Pathways to net-zero are largely dictated by competing S&T advances, technology adoption rates and economic competitiveness

Peter F. Green
Chief Research Officer
June 23, 2021

OUTLINE

I. Scope of the Challenge

II. Progress toward addressing the challenge: *current status*

III. Viable pathways are proposed: electrification and storage are key components. How fast, at what cost and with what level of success?

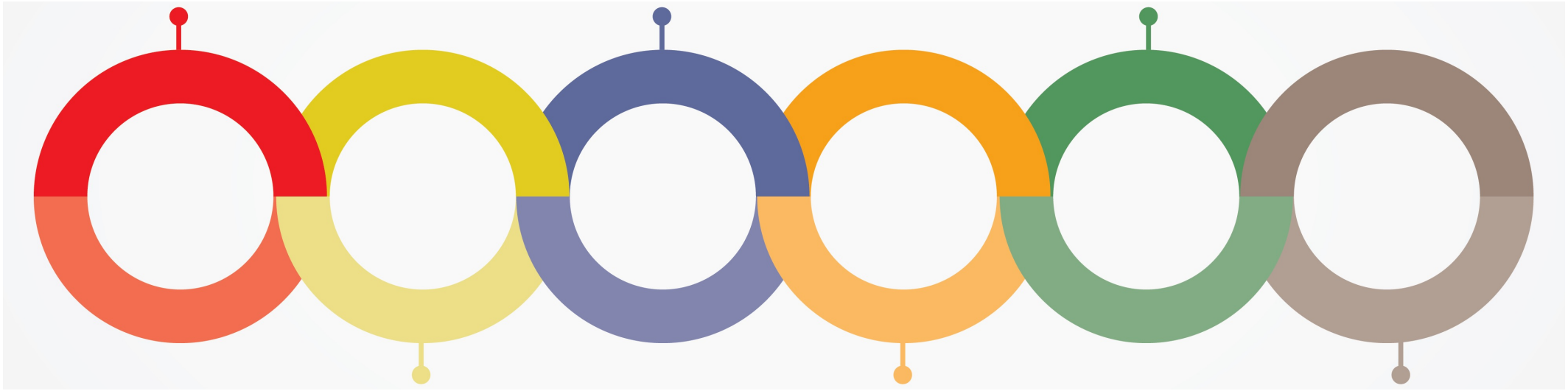
IV. DOE has a variety of effective partnership (public-private) mechanisms: *will they be sufficient?*

