- Success in addressing this global challenge *requires coordination and alignment across geographies, governments, and cultures*
  - In addition to technological solutions, social and institutional aspects are also critical

Deep Energy Transitions Are Prolonged Affairs

- **Energy Transitions:** Shifts in fuel sources and associated technologies…to switch in fuel-dependence of an economic system…**to shifts in patterns of energy use in the society**

- *“**Energy transitions have been, and will continue to be, inherently prolonged affairs, particularly so in large nations** whose high levels of per capita energy use and whose massive and expensive infrastructures make it impossible to greatly accelerate their progress even if we were to resort to some highly effective interventions …” (V. Smil, 2012.)*

Transitions are Inherently Temporal *and* Spatial Processes, involving Long Formative and Diffusion Phases

Formative phase: roughly from early innovation efforts to 1-2% share. Involves intense experimentation, refining, and adaption

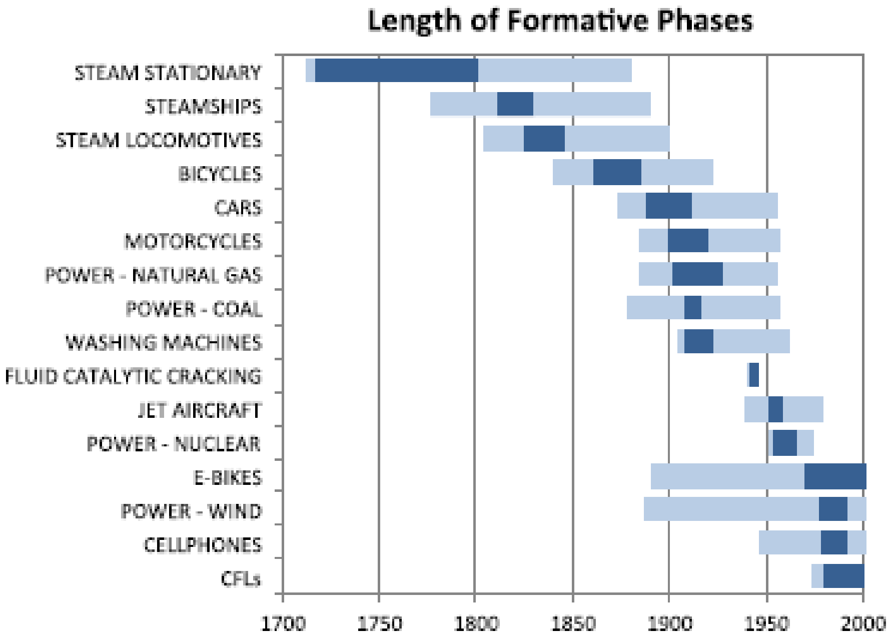


Fig. 1. Durations of formative phases for energy technologies are at a decadal scale [4]. Note: Ranges refer to alternative definitions for the start and end points of formative phases, and so capture measurement uncertainties.

