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NATIONAL RENEWABLE ENERGY LABORATORY

Advanced Energy Technologies and Advanced Manufacturing: achieving decarbonization goals and facilitating economic growth

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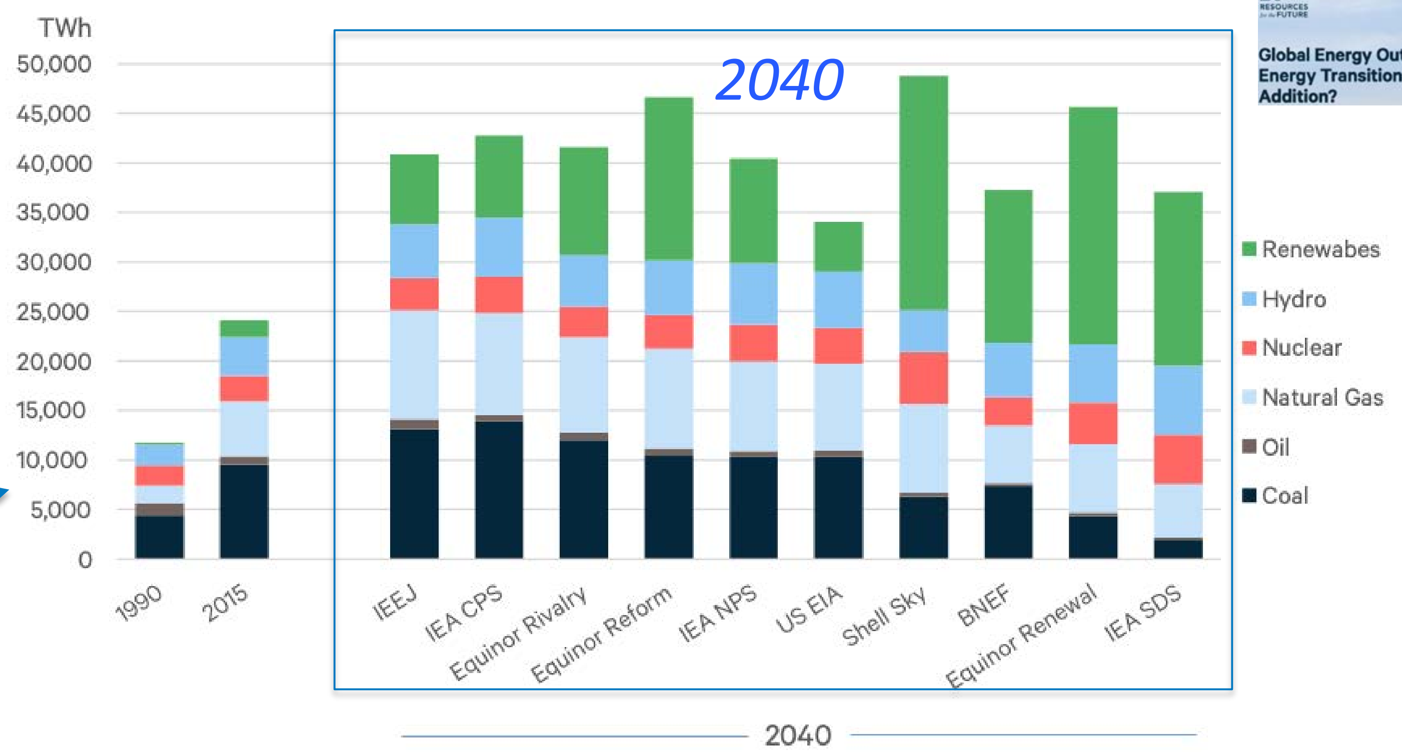
August 4, 2020

As global energy consumption continues to increase, renewables make more prominent contributions

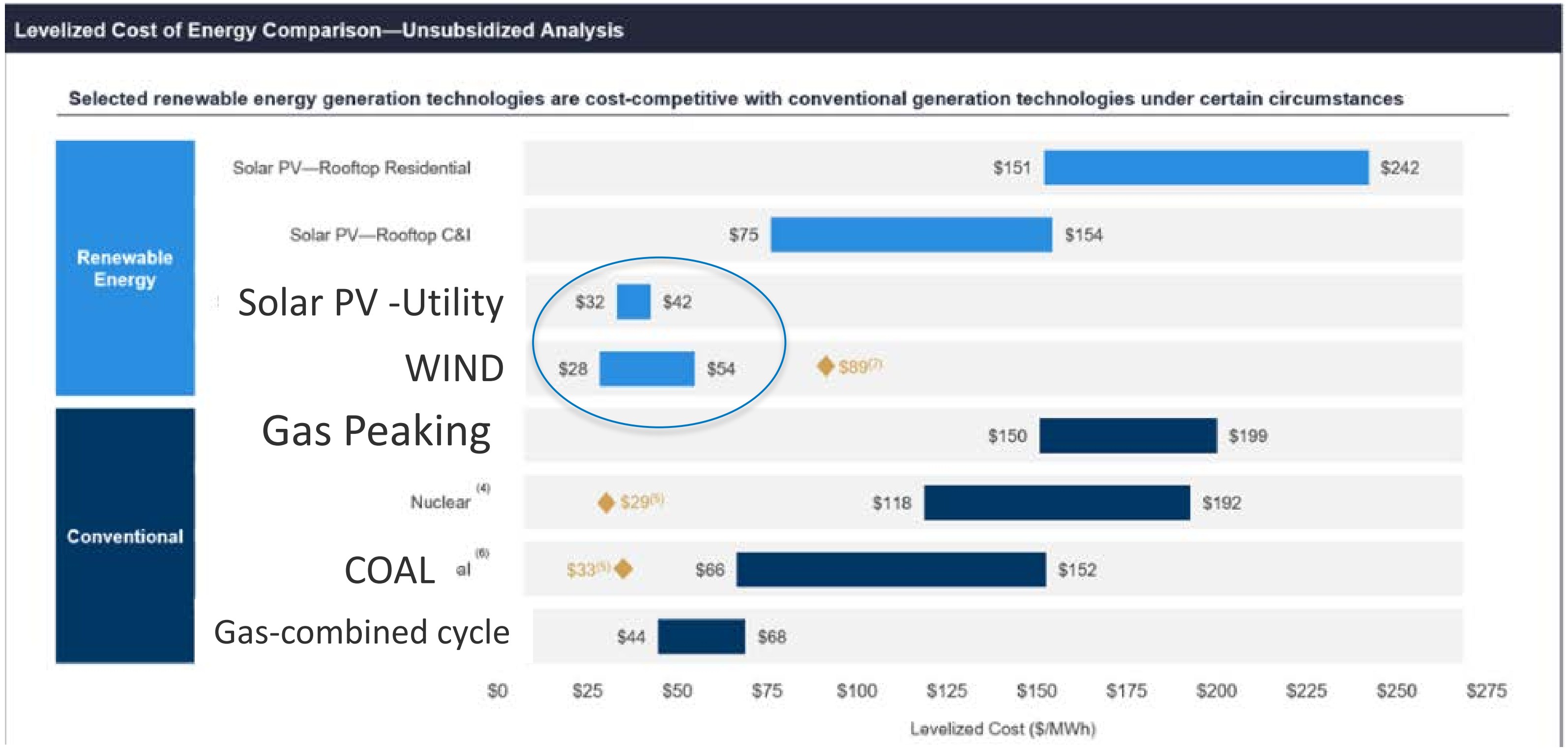
- Global energy consumption will likely increase by 30-50%, by 2050
- Various scenarios indicate that fossil fuels would continue to be the dominant primary energy source in 2040
- **The contribution of renewables to electricity generation promises to be significant, based on most scenarios, in 2040**