Megatrends

Cyberthreats

Resource Competition/ Food and Water

Economic Development



Electrification

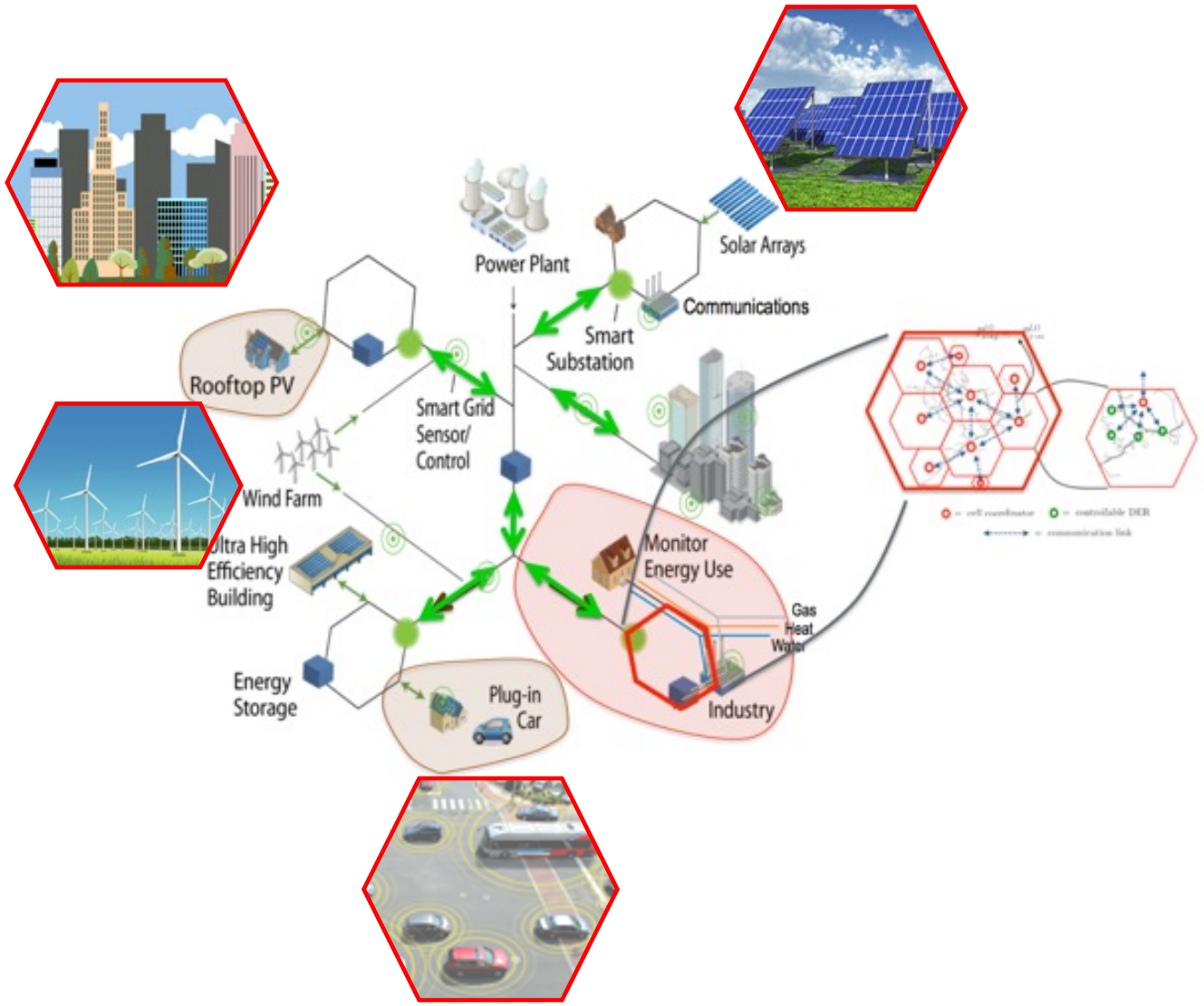
Population Growth

Urbanization

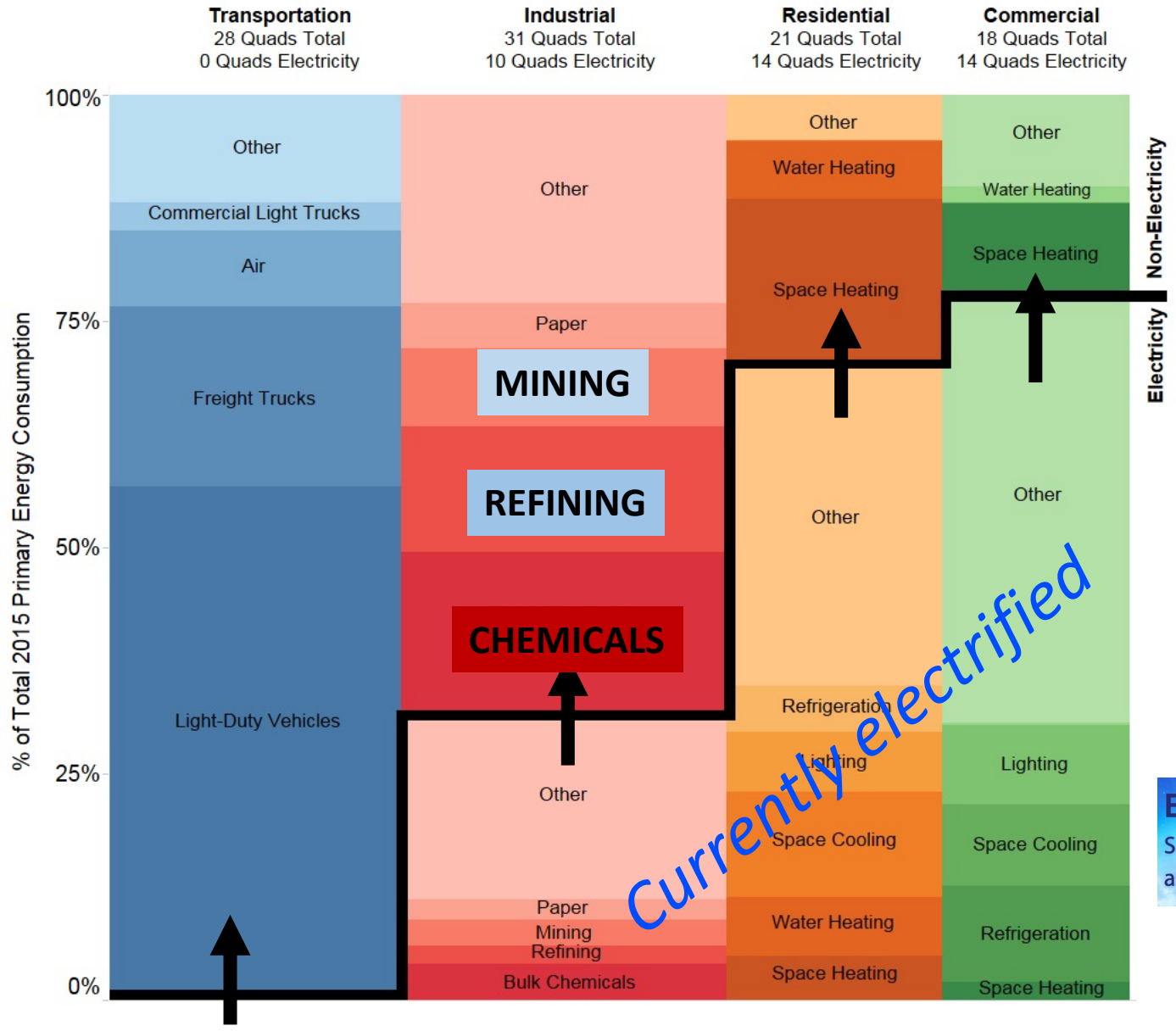
- By 2050 the global population is projected to increase by approximately 20%; GDP is projected to increase by a factor of 2 –*emerging economies*
- In the absence of *sensible* measures, the global energy consumption would likely increase by approximately 40%, and CO_2 missions by 60%

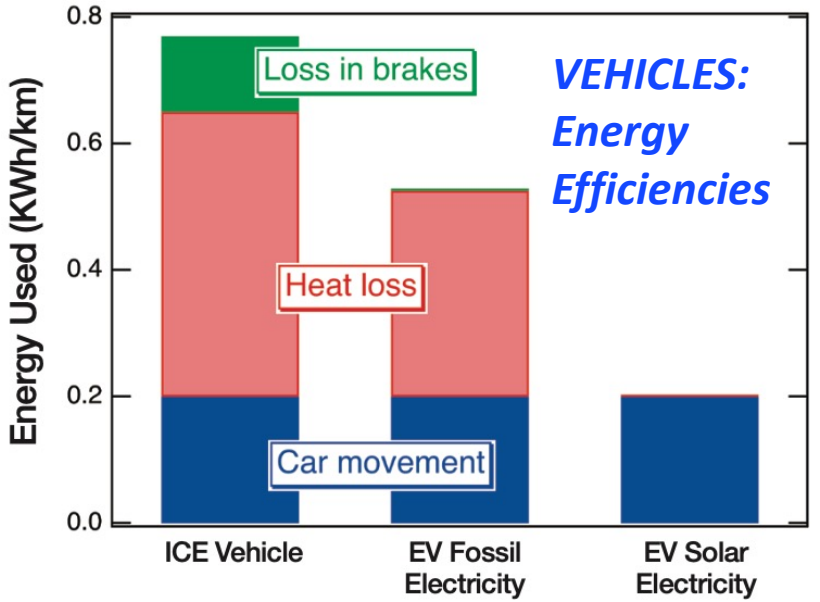
The power system of the future

- **Autonomous** control of millions of devices
  - storage, distributed energy resources, smart appliances, EVs…
- **Diverse power generation sources**
  - *High penetrations of wind and solar (inverters)*
- **Electrification** –transportation, industry
  - Grid interactive buildings/communities
  - Different Storage technologies (*time scales)*
  - *Mobility…connectivity*
- **Low carbon products:** marine, rail, air
  - Chemicals, materials, **fuels**
  - Carbon Capture Utilization (chemicals, materials, fuels)
  - **Hydrogen (electrolysis) infrastructure**
- **Cyber and physical security, reliability, resilience**
- **Circular economy** –design and manufacture energy systems with new materials/processes to minimize waste



The Transportation and Industrial sectors represent the most significant opportunities for electrification