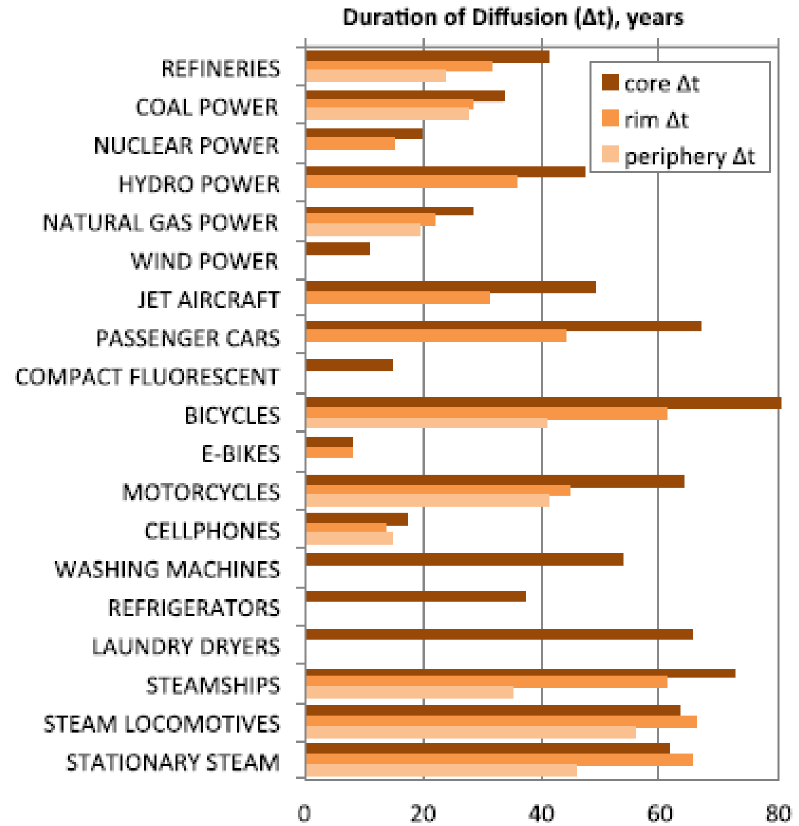
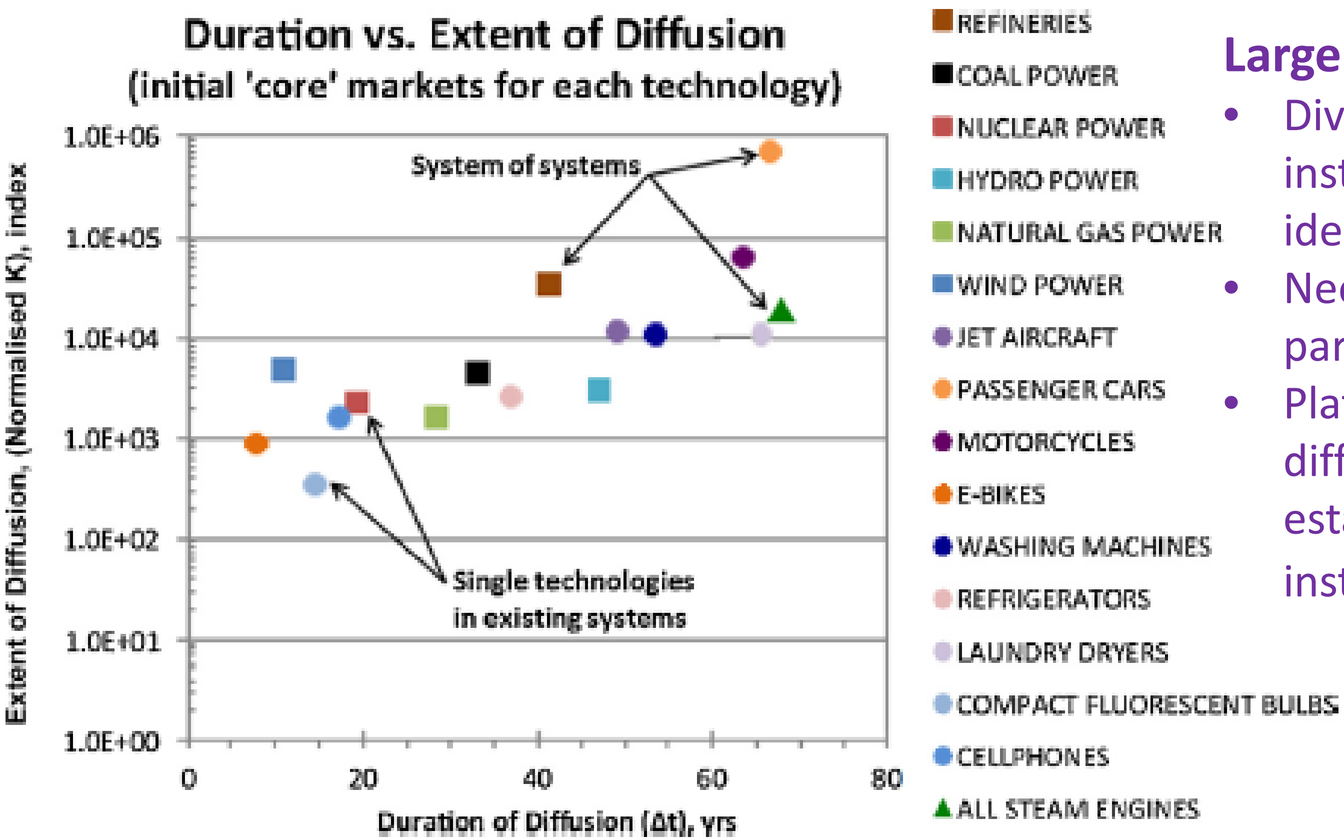