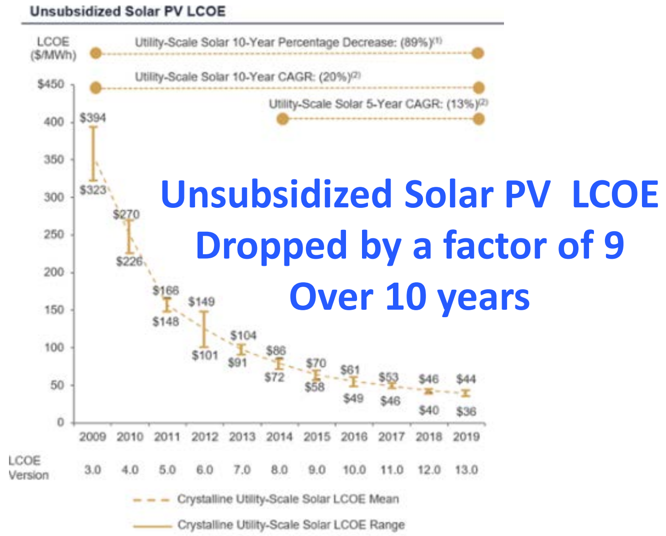
- GOAL: Achieve aggressive decarbonization goals, while maintaining economic competitiveness
  - A future advanced power system -resilient, secure, cost effective, high functionality -providing a diverse range of services to sophisticated customers.
  - The system will be enabled by new advanced energy technologies, and new advanced manufacturing strategies, driven by foundational research and innovation.

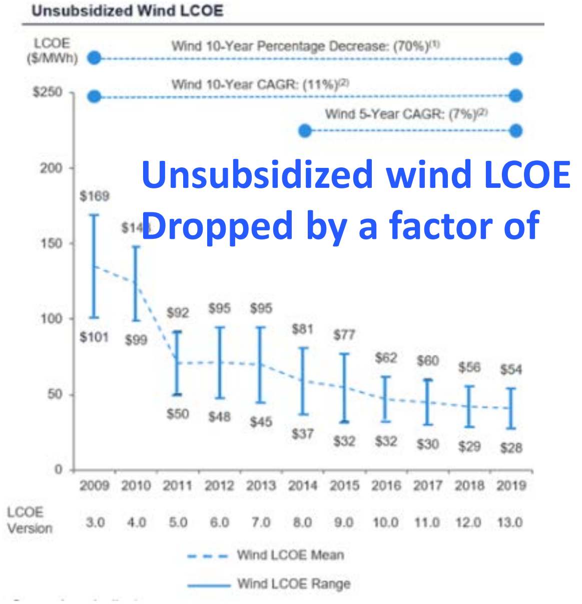
Renewable power generation costs achieve parity with power generation from fossil sources, and continue to decrease