MRS Bulletin 2020

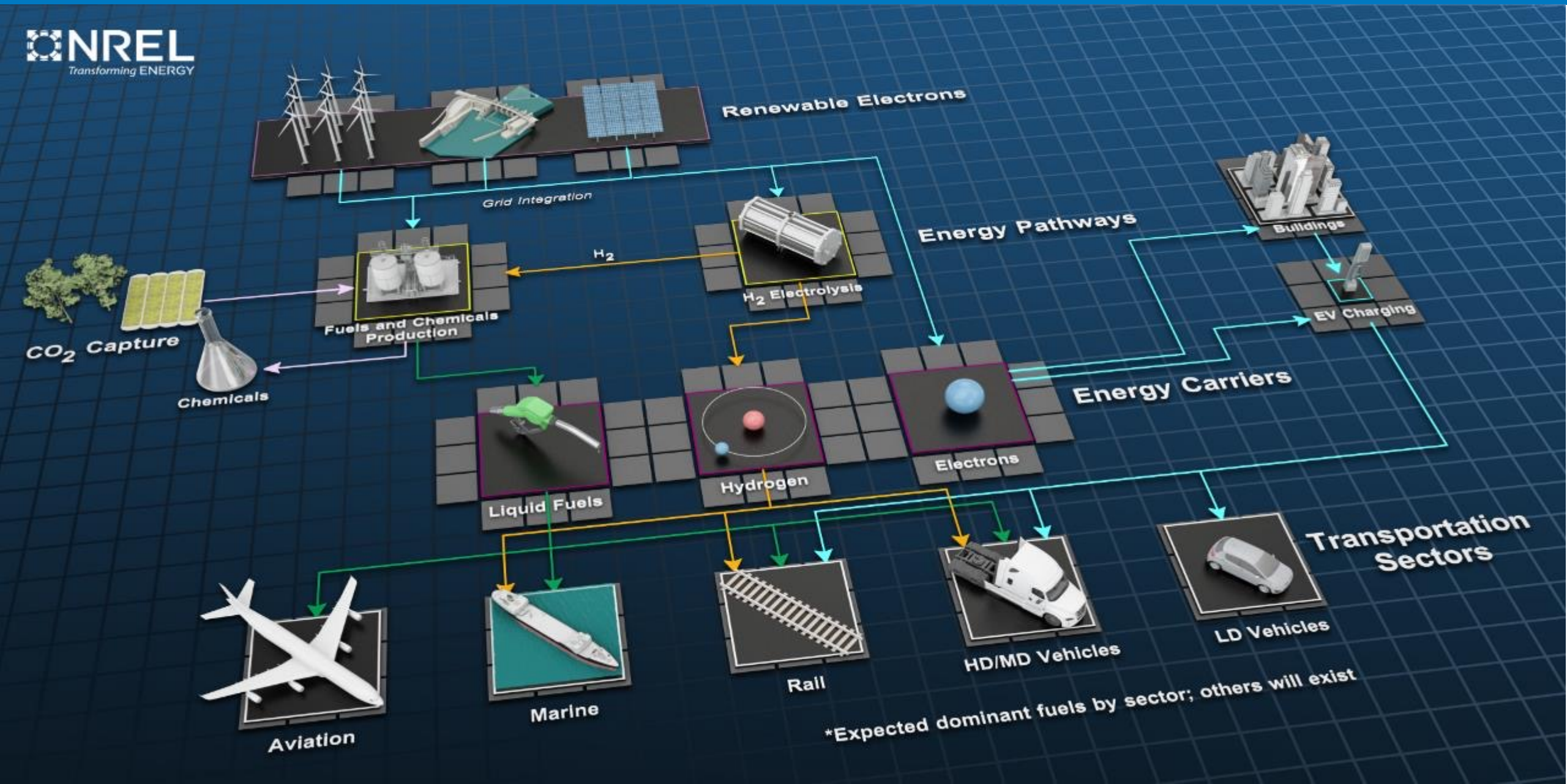
Revisiting the Terawatt Challenge

By **Sarah R. Kurtz, Ashling (Mehdi) Leilaeioun, Richard R. King, Ian Marius Peters, Michael J. Heben, Wyatt K. Metzger**, and **Nancy M. Haegel**

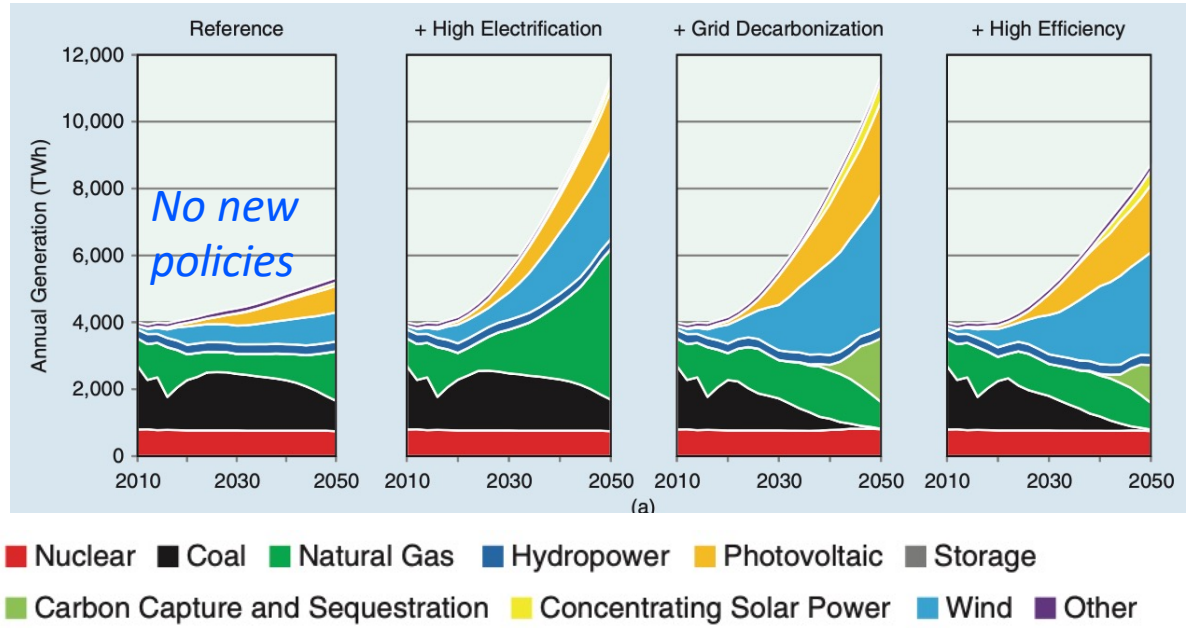
Electrification Futures Study:
Scenarios of Electric Technology Adoption and Power Consumption for the United States