Fig. 2. Diffusion speeds accelerate as technologies diffuse spatially. Notes: Bars show durations of diffusion measured by cumulative total capacity installed, with historical data fitted via a logistic growth curve and the diffusion duration expressed as Δ t in years. 'Core' is typically within the OECD; 'Rim' is typically Asian countries; 'Periphery' is typically other world regions. For details and data, see: [42,3].

Source: Grubler *etal., Energy Research & Social Science,* 2016.

Larger the Scope of Change, Longer it Takes



Larger scope implies:

- Diverse set of actors and institutions: many competing ideas and stronger inertia
- Need to integrate with other parts of the system
- Platform to support wider diffusion needs to be established (actors, resources, institutions, and knowledge)

Diffusion durations scale with market size. Notes: X-axis shows duration of diffusion (t) measured in time to grow from 10% to 90% of cumulative total capacity; y-axis shows extent of diffusion normalized for growth in system size. All data are for ‘core’ innovator markets. Round symbols denote end-use technologies; square technologies denote energy supply technologies; triangular symbol denotes general purpose technologies (steam engines). Arrows show illustrative examples of system of systems (refineries describing the rise of multiple oil uses across all sectors, cars describing the concurrent growth of passenger cars, roads, and suburbs, and steam engines are a proxy of the growth of all coal-related technologies in the 19th century). Arrows also highlight examples of single technologies diffusing into existing systems substituting existing technologies (nuclear power, compact fluorescent light bulbs).

Source: Grubler *etal., Energy Research & Social Science,* 2016.

Typically, Growth in Early Phases is *Overestimated* and in Later Phases *Underestimated*