Wind and utility Solar PV -cheaper than gas and coal

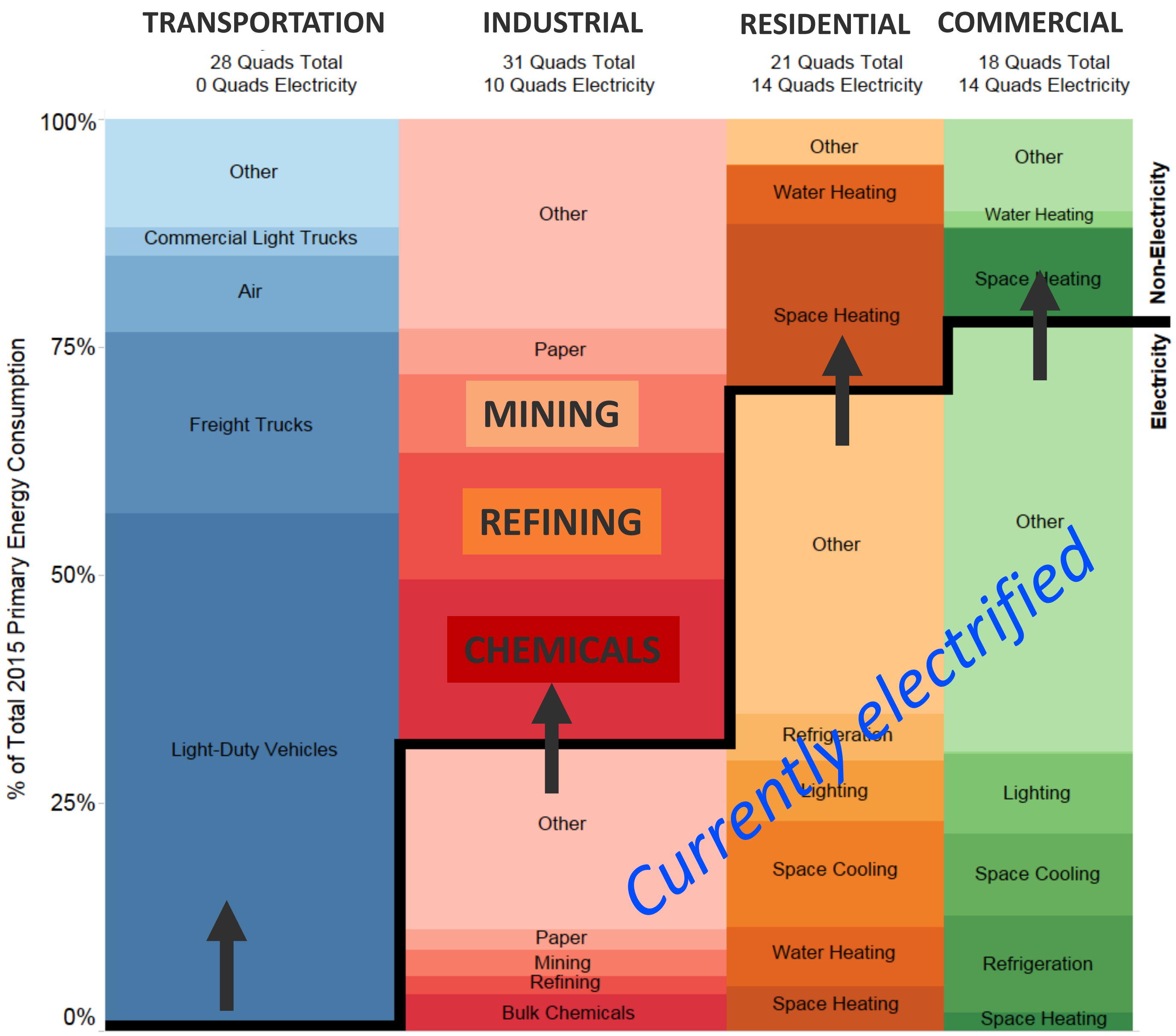


Lazard.com | Levelized Cost of Energy and Levelized Cost of Storage 2019





The electric power sector promises to account for most of the primary energy consumption in 2040



- Currently, electrification accounts for approximately 18% of primary energy consumption and is anticipated to grow to ~40%, globally, by 2040
- Current contributions to electricity in the US: 18% renewable energy, 19% nuclear (fossil sources are dominant)
- The goal of reaching 100% “zero” carbon sources is realistic –*many pathways exist*

NREL Electrification Futures Study -US

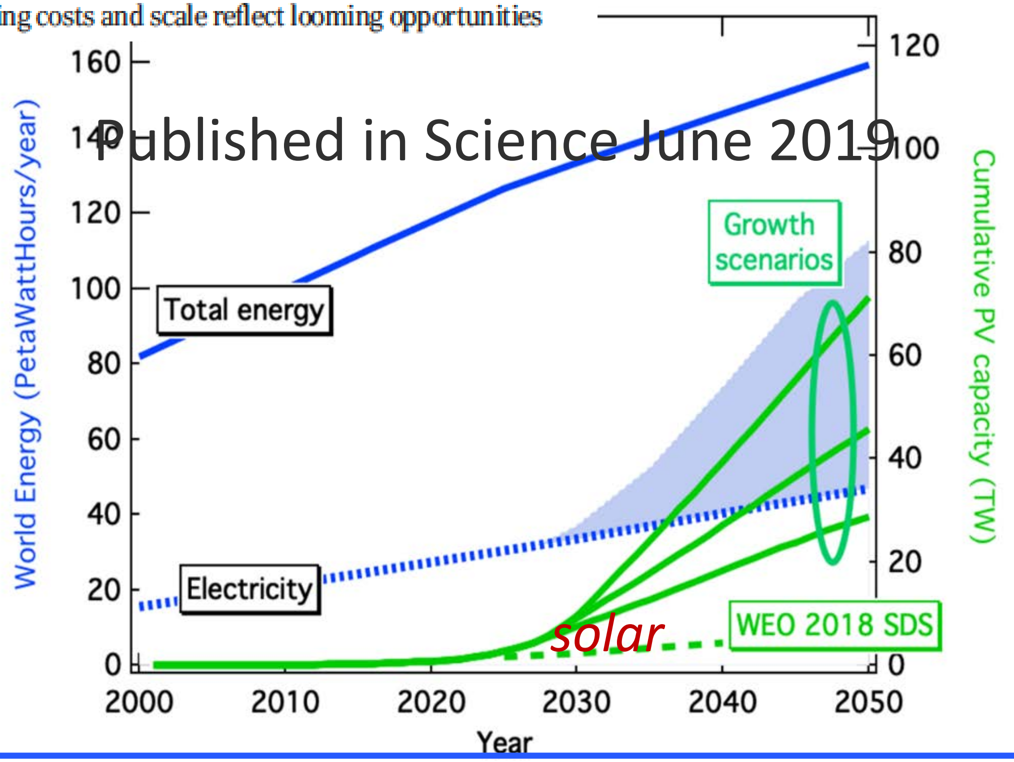
Solar and Wind Energy must provide TWs of power by 2040: Policies and academia-National Laboratory interactions