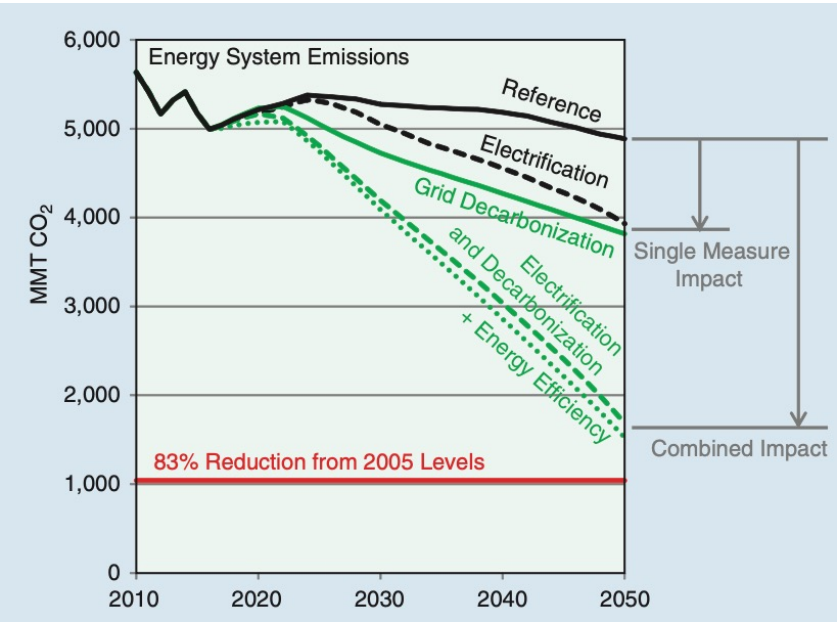
2021 Trieu Mai, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson

NREL's Vision for Decarbonizing the Transportation Sector



Significant amount of wind and solar (TWs of power) required for any viable scenarios





Not a net-zero study (no carbon abatement)

1. Assumption: High electrification of end-use technologies

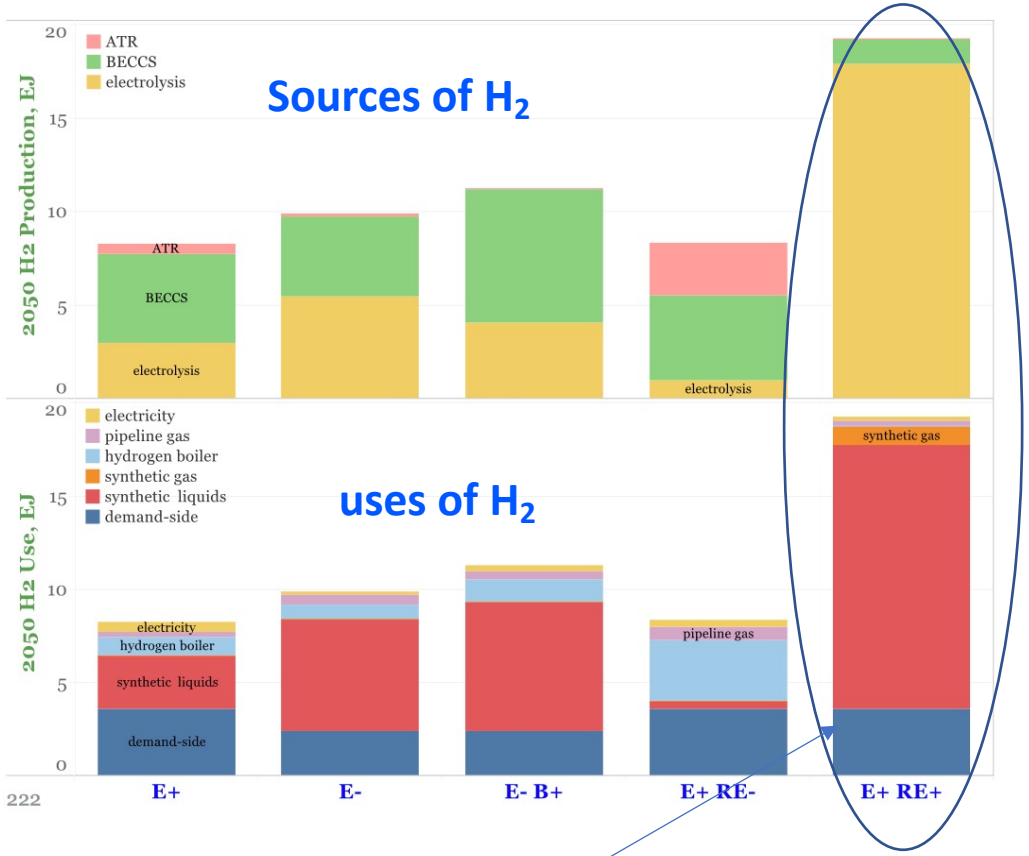
- Achievable electrification of end-use technologies

2. Impacts of CO_2 emissions –*decline 75% of 2005 levels*

3. Need combined decarbonization and electrification

An Electrified Future — By Trieu Mai, Daniel Steinberg, Jeffrey Logan, David Bielen, Kelly Eurek, and Colin McMillan — IEEE 2018

Significant amount of wind and solar required for any viable Net-zero scenarios -cost <6% GDP