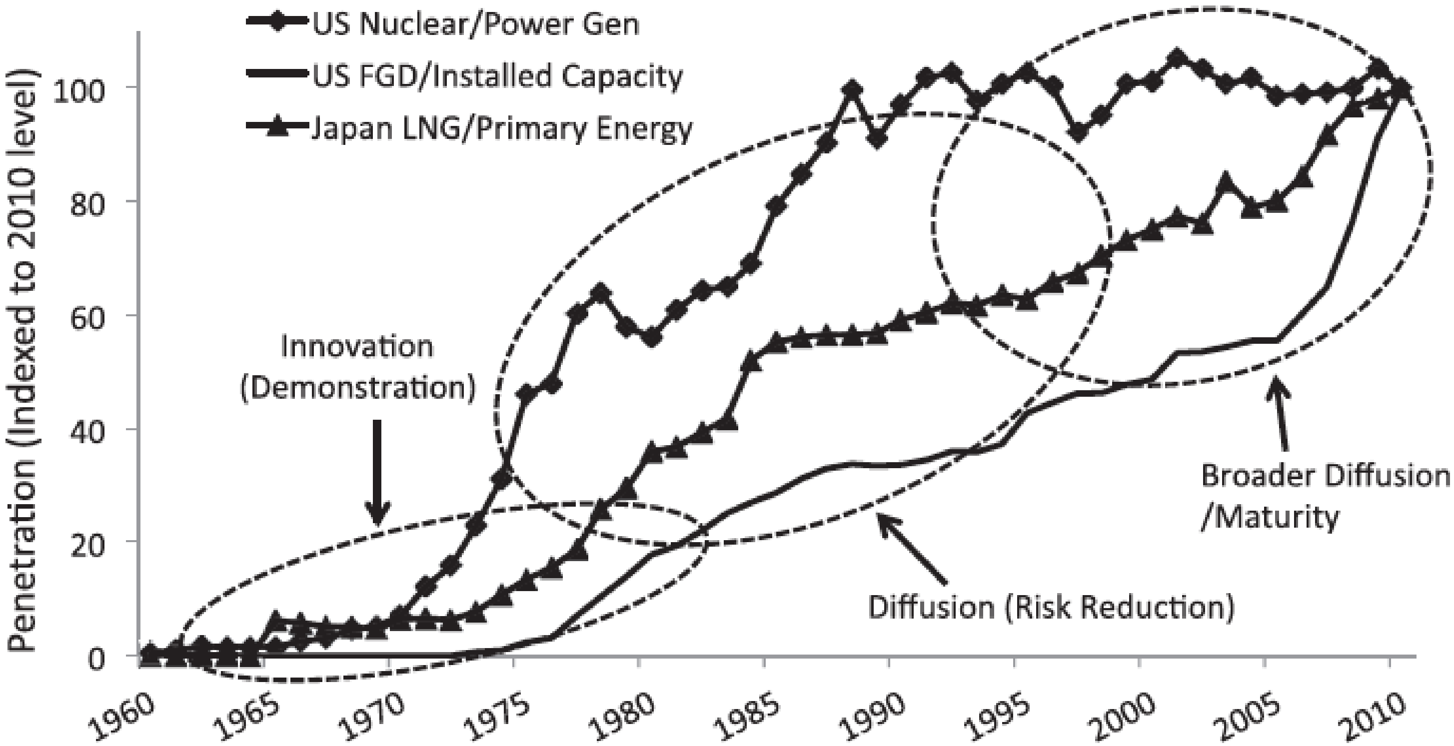


Figure 4: Growth of Indexed Market-Share Penetration of Some Energy Technologies Market share in 2010 is assigned an index equal to 100. Calculation of market share: U.S. nuclear power as percent of total U.S. power generation; U.S. FGD capacity as percent of U.S. coal-based installed capacity; LNG consumption in Japan as percent of Japanese primary-energy consumption. Adapted and updated from Rai et al. (2010).
Data source: BP (2012), EIA (2012), and Taylor et al. (2005).

Source: Rai *etal., Energy Policy*, 2010; Heguy & Rai, *The Electricity Journal*, 2013.

Deep Decarbonization Expensive w/o CCS

"Without CCS, the transformation of the power sector will be at least USD 3.5 trillion more expensive. In a "no CCS in power" scenario variant of the 2DS, **deployment of renewable technologies would need to be expanded by an additional 1900 GW by 2050** over and above the 2DS requirements. This is equivalent to around four times the total wind and solar PV capacity additions achieved in the last decade."

To meet CCS targets, investment and deployment needs to be ramped up, yet the reality on ground is quite different…

Source: Bistline and Rai, *Energy Policy,* 2010.

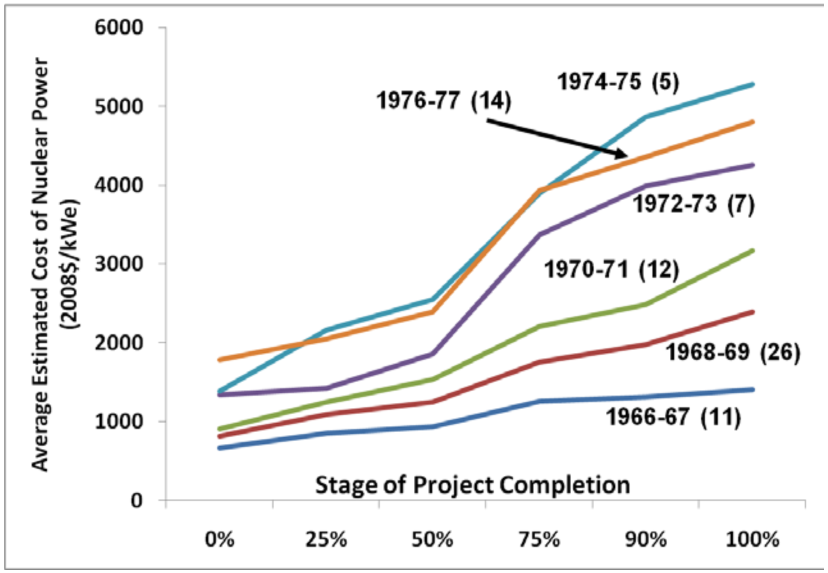
Source: IEA.

CCS Project Cancellations

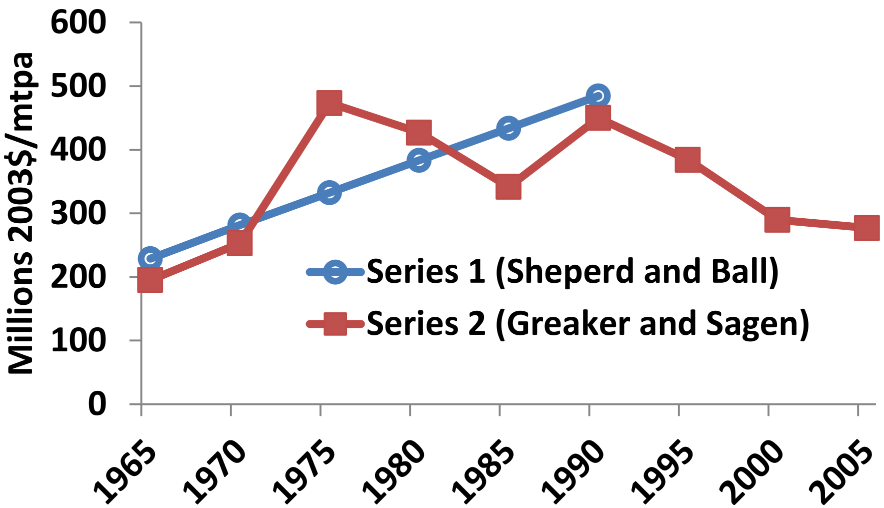
CCS Projects in Europe on hold/canceled.

CCS-Project				Official reason for cancelling				
Project name	Leader		Size	Economics	Legal issues	Support by politics	Others	Reason in detail
Goldenbergwerk	RWE	DE	450 MW		x			Lack of German Carbon Storage Law (KSpG)
Jänschwalde	Vattenfall	DE	250 MW		x		x	Environmental fears and lack of legal framework
Compostilla	ENDESA	ES	323 MW					n.a.
FINNCAP	Fortum	FI	565 MW				x	Abandoned due to company strategy
Porto Tolle	ENEL	IT	250 MW				x	Environmental reason, complaints from green groups/local industry
Green hydrogen	Air Liquide	NL	0.55 Mt/yr			x		Dutch gov. was unable to confirm the co-funding of €90 million
Eemshaven	Essent	NL	1,600 MW			x		Dutch gov. decided to support Green Hydrogen instead
Barendrecht	Shell	NL	0.4 Mt/Yr		x	x		Local opposition about CO_2 storage
ROAD	E.ON	NL	250 MW	x				Project team waits for financing
Magnum	Nuon	NL	1200 MW	x	x			Dutch law caused additional problems with where to store the CO_2
Kårstø	Naturkraft	NO	420 MW	x				No grants to continue the process on Kårstø
Halten	Statoil	NO	860 MW	x		x		Poor profitability of the power plant even without carbon capture
Zeng Risavika	CO2 Norway	NO	50 MW					n.a.
Belchatow	PGE	PL	260 MW	x				Lack of funding
Getica	Turceni Energy	RO	330 MW	x				Sponsors seek funding to enable the work to progress
Longannet	E.ON UK	UK	300 MW	x				Focus on other projects with the £1bn funding
Hunterston	Ayrshire Power	UK	1,600 MW	x			x	Economic slowdown and funding uncertainty for the move
Teesside low carb.	Progressive	UK	400 MW	x			x	No funds available
Killingholme	C.GEN	UK	470 MW	x			x	Construction of gas-fired power plant instead
Petershead	Shell and SSE	UK	385 MW	x				UK £1bn CCS Competition was cancelled before it was to be
White rose	Capture Power	UK	426 MW	x				awarded.
Don valley power project	Sargas	UK	900 MW	x	x			Dept. for Business, Energy and Industrial Strategy refused development grant for CO_2 pipeline, extension of EEPR grant was declined

With Increasing Unit Size, Cost Reductions May Not Automatically Hold For Capital Intensive Technologies



Average estimated cost of nuclear power

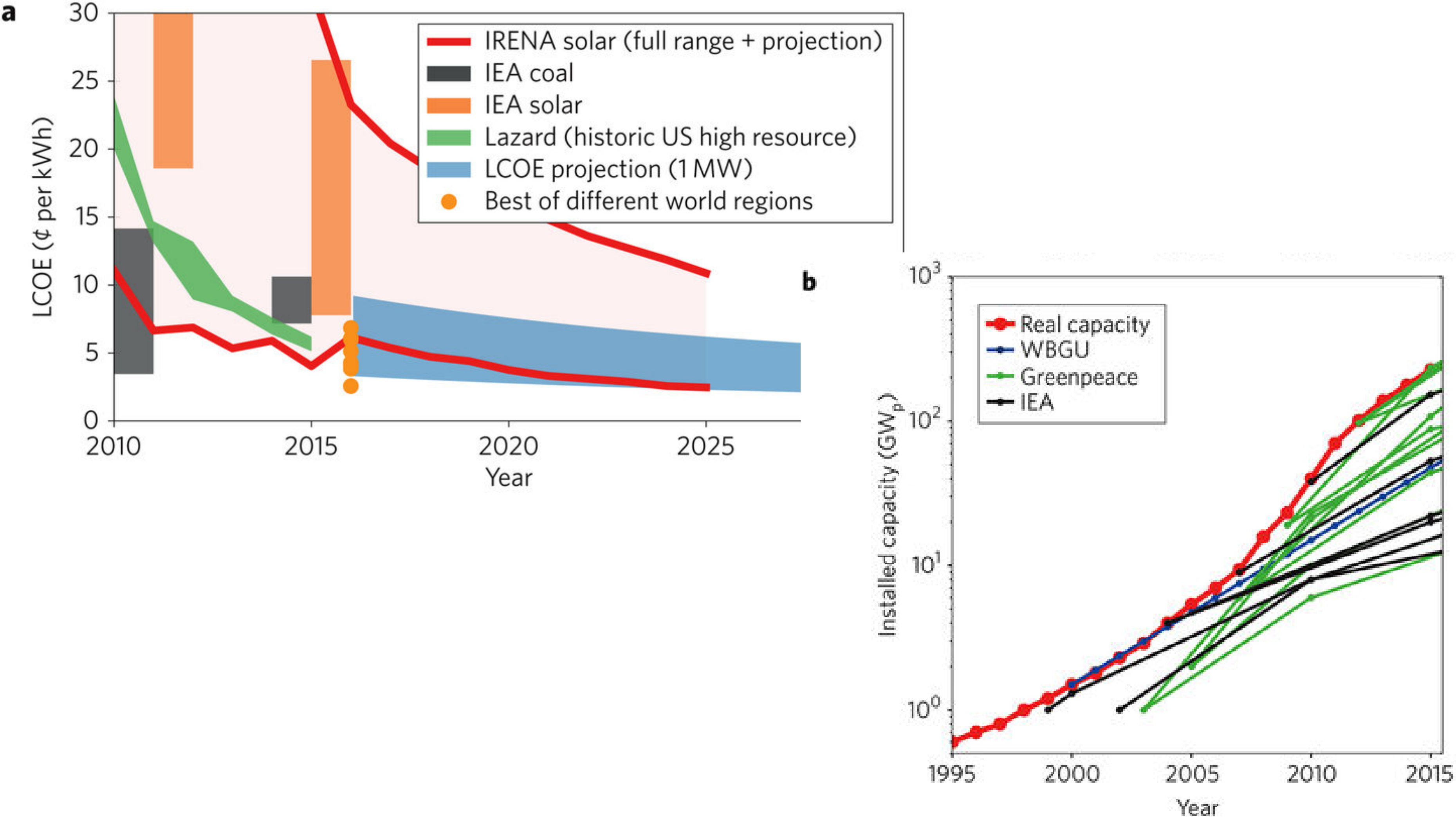


Unit cost of natural gas liquefaction plants

- **Cost increases due to unanticipated technological and regulatory bottlenecks; and market structure effects**
- Appraisal optimism or “low balling”
  - Optimistic forecasts, understatement of costs
  - Once support secured and funds sunk, reveal true costs

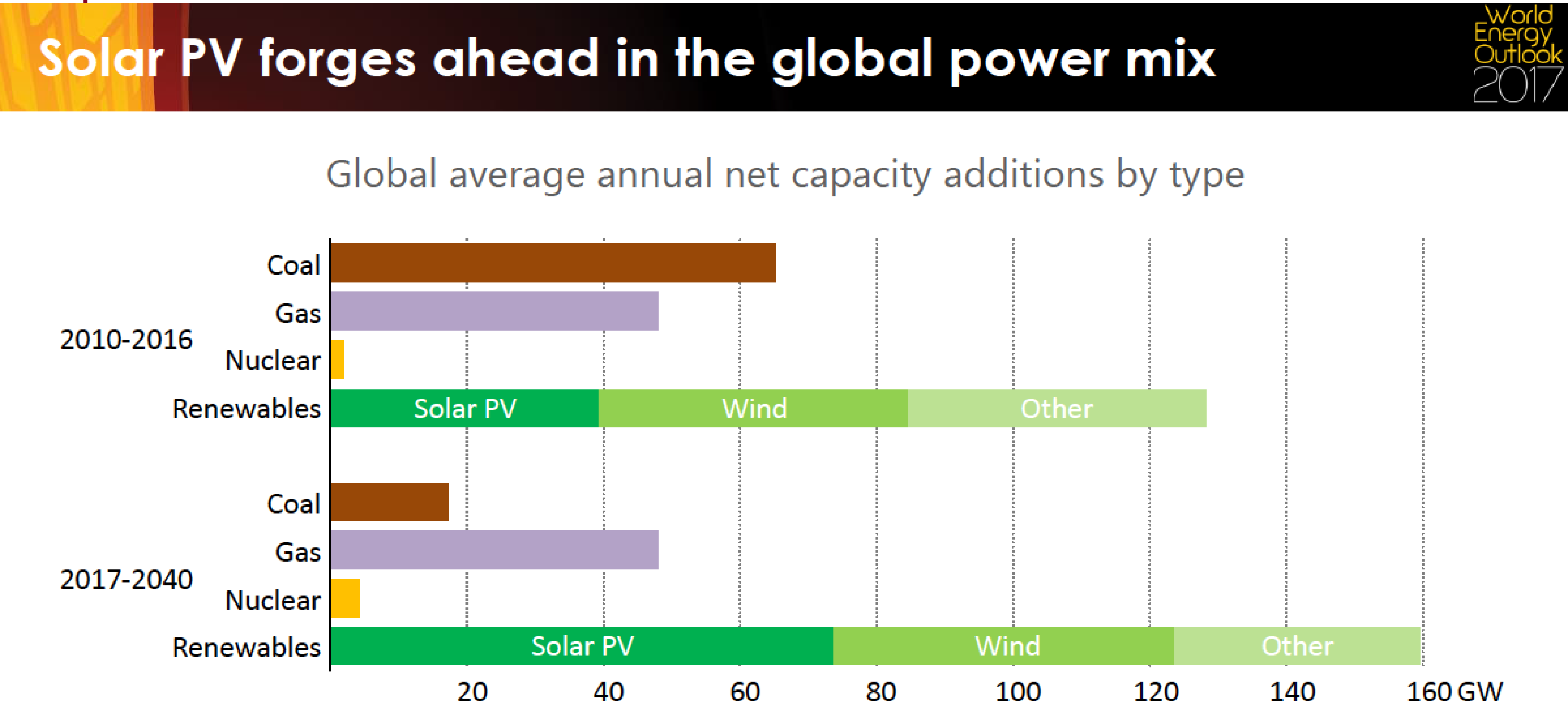
Source: Rai et al., *Energy Policy,* 2010.

Photovoltaic (PV) Prices and Installed Capacity



Source: Creutzig, F., etal. The underestimated potential of solar energy to mitigate climate change. *Nature Energy*, *2*, nenergy2017140.

Changing Global Power Mix: Less Coal



China, India & the US lead the charge for solar PV, while Europe is a frontrunner for onshore & offshore wind: rising shares of solar & wind require more flexibility to match power demand & supply

Source: World Energy Outlook, IEA, 2017.

Concluding Thoughts

- When scaling up, only technological improvements not sufficient. *Policy, regulatory, business, and public experience with actual deployment across markets critical*

- Large scale energy transitions are expected to be long affairs. **To speed things up abnormally, *need careful design of technology-push and demand-pull, coupled with transformed social norms***

- **Need careful design of learning cycles between generations of the technology and across jurisdictions**

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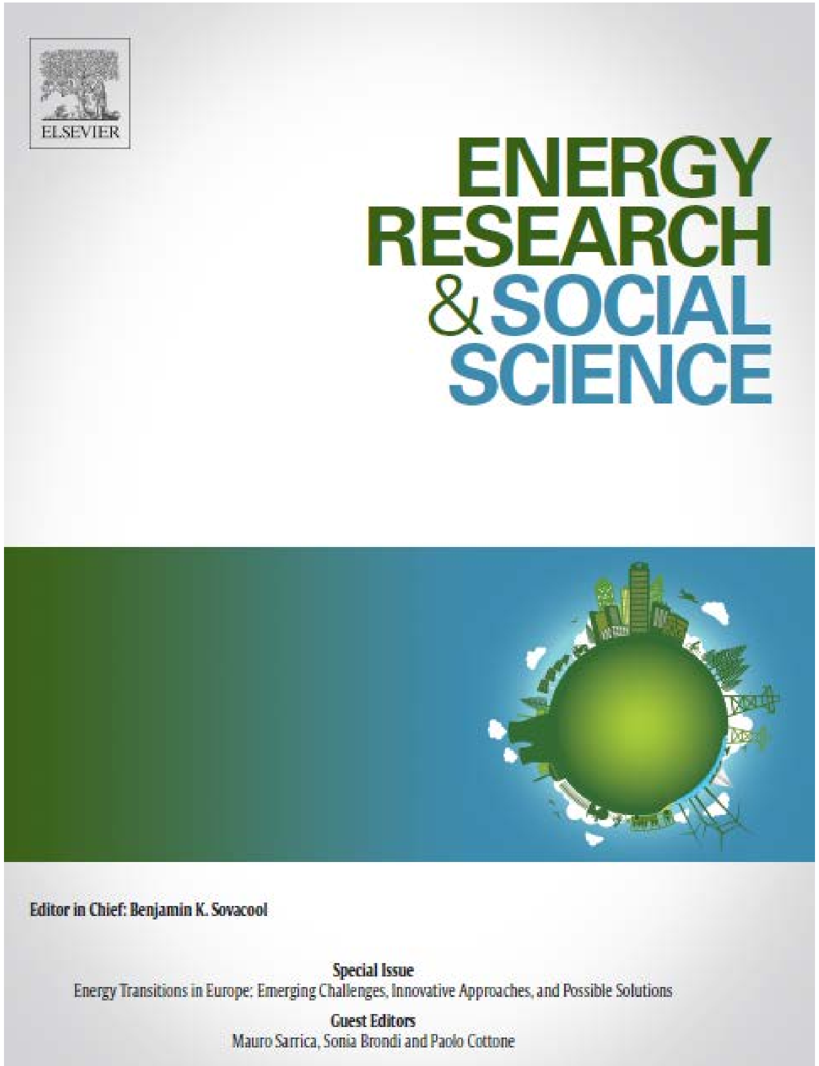

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Special Issue

Energy Transitions in Europe: Emerging Challenges, Innovative Approaches, and Possible Solutions

Guest Editors

Mauro Sarrica, Sonia Brondi and Paolo Cottone

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