RENEWABLE ENERGY

Terawatt-scale photovoltaics: Transform global energy

Improving costs and scale reflect looming opportunities

Published in Science June 2019

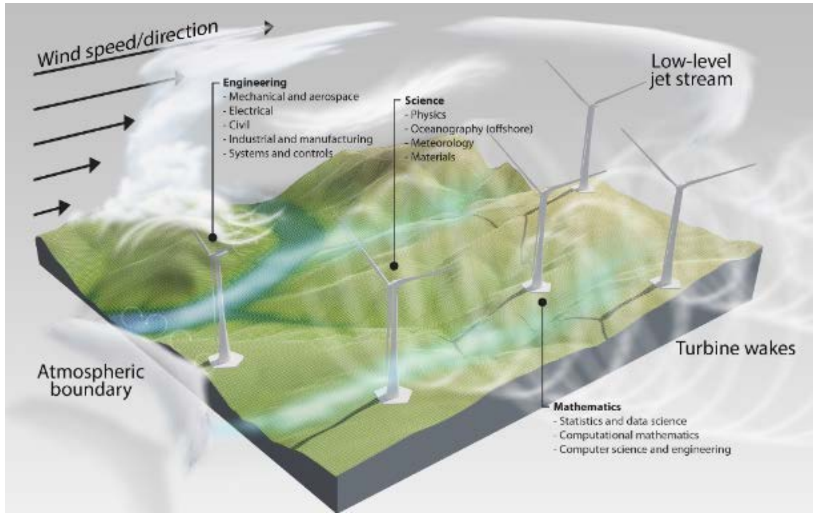


- New Solar technologies
- Improved technology efficiencies
- Improved manufacturing yields/performance
- Sustainability –circular economy, new materials/processes

Science *REVIEWS*

Cite as: P. Veers *et al.*, *Science* 10.1126/science.aau2027 (2019).

Grand challenges in the science of wind energy

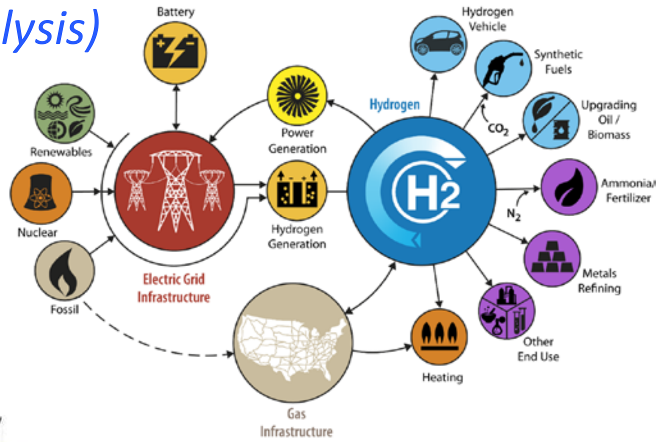


- New science and innovations in design and manufacturing innovations (additive manufacturing, new materials/processes)
- Sustainability –new designs, materials, processes (circular economy)

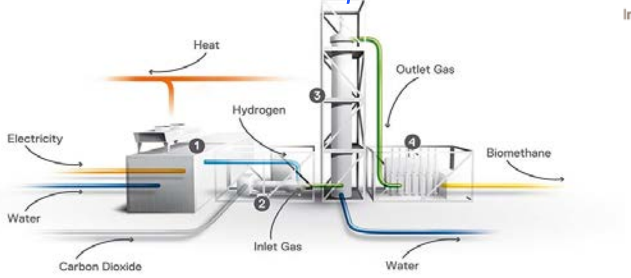
Reducing CO_2 emissions: Challenges/Opportunities

- **Power Generation from non-fossil sources**

- **Mitigation Strategies**
  - Carbon Capture and Utilization (CCU)
    - Power-to-X (fuels, materials)
      - *Hydrogen (from electrolysis)*



      - *Synthetic methane, CH_4*



$$4H_2 + CO_2 \xrightarrow[+\ \text{Heat}]{\text{Biocatalyst}} CH_4 + 2H_2O$$

- **Efficiencies/reduce energy intensity**
  - Manufacturing strategies and processes
    - additive manufacturing
    - machine learning/artificial intelligence

- **Sustainability**
  - Circular Economy
    - *recycle, reuse, repurpose*
  - Materials substitution – earth abundant

Power System of the Future: challenges/opportunities for reducing CO_2 emissions:

Power System of the future must provide significant functionality, serving a new generation of sophisticated customers –

internet of things, interconnected devices, appliances, EVs, distributed power generation, smart homes and communities, sensors.

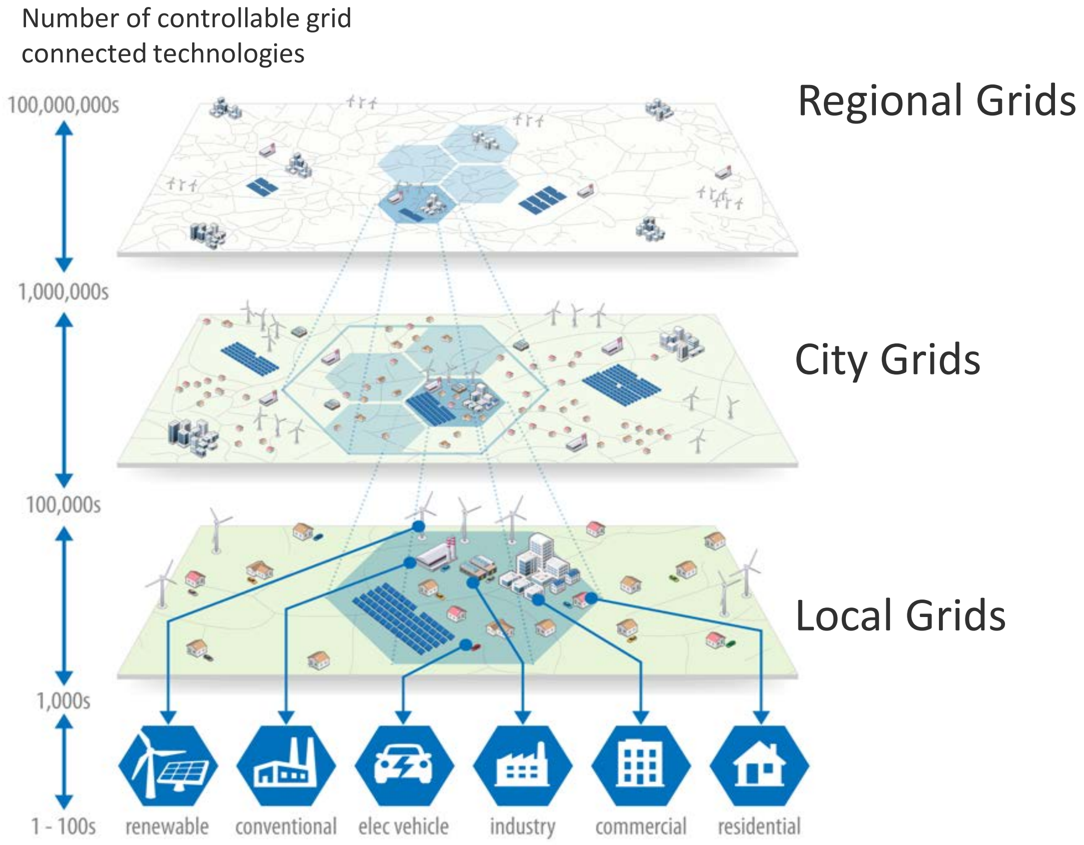
It must be secure resilient, CO_2 emission reduction, facilitate of economic growth.

Support for: CCS, CCU…Power-to-X (fuels, materials)

Operate Efficiently with high levels of renewable penetration and non-renewable sources

It will be autonomous -control of millions of DERs (AI/ML, massive amounts of data)

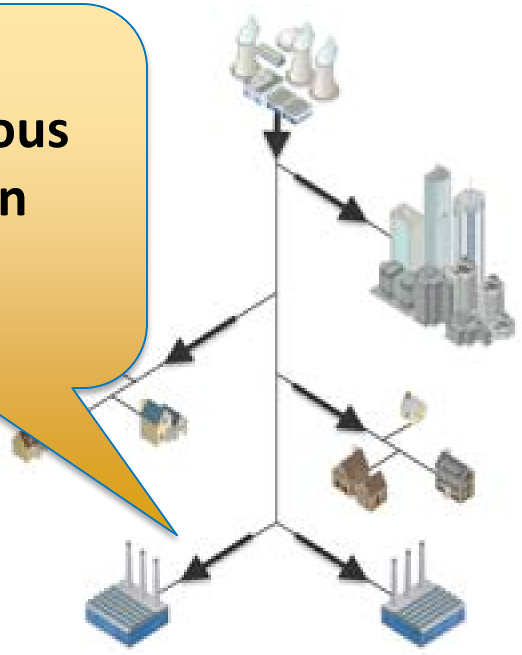
Controlling massive amounts of variable and distributed generation in the power system of the future



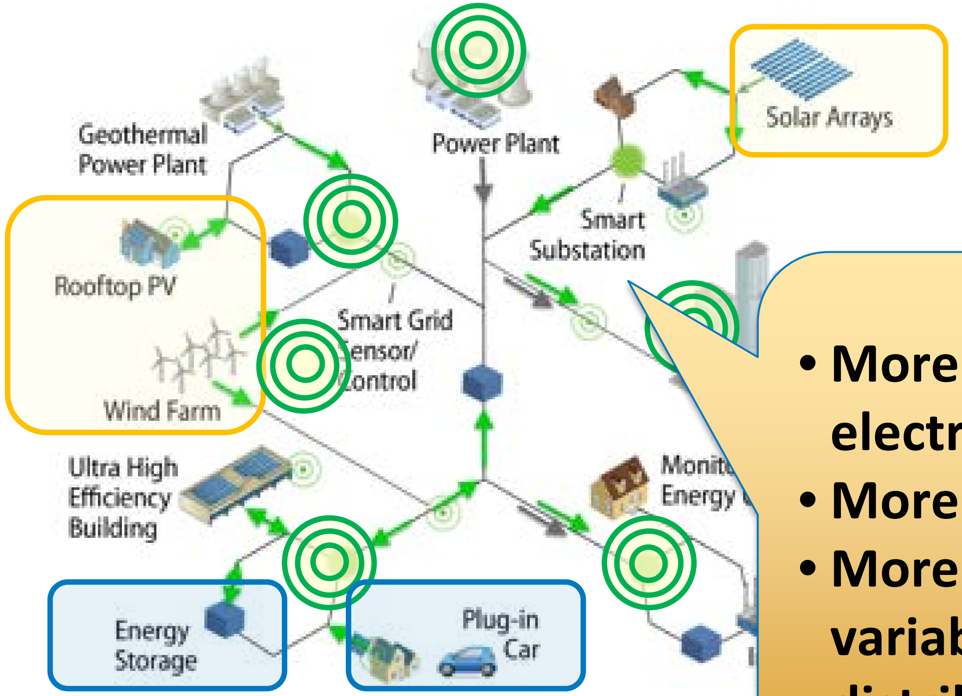
Transformation of the Power System

Current Power System

- Large synchronous generation
- Central control



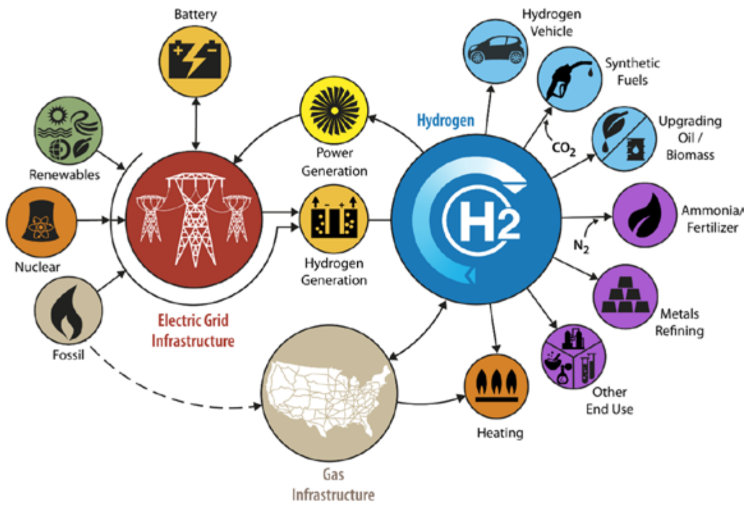
Future Power Systems

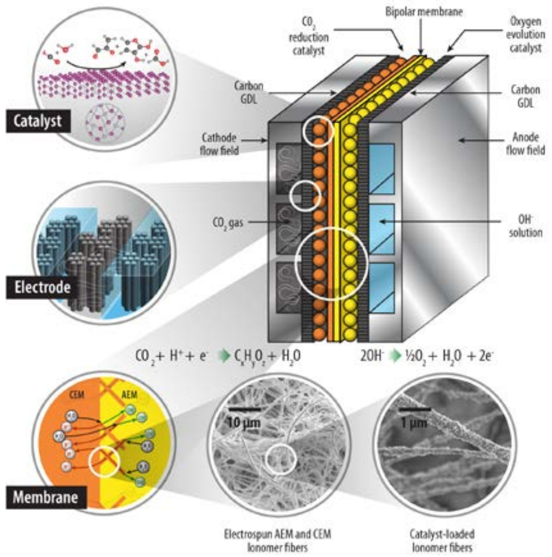


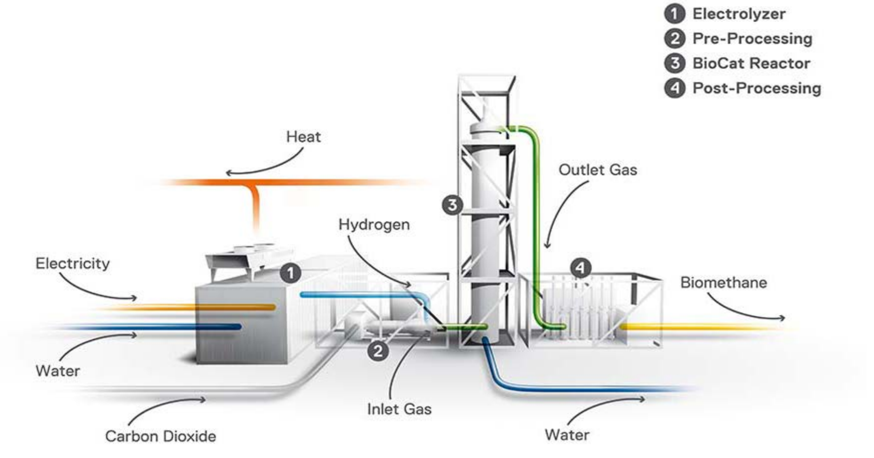
- More power electronics
- More data
- More variable and distributed resources

New challenges in a modern grid:

- Increasing levels of power electronics-based VRE: solar and wind
- More use of communications, controls, data, and information (e.g., smart grids)
- Other new technologies: electric vehicles (EVs), distributed storage, flexible loads
- Becoming highly distributed—more complex to control





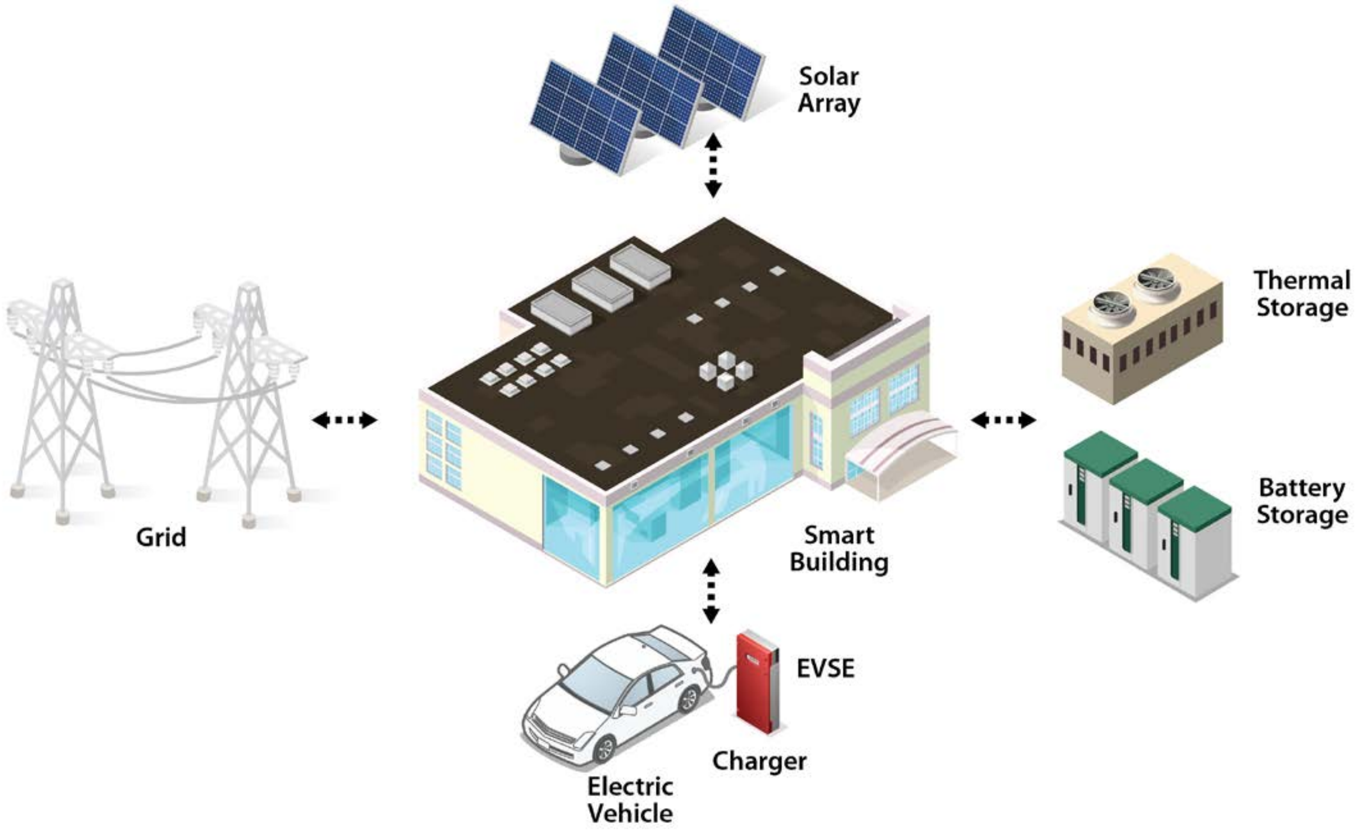


$$4H_2 + CO_2 \xrightarrow{\text{Biocatalyst}} CH_4 + 2H_2O + \text{Heat}$$

Key Questions for Renewable Power to Molecules

- Use of Renewable Electricity as an Energy Source
- Lowering Cost of Electrolytic Generation of Hydrogen – DOE's H2@Scale
- Development and Demonstration of Electrochemical Routes for Reduction of CO_2 to e-Fuels and Chemicals
- Reactive Carbon Capture and Conversion
- Combining Abiotic and Biotic Processes: Power to X
- Energy Storage of Electrons in Chemical Bonds
- Novel *Electricity-Driven Processes for Industrial Manufacturing*: Generation of Chemicals such as Ammonia and Ethylene

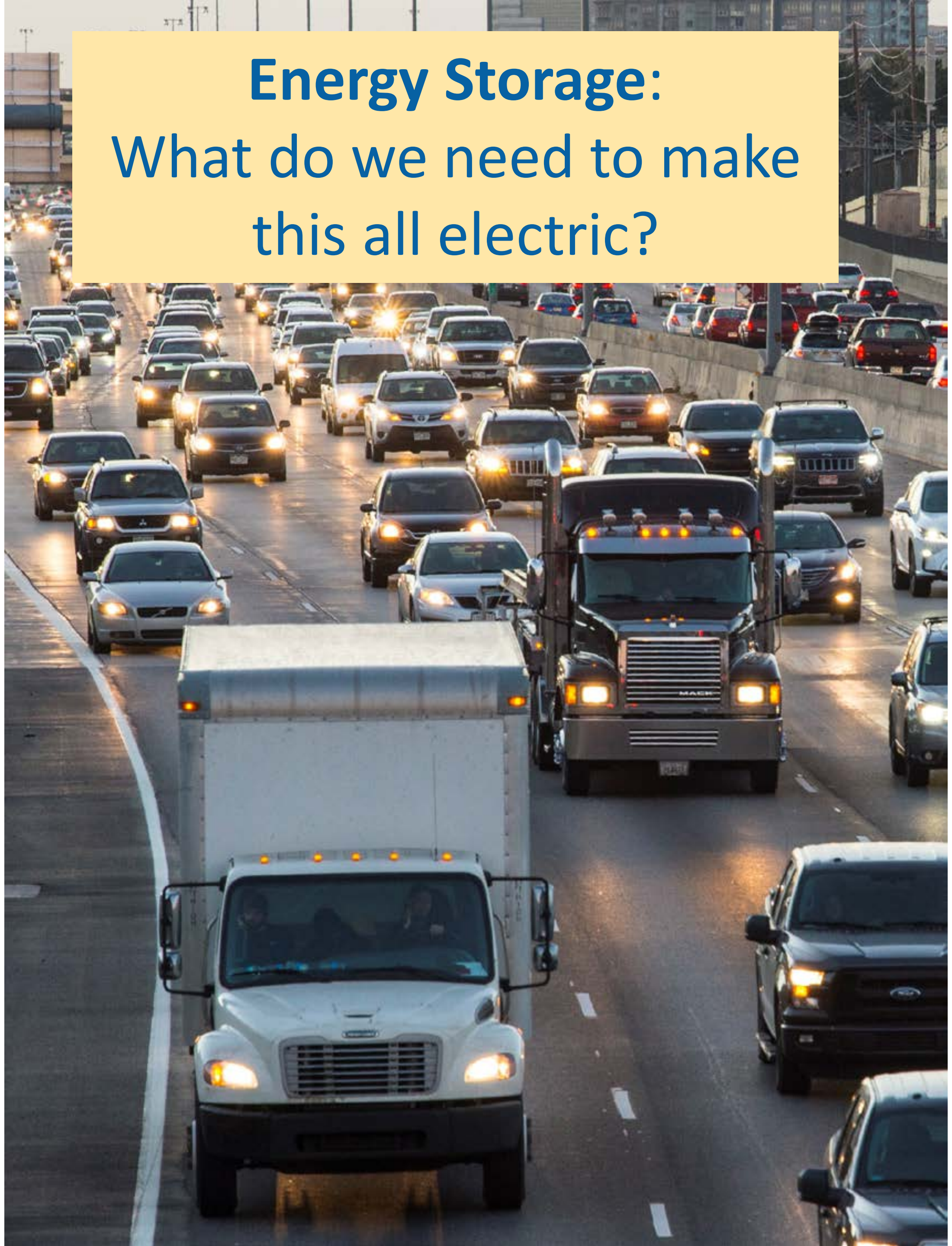
Key Opportunities for Smart, Connected Buildings and Low Carbon Communities



Research Goal: Connected, intelligent, and efficient buildings with flexible demand that can be controlled in synergy with time and spatially variant electricity generation

- What are the new generation of thermal energy storage (TES) materials that have **energy and power** densities required to meet storage requirements of a future energy system with a growing share of renewable electric generation, transmission and distribution constraints and increased peak electricity demand?
- How can the next generation of behind-the-meter TES technologies and systems be developed to enable co-optimization with building controls, electrochemical energy storage, vehicle charging, and distributed renewable energy generation?
- How can fundamental advances in controls, forecasting, and optimization science be leveraged for integrated systems of buildings, mobility, and distributed energy generation at the scale of communities and cities?

Energy Storage: What do we need to make this all electric?



Cost : Attempting parity with current ICE technology. Cost target of $80/kWh by 2030 - currently at $197/kWh

Range: Increased energy density allows for longer range. Targeting cell energy density greater than 400Wh/Kg.

Safety: Always the top priority – need to continuously adapt safety measures for future chemistry advancements

Extreme Fast Charging: Charge time needs to be on par with present refueling time of ICE vehicles.

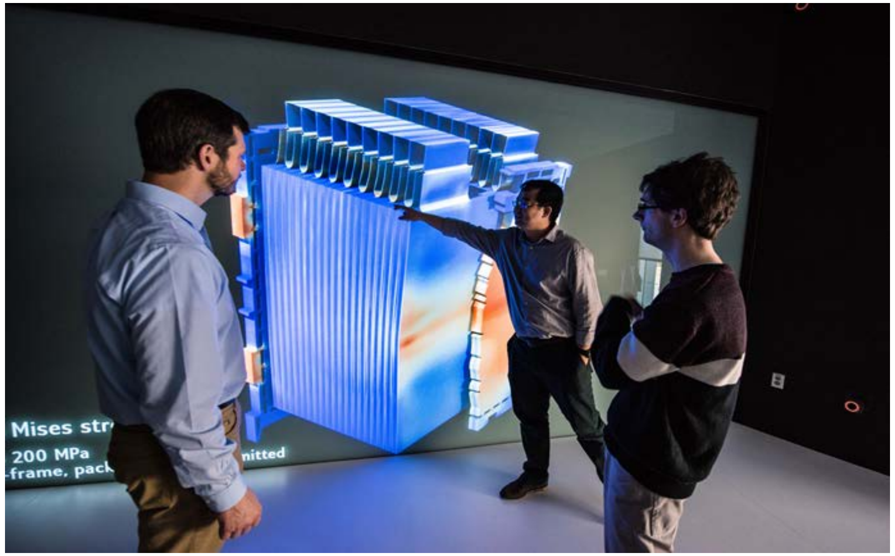
Transportation Key Opportunities and Challenges

OPPORTUNITIES

- **Heavy Vehicle Electrification –** develop components and systems to shift commercial vehicles to electrified solutions (battery and fuel cells)
- **Energy Efficient Mobility Systems –** pursue transportation solutions that decouple the movement of people and goods from GHG emissions
- **Sustainable Transportation Fuels –** develop low-carbon liquid fuels for heavy-duty vehicle, aviation, and marine applications that cannot be electrified.
- **Autonomous Vehicles –** additional steps needed for advanced vehicles on the roadways.

RESEARCH CHALLENGES

- Higher-power vehicle charging systems, including wireless charging, that integrate with the grid and maintain battery life
- High energy-density, low-cost, durable, and safe energy storage solutions
- Integrating connected, automated, and electrified vehicles with community systems and the built environment
- Fundamental fuels and combustion science to enable the use of sustainable liquids for transportation applications



Final Remarks

- We are in the midst of an inevitable transition from the reliance of power generation accompanied by high CO_2 emissions to “zero” carbon power generation sources and power generation with effective CO_2 emission mitigation measures.

- DOE has helped to advance renewable energy solutions (storage, mobility, power generation, Grid Modernization Initiative) via management/funding -often joint academic-national lab-Industry collaborative interactions), roadmaps.

- NSF/DOE (BES, BER) have been critical for the advancement of foundational science, leading to innovations for new materials/processes, efficiencies, cost reductions and new Advanced Manufacturing strategies

- Future enabling activities are needed to address the most sophisticated challenges that have ever confronted the globe
  – Creative funding mechanisms to rapidly advance low carbon solutions and supply chains
  – Coordinated national portfolios to spur innovation for a low carbon economy
  – Regional innovation centers
  – Creative new policies and market adoption strategies.


THANK YOU