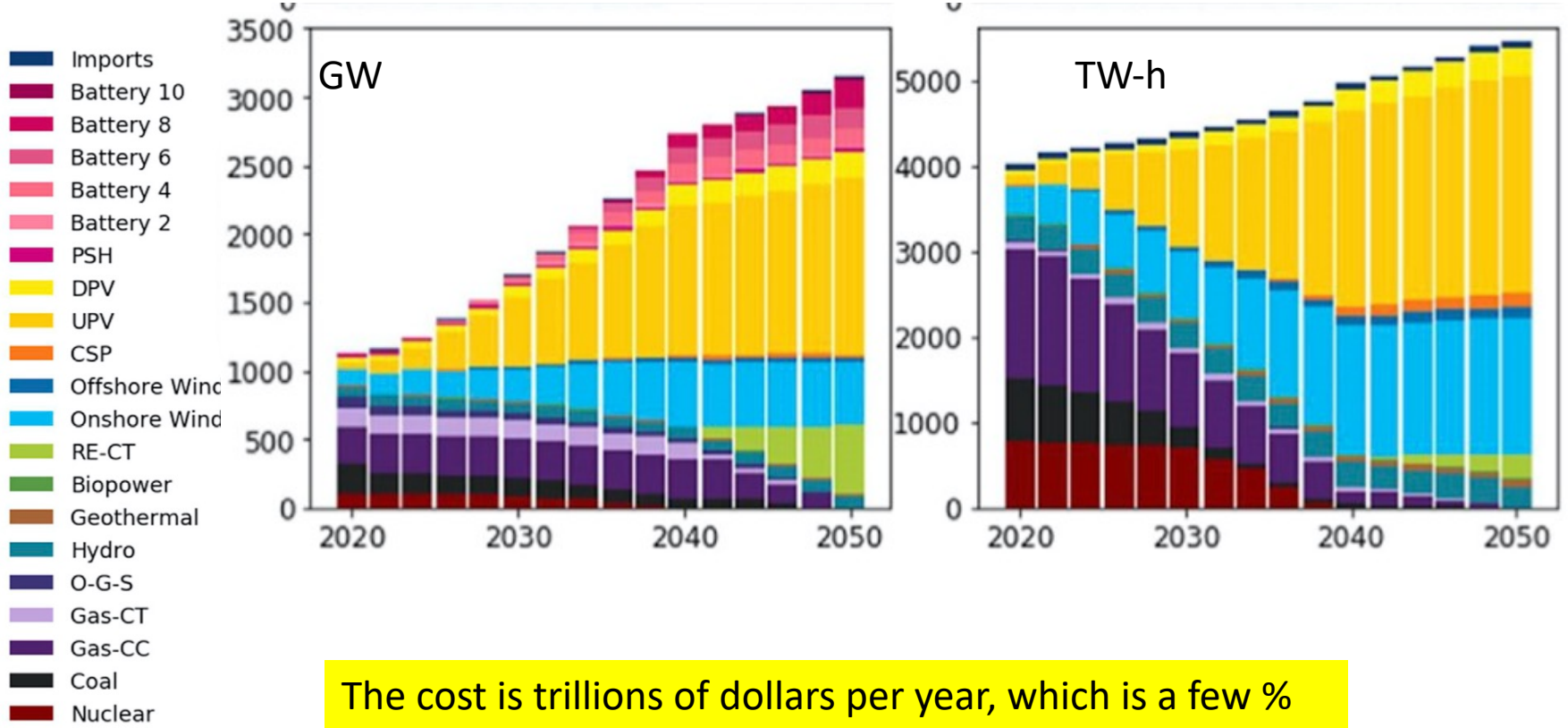
Net-zero goals:
Costs <6% GDP

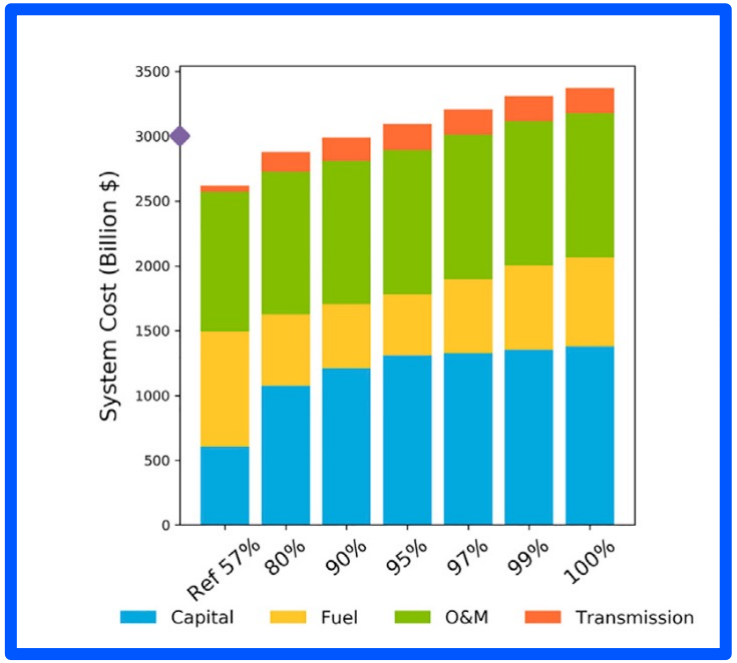
Power generation:
renewables, including hydro.
Nuclear
Natural gas,
natural gas + CCU/CCS
coal, biomass + CCU

Electrolysis: H_2 production is significant

-(98% for E+ RE+ by 2050)

100% Renewable Power: what would it cost?





The cost is trillions of dollars per year, which is a few % of the GDP

Joule

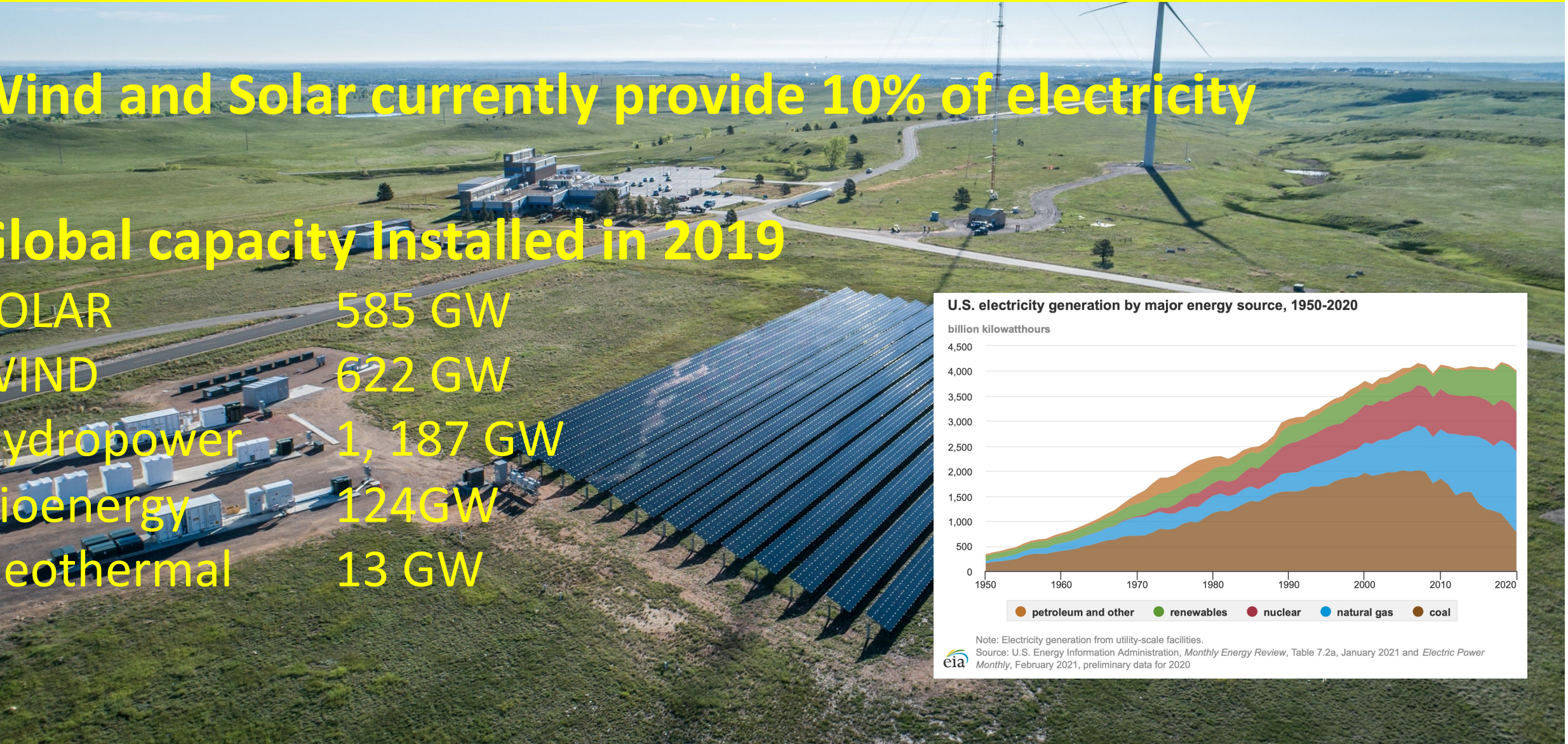
CellPress

Article

Quantifying the challenge of reaching a 100% renewable energy power system for the United States

RENEWABLE POWER GENERATION

SOLAR, WIND, GEOTHERMAL, WATER POWER



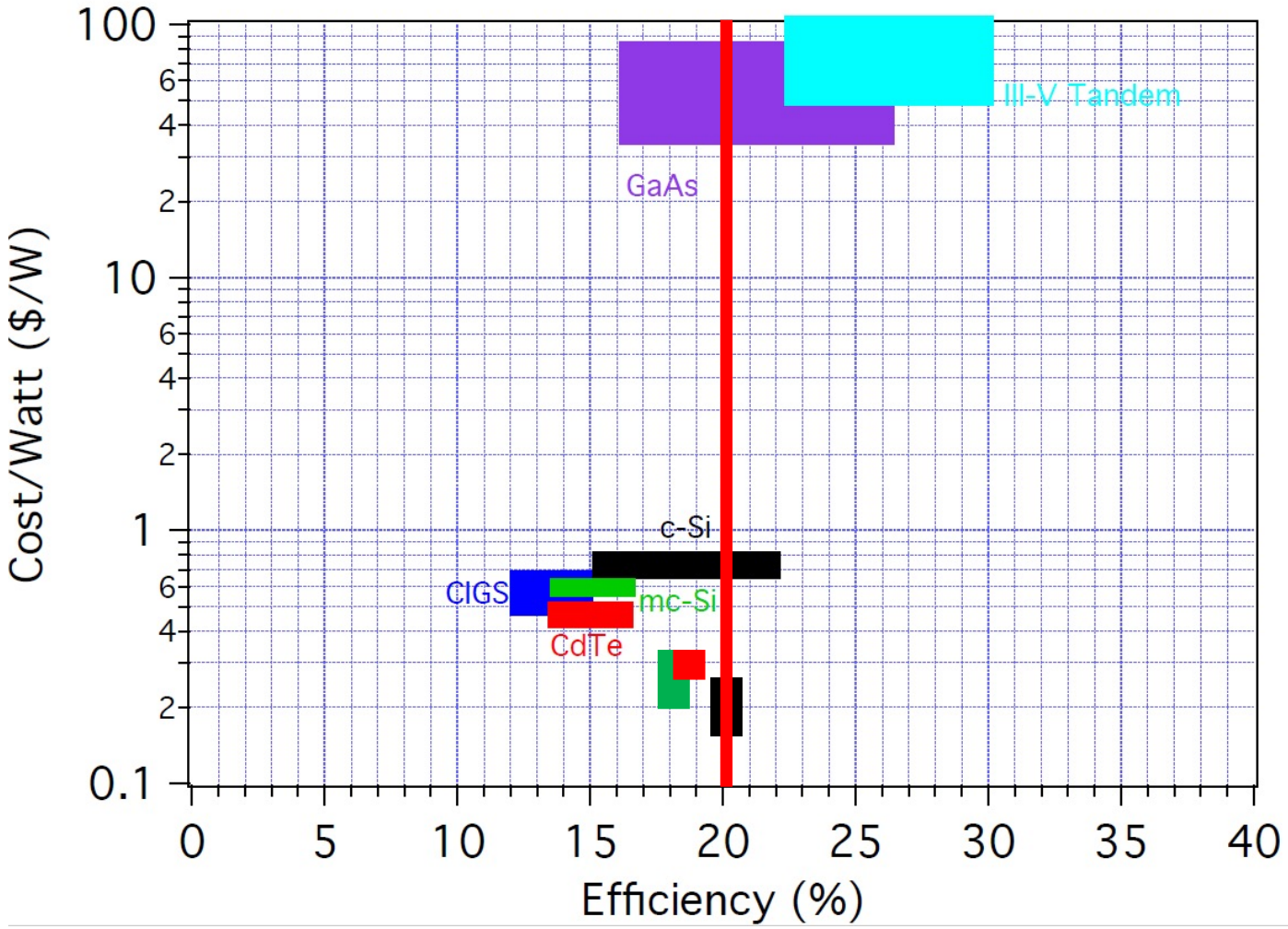
Wind and Solar currently provide 10% of electricity

Global capacity Installed in 2019

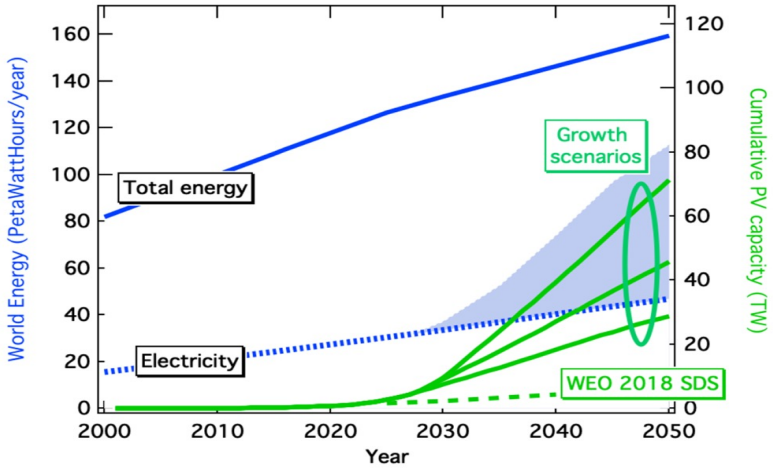
OLAR	585 GW
VIND	622 GW
ydropower	1, 187 GW
ioenergy	124GW
eothermal	13 GW

Efficiency up, costs down in major markets

Original data 2015



2019 US installations
20-80% ranges

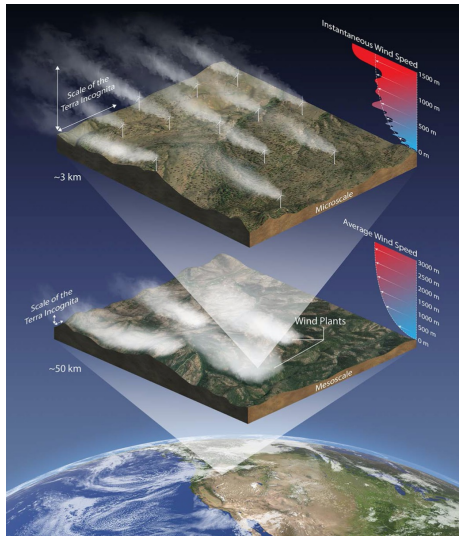


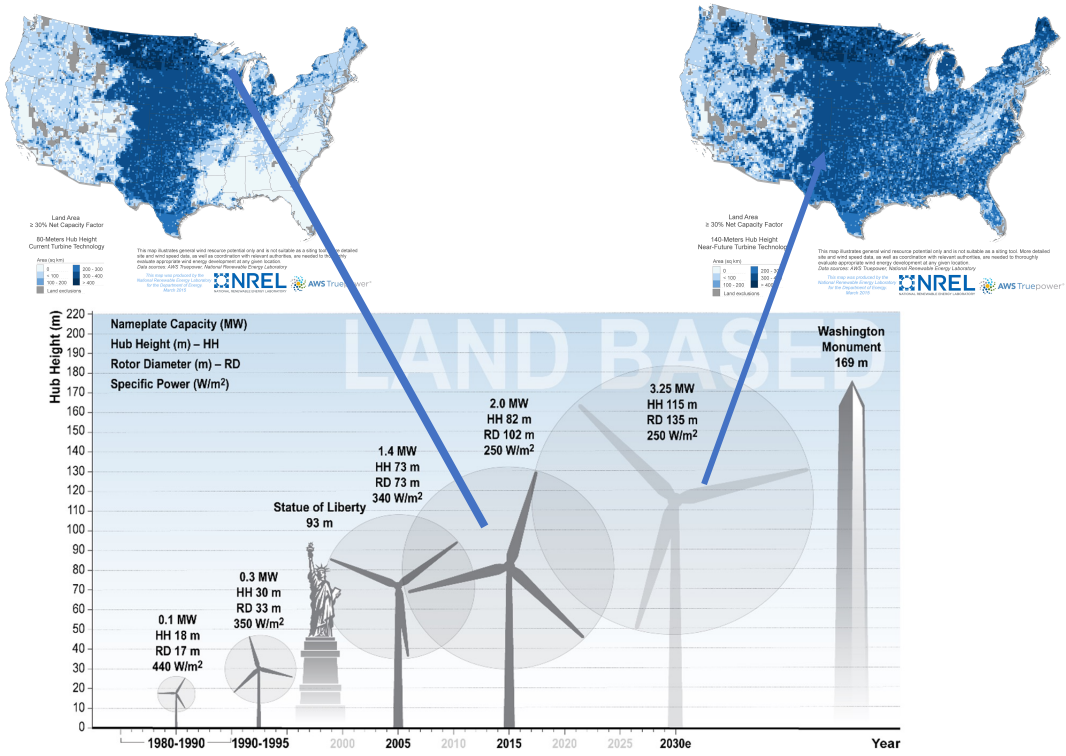
RENEWABLE ENERGY

Terawatt-scale photovoltaics: Transform global energy

Improving costs and scale reflect looming opportunities

Science **356**, 141 (2017) and Science **364**, 6443 (2019)





How can wind energy meet future demands?

- **Grand challenges**
  - Optimizing wind farm power production: New physics associated with atmospheric resource and wind plant flow
  - Off-shore wind power: aerodynamics, structural dynamics and fluid dynamics
  - Grid integration

- **Current goal:** Simens-Gamesa 14 MW wind turbine 222 ft. rotor (Denmark F'24)

Science REVIEWS

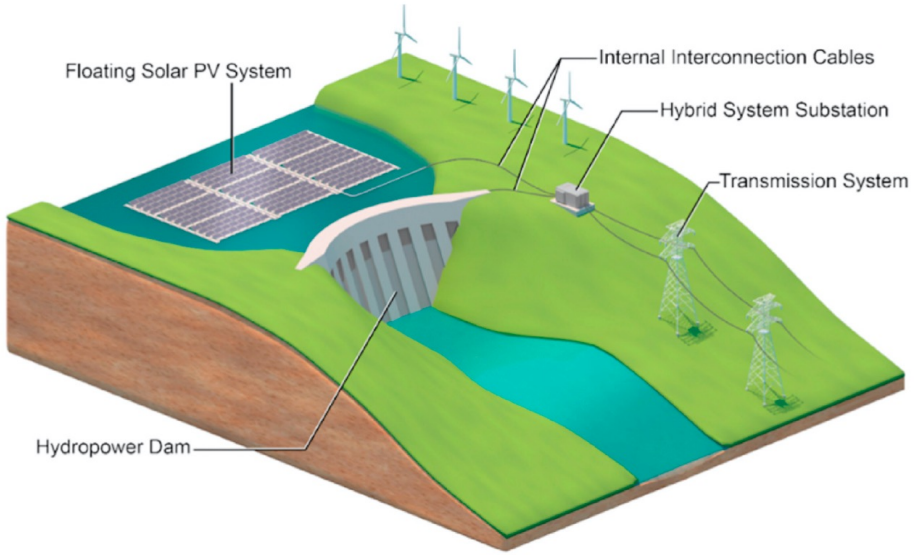
Cite as: P. Veers *et al.*, *Science* 10.1126/science.aau2027 (2019).

Grand challenges in the science of wind energy

Hybrid Energy Systems: storage + generation…

- Coupling power generation systems with storage systems has numerous advantages: power production, efficiencies, cost…

  - **Wind and Hydrogen Project**
  - **Hybrid Floating photovoltaic +hydropower**
  - **Solar PV+ battery storage systems**



Renewable Energy, 2020,

Elements of the Challenge

- ***New technologies/industries, with manufacturing infrastructure needed***

- Hydrogen at scale –(infrastructure, cost, *electrolysis)*

- Direct Air Capture S&T
- Natural gas (+CCU+CCS)
- Transmission lines and infrastructure
- …

- Power electronics
- Cybersecurity
- New ML/AL algorithm development
- Energy storage (batteries, compressed air…)
- Hybrid energy Systems
- Solar, wind, geothermal (new and advanced)
- Nuclear (fission and fusion)
- New Materials compositions (AI/ML directed)

Scale-Cost-Pace is unlike anything mankind has encountered…"the bill is now due"

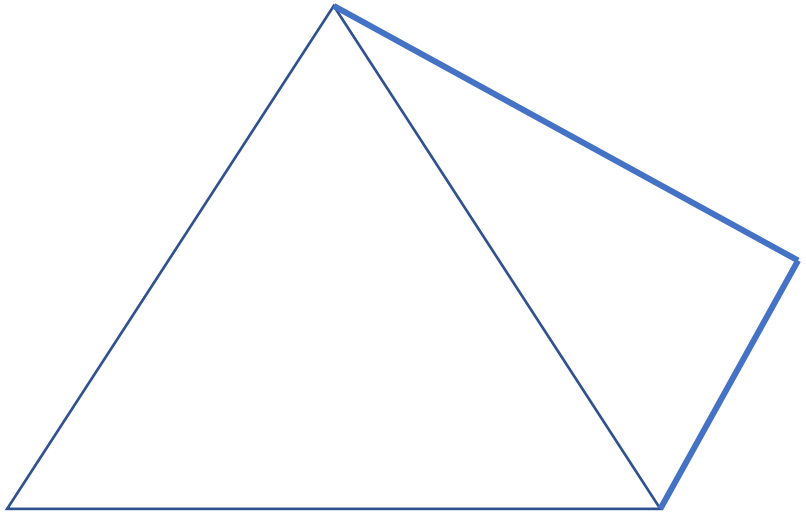
Who bears the costs? What are the time scales of spending and how can they be accelerated?

Opportunities and Challenges

Jobs, social acceptance (varies by location), consumer preferences, environmental justice (can't solve the problem without understanding is in its entirety), cost (local and global)

Achieving the goals will be a highly collaborative process

S&T Advances
National Labs, Industry, Academia



Investment decisions
a. Corporate
b. Private Equity
c. Financial markets/Banks
d. Government

Adoption
a. Consumer
b. Markets
c. Social
d. economics

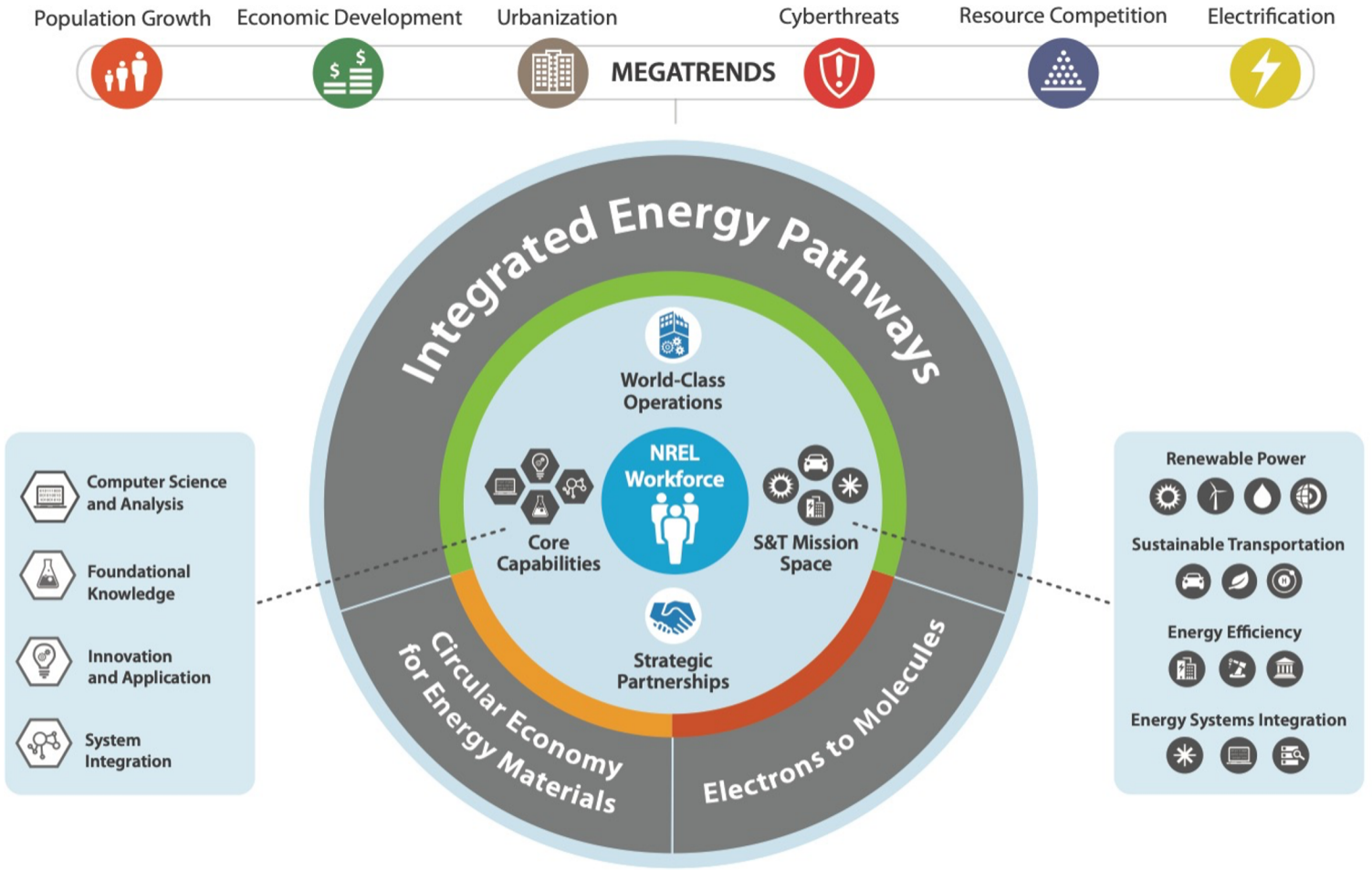
Policy
Government

- Numerous pathways can be followed to achieve the goals
- Each pathway may involve a different mode of interaction between diverse entities
- What new public/private/partnerships mechanisms should be developed?


Thank you

NREL's 10-Year Plan: A Vision for the Future

NREL has Over 900 partners



CRITICAL OBJECTIVES

Circular Economy for Energy Materials

Circularity for Polymers and Composites
Advanced Energy Materials and Technologies
Future Adaptