What's been happening and where are we going?

The changing landscape of a swiftly tilting planet

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ESIG Spring Technical Workshop

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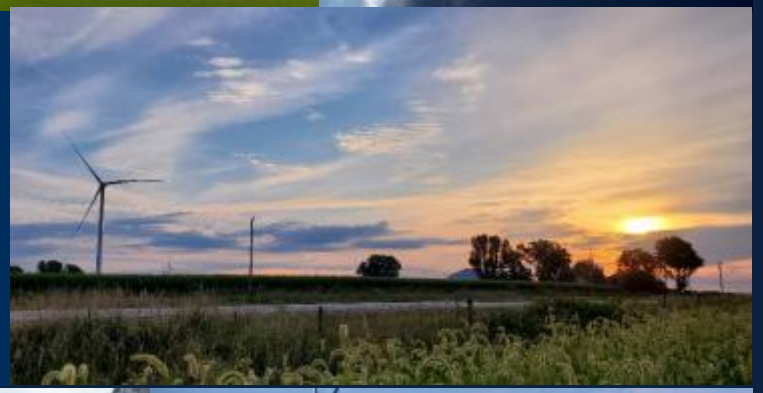
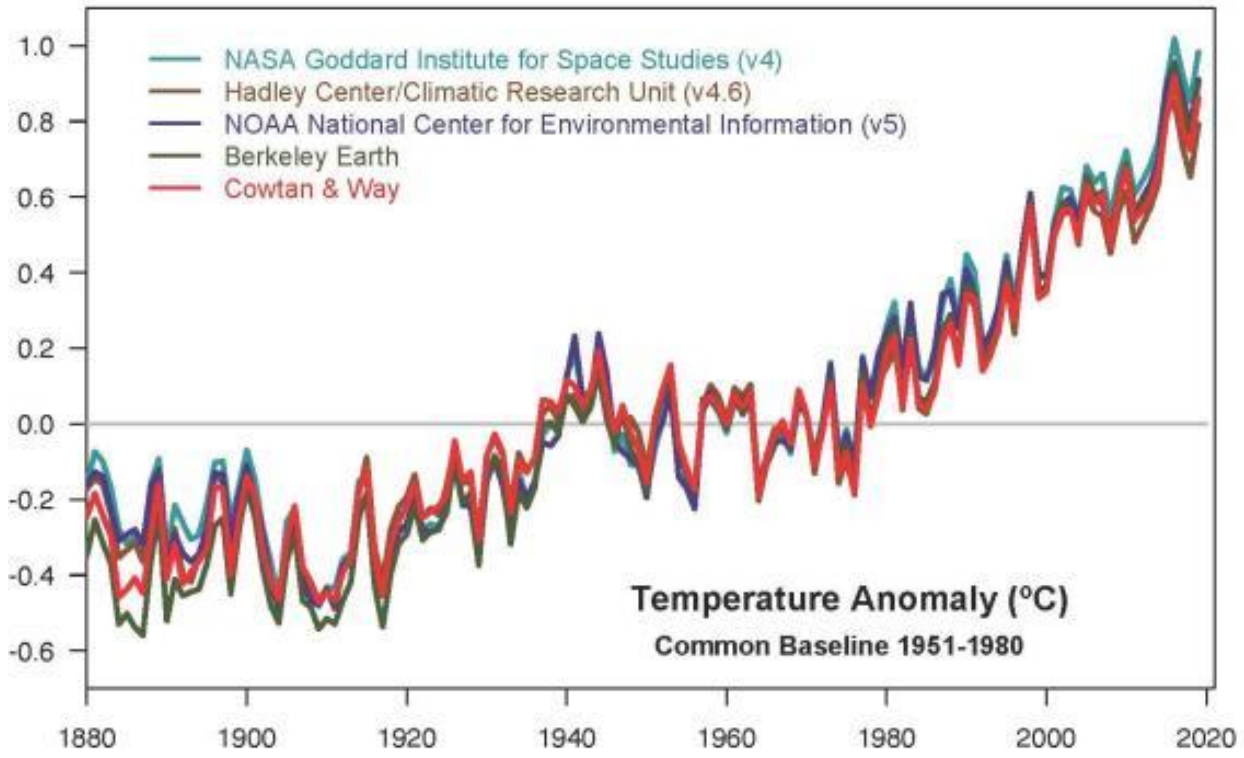
ENERGY transition

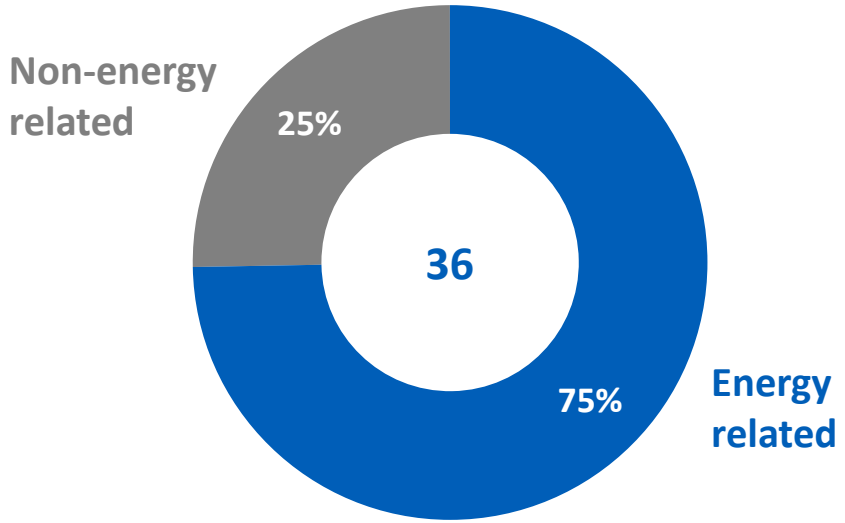


In a world of rapid change, one unfortunate constant

… extensive use of fossil fuels driving climate change



Total CO_2eq emissions Gt/year (2021)

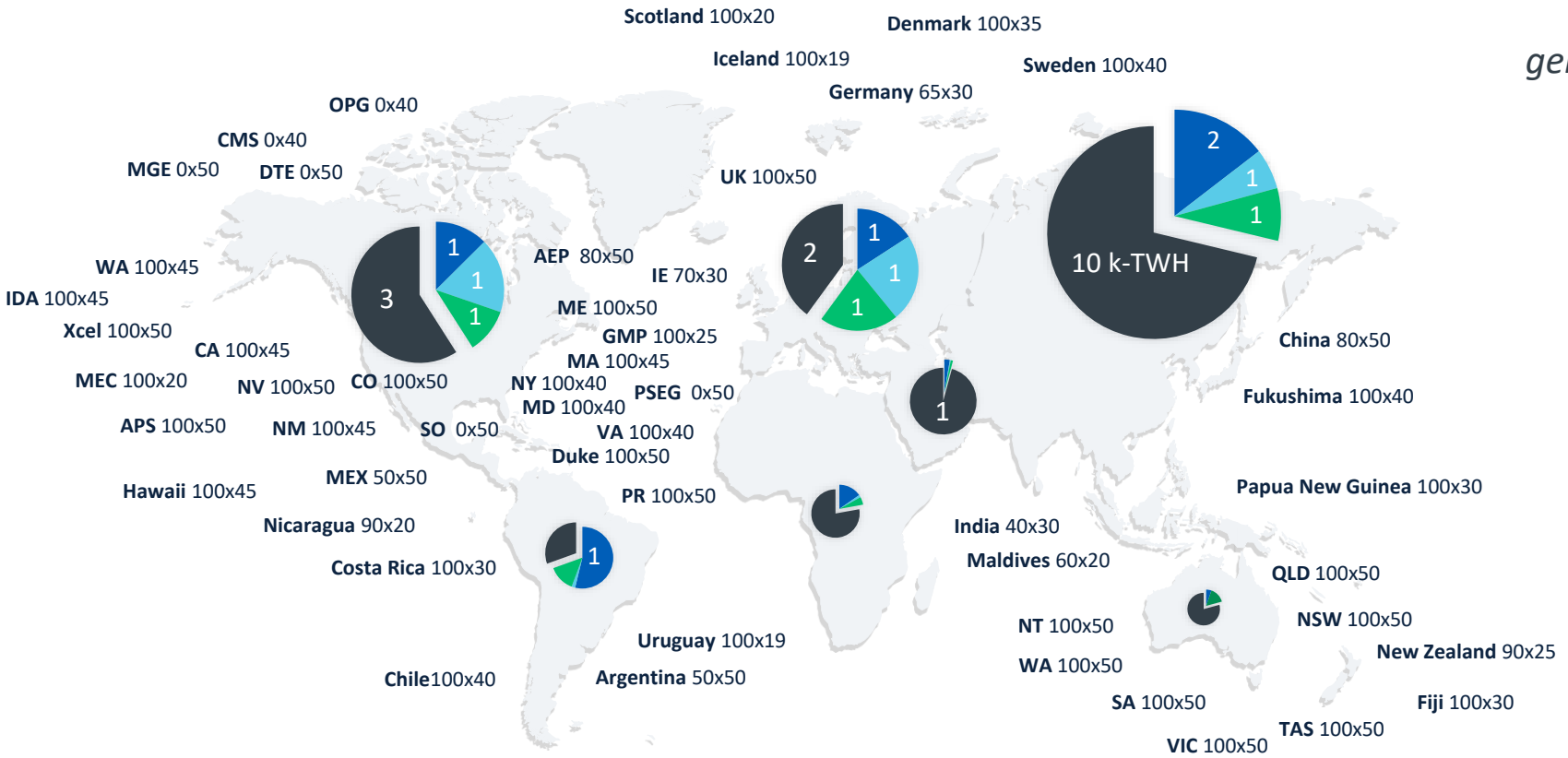


"Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades."

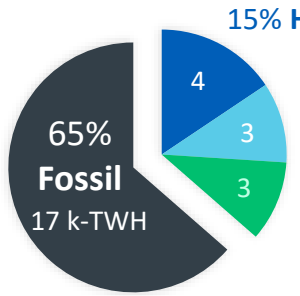
Source: IPCC (Intergovernmental Panel on Climate Change), "6th Assessment report", August 2021

100% CO_2-free power

Goals emerging globally



Global generation



2019 Annual avg % generation

CO_2/REN goals
(% goal) x (year)

Decarbonizing fossil-based generation will require record levels of *VRE*

Ref: BP statistical review of world energy 2019

*VRE; Variable Renewables … e.g. Wind + PV

Unprecedented events impact global perspective

… creating opportunity for significant change

Global Pandemic – Covid 19

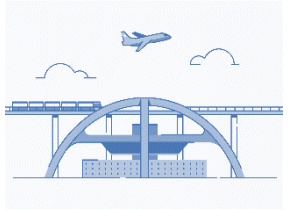
Global shock exposed **fragility of supply chains**, highlighted **social inequities**, and led to a **global economic crisis**, but also demonstrated …

- New proof points for digital solutions
- Ability to change ingrained social habits
- More efficient information exchange via virtual engagement
- Rapid deployment of new technology

Recovery planning drives gov't support for

- Local content and jobs
- Infrastructure investment

Energy Transition as vehicle for growth



Climate crisis consensus

Youth movement leads to **climate as top voting issue in EU**. Green parties winning, influencing legislation.

Pressure at COP 26 resulted in announced policies tracking to 1.8 °C, down 0.5 °C

Growing occurrence of **extreme weather events** further challenges grid resiliency

March '22 IPCC report offers starkest warning yet … clear and present danger to humanity, ecosystems at point of no return.

Russian invasion of Ukraine

Intensified focus on **energy security**

Swift **shift away from Russian gas**, 40% of European gas (NordStream2 cancellation)

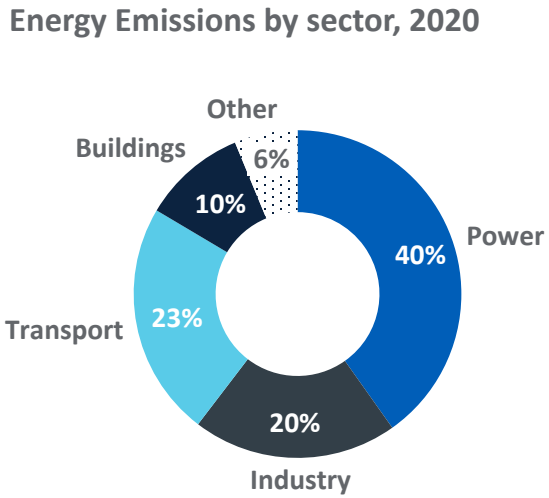
Expectations for persistent higher gas price, increased demand for US LNG

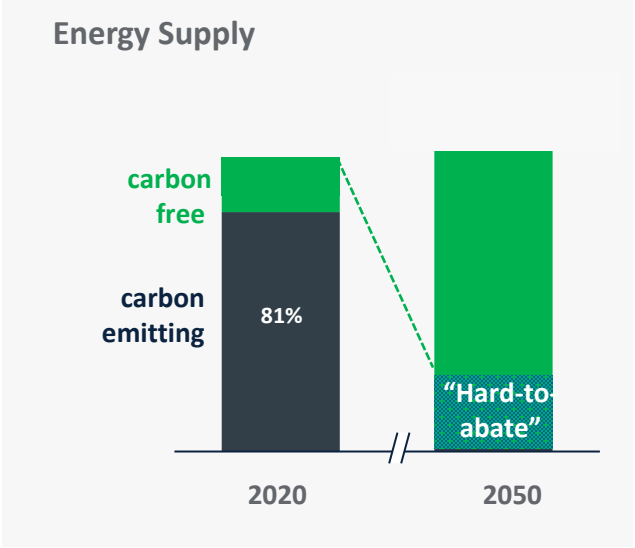
Appetite grows for **fast-track green transition** comparable to WWII mobilization

Confidence builds that we can – *and must* – change course through Energy Transition pathway

Energy transition … *Get to net zero, retaining reliability and affordability*

Decarbonizing energy sector through clean electricity





Societal, geopolitical and historical choices drive different solutions at regional and country level

… drives 3 simultaneous grid transformations

Physics transformation

synchronous machines → power electronics

Operational transformation

constant fuel central generation → variable "fuel" DERs, 2-way flow

Economic transformation

fuel cost value of energy → free "fuel" value of flexibility & capacity

5% ····· % variable renewables ·····▸ **100%**

… and a need for grid infrastructure

aging infrastructure classic grid design → new interconnects grid modernization

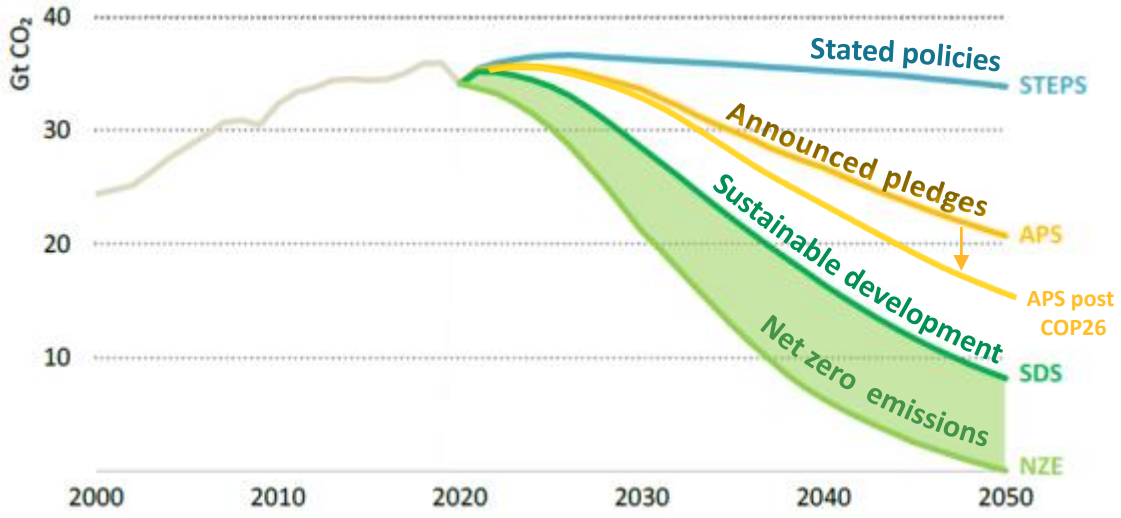
New technology, codes & standards, policies, and market instruments are the enablers

Source: BNEF NEO'20 (Nov.'20) & 21 (Jul. '21)

Energy transition - Scenarios to 2050

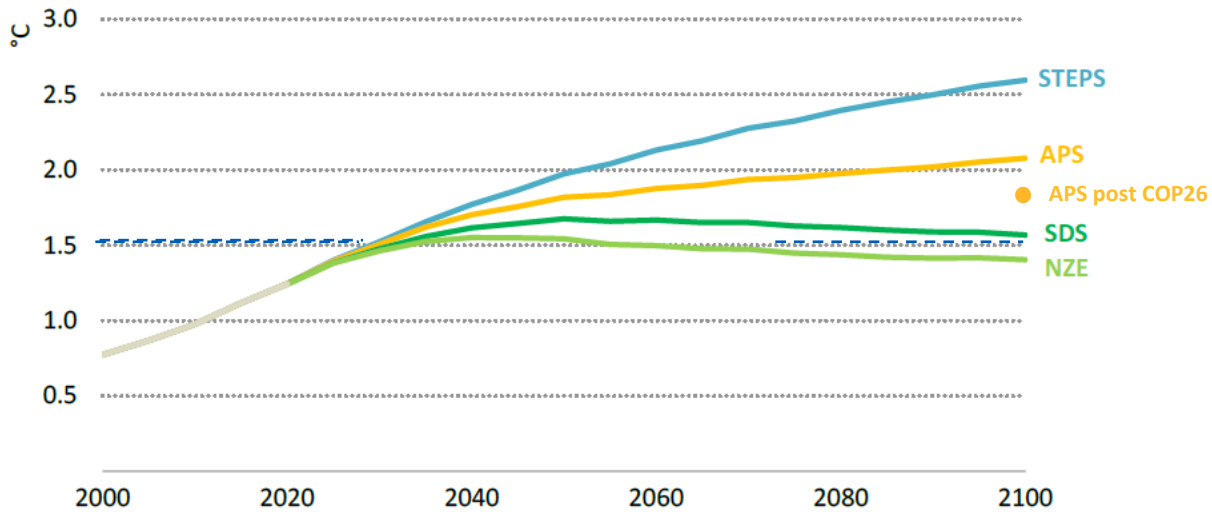
IEA highlighted multiple scenario trajectories … updated after COP26

CO_2 emissions in the *WEO-2021* scenarios over time



- **STEPS shows "implementation gap"** between policies & pledges
- **SDS goes further/faster** to be aligned with the Paris Agreement
- **NZE delivers net zero emissions** by 2050

Global median surface temperature rise over time



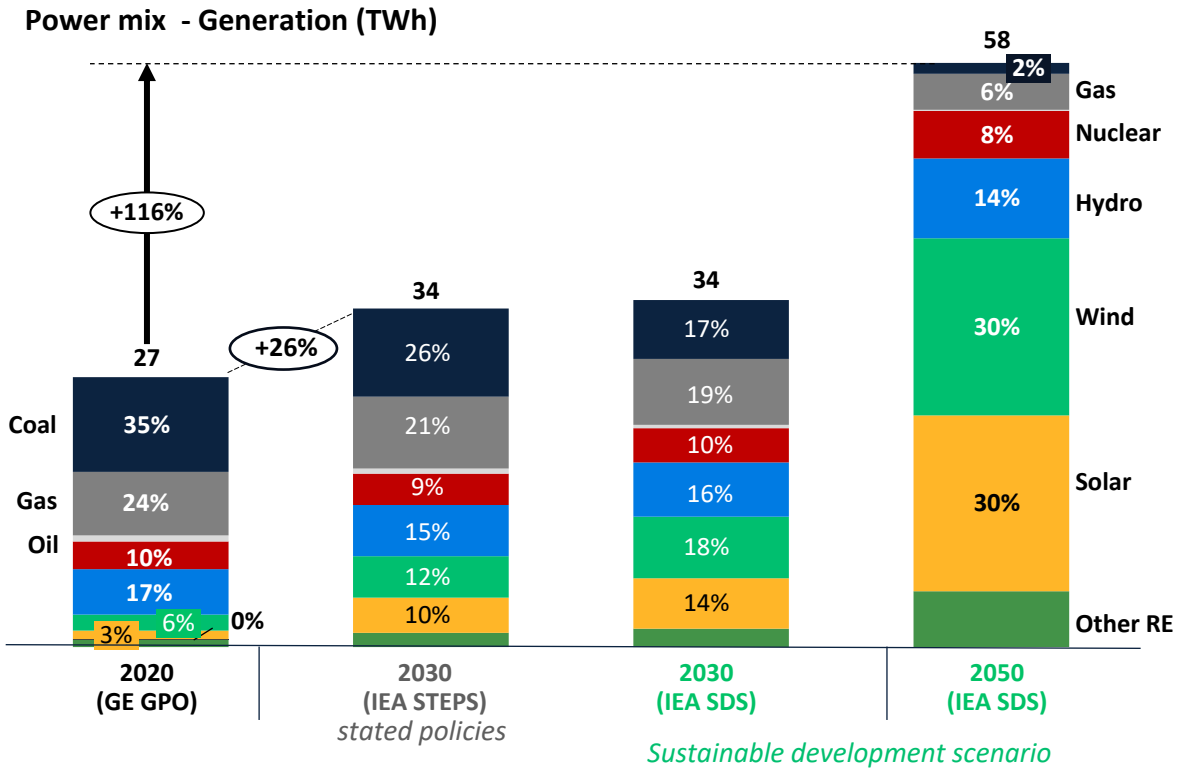
- Current policies and announced pledges lead to **temperature rise deemed unacceptable** (>2°C by 2100 and rising)
- **Temp increase peaks at 1.7°C in the SDS … 1.5°C in the NZE around 2050** (both with a 50% probability)

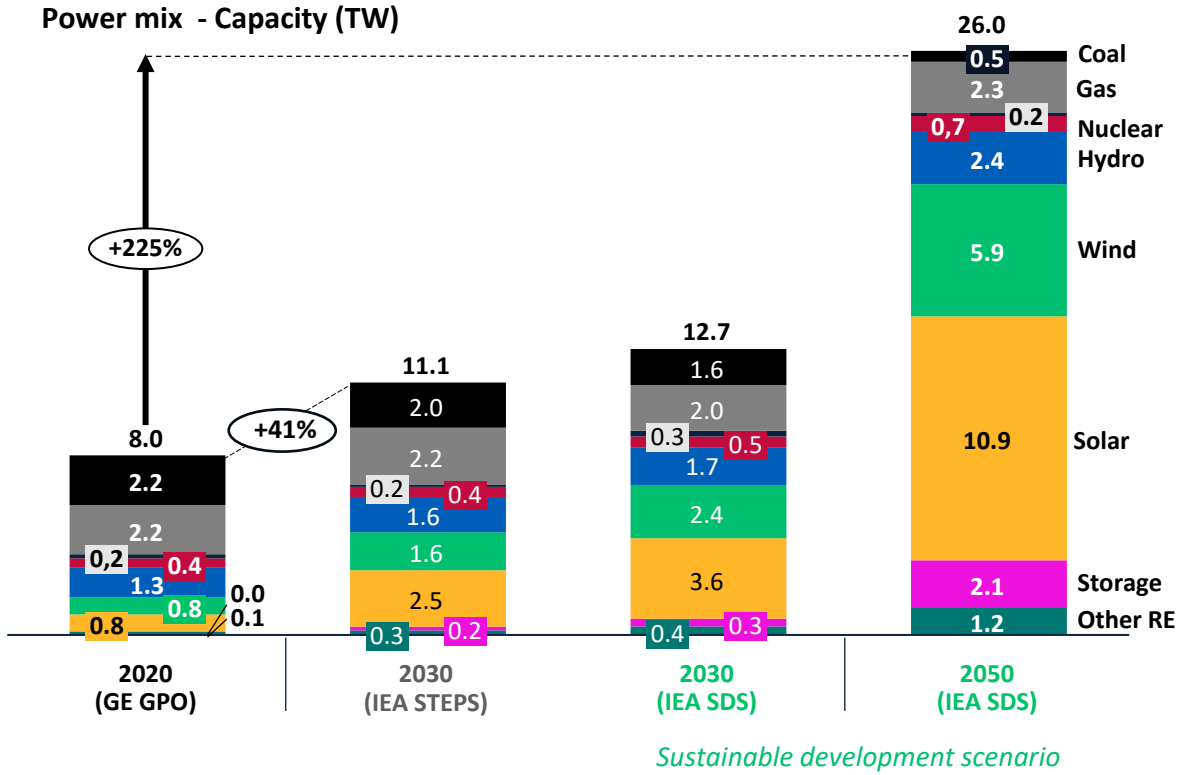
Technology & interoperability required to reach the green zone … challenge grows with further delay

Source: IEA WEO 2021

Power mix evolution by 2030 … 2050

How could the energy transition translate into the power mix?





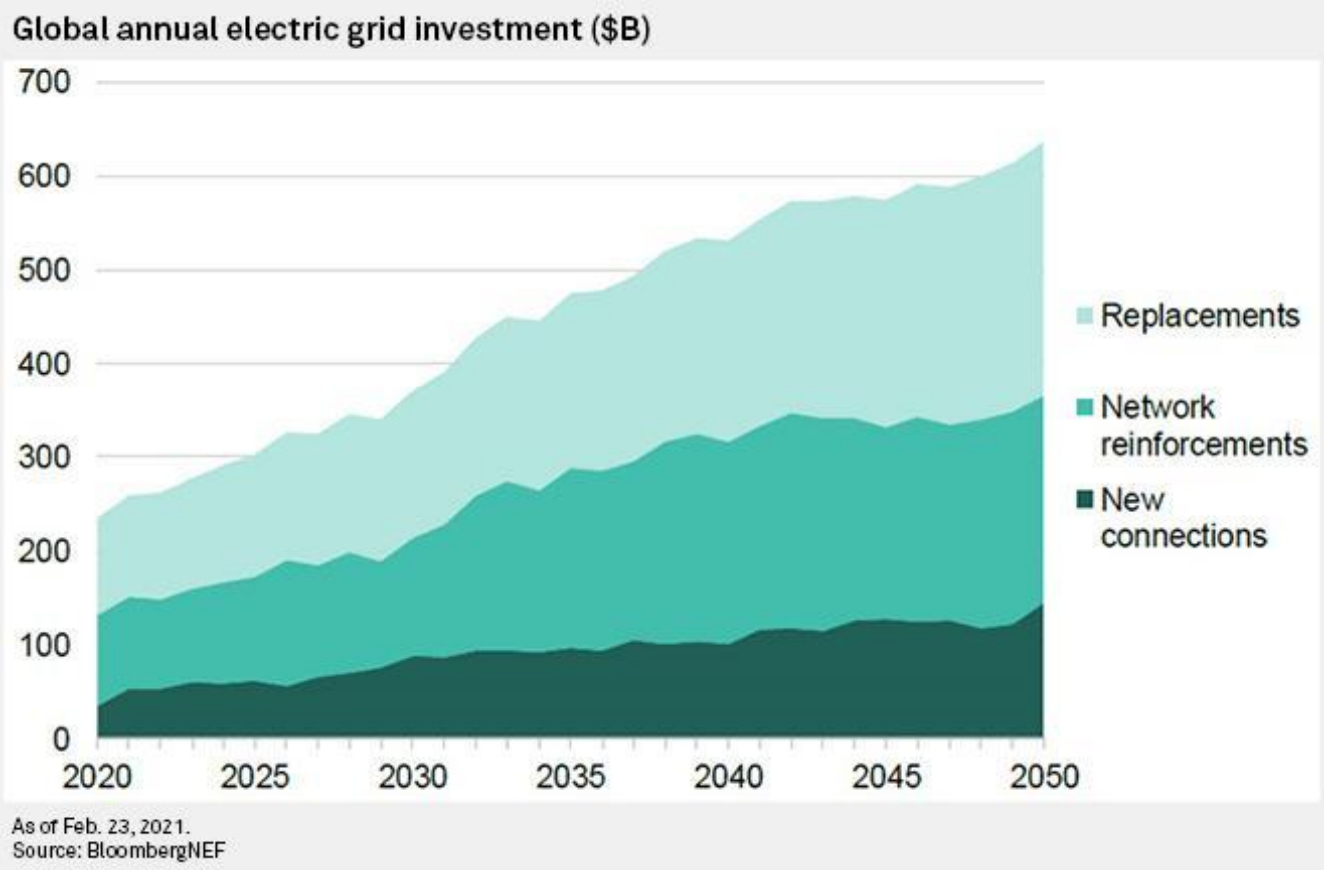
Global power generation to increase by >25% by 2030
… and more than 2× by 2050 to meet 1.5°C Paris goals
Solar & Wind soar … Coal phasing out

Global power capacity to increase by >40% by 2030
… and more than 3× by 2050 to meet 1.5°C Paris goals
Solar & Wind soar … Gas capacity stable

Scenarios assume solutions for current grid constraints

Sources: GE GPO 2021, IEA WEO 2021

Path to net zero boosting grid demand considerably



Changing paradigm for transmission

- FERC revamping incentive policies for transmission buildout
- FERC Order 2222 allowing aggregated DER in ancillary services markets
- New DoE 'Coordinated Transmission Deployment Program'
- New trends in requirements for IBR tech deployment (GC0137 & IEEE 2800)

Growing investment share for key trends

- Decentralization (52% → 63%)
- Digitization (19% → 42%)

(2020 →2050)

Policy

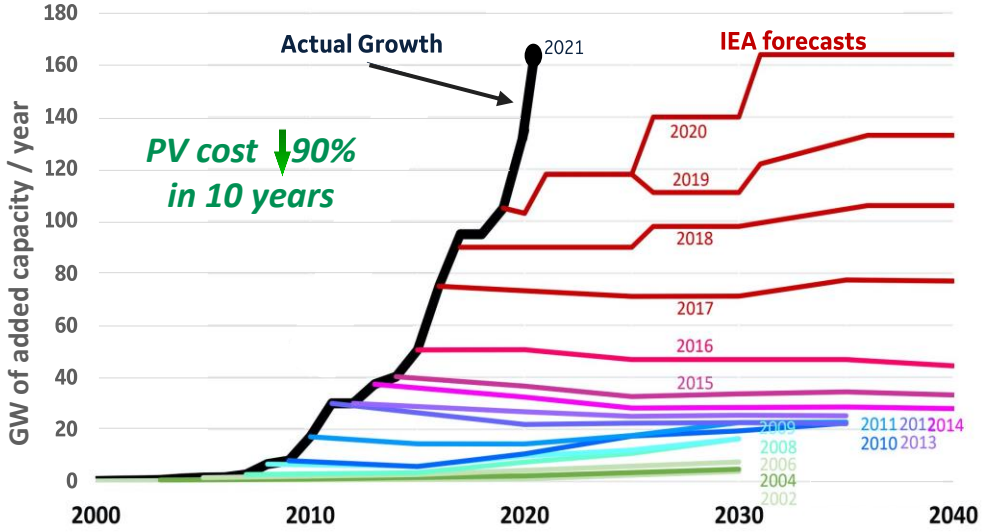
- Key variable to support RE buildout
- Stakeholder models to overcome local opposition
- Facilitate siting and permitting procedures

$14 trillion in global grid investments to decentralize and digitize energy infrastructure

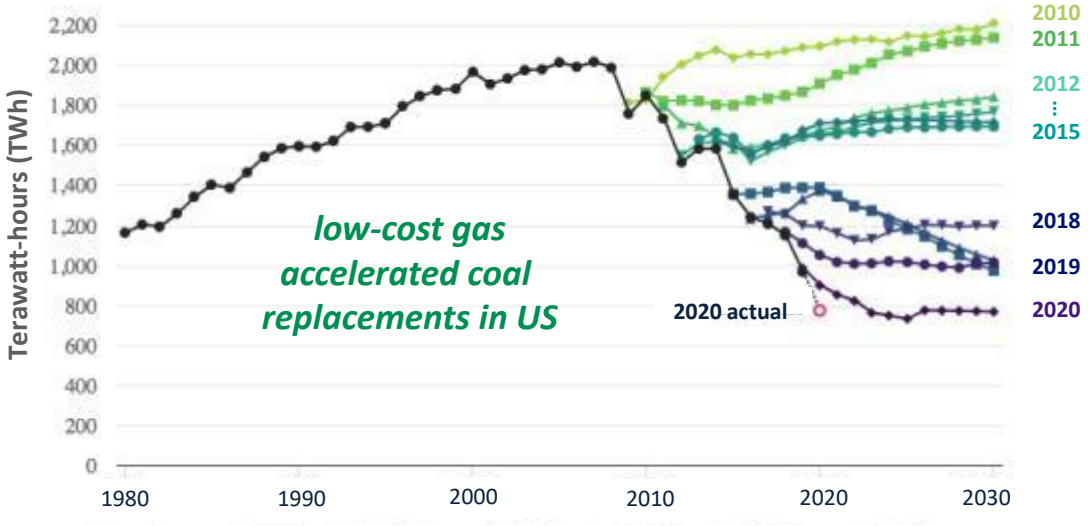
Is this rate of change even possible? … history says “yes”

Exponential change in action warps forecasting capabilities

Actual growth of global solar power vs. expert forecasts



Actual decline in US coal generation vs. expert forecasts



‘Sector Coupling’ creates drivers for accelerating change

Example: **Energy & Transport sector interactions**

- Growing electric vehicle fleet provide options for vehicle-to-grid services
- Electrifying U.S. vehicles wipes out the equivalent of the US’s entire current power demand
- 40% of all shipping cargo is fossil fuel
- 25% of tonnage hauled by US rail is coal, *most of which is for electricity generation*

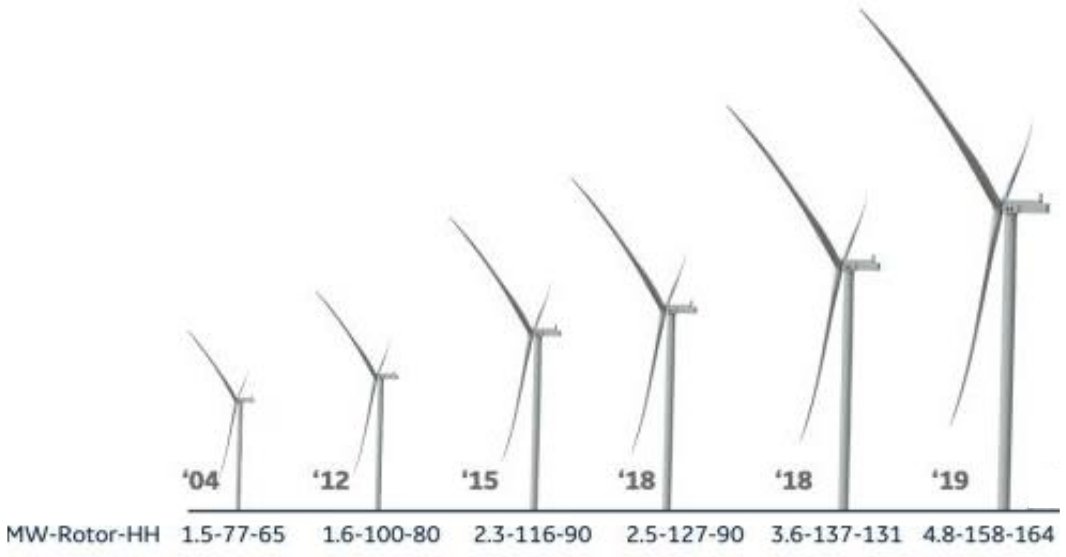
Ramez Naam; IEA WEO

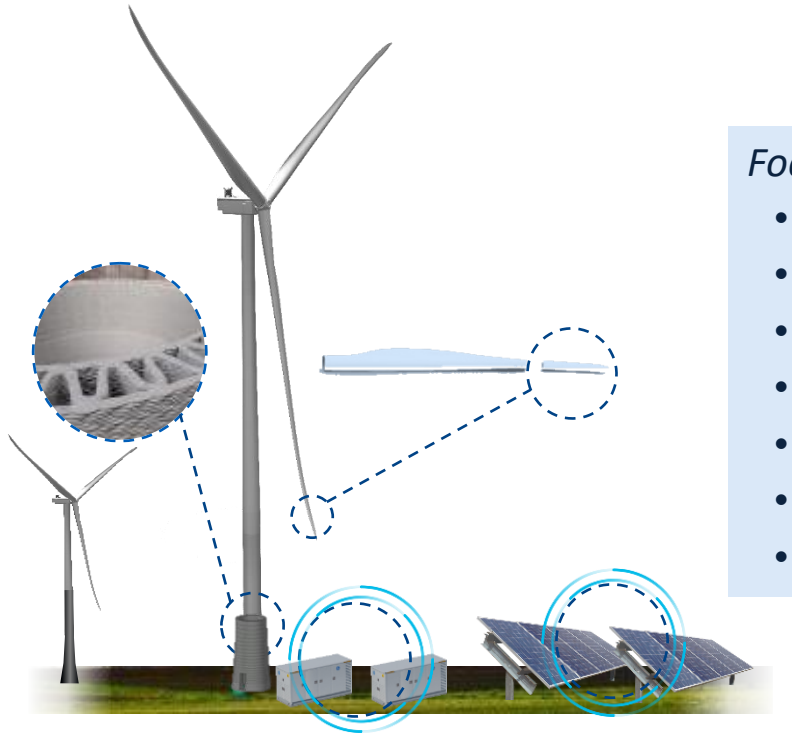
What's needed to scale renewable energy at necessary pace?

… advancements in technology, financing, markets, and regulation

Example: The challenge for Wind

- Expected to scale rapidly, reaching 390GW by 2030
- Recycling end-of-life turbine blades
- Demand for critical minerals ↑ 4× by 2050





Focus on:

- *cost*
- *quality at scale*
- *recyclability*
- *forecasting*
- *logistics mgmt.*
- *serviceability*
- *grid integration*

Energy production ↑4× higher … CapEx 25% lower … LCOE 70% lower

turbine size & volume scale → **TODAY** → *advanced mfg, modularity, recycling & grid integration*

Electrical Grid … the backbone of the Energy Transition

System of systems (Generation + T&D + Loads)

The grid was designed for a different way of producing and consuming power

	FUEL	GENERATOR	GRID	DEMAND
FROM	• Easy to store & control • Dispatchable on demand	• Synch. machines as grid interface • Provides synch. inertia • Can start grid from zero	• Large, central generation • One-way dispatchable flow of electricity	• Predictable • Passive
TO	• Free fuel • Variable generation • High dispatchability through hybridization	• Power elec. as grid interface • Limited inertia & grid start • Fast versatile controls, highly programmable	• Many Distributed Energy Resources (DERs) • Two-way variable flow of electricity	• Mobile & less predictable • Prosumers

… leading to annual T&D grid investment of $250B, growing at 3.4% CAGR

Innovation Focus Areas

Operation optimization

- Maintain reliability & resiliency
- Grid orchestration & protection
- Flexibility from DERs
- Visibility & Modeling

Grid stability

- Grid forming & storage integration
- Wide area controls
- Interoperability & cybersecurity

Performance Optimization

- APM, Digital twins
- Modeling & analytics
- Dynamic rating

Grid re-enforcement, modernization and new technologies are needed

Problems Worth Solving

① The Electric Power Grid … operation, optimization, stability, and control

- High IBR penetration is a certainty – needs cost-effective enhanced grid capabilities
- Integrated planning & modeling across stability, operations & adequacy disciplines, T&D interface and industry sectors
- Interoperability of controls across multiple resources

② Legislation & Regulation … we need a clear path forward

- Requirements, standards & interconnection processes need reform to unlock full IBR growth potential
- Grid development is highly complex… requires stakeholder collaboration at a new level
- Planning for policy goals requires holistic mindset

③ Cybersecurity … an increasing concern

- More digitalization leads to higher vulnerabilities
- Cloud-based control necessitates cybersecurity
- New type of products are needed with design-for-security from the ground up

Building a world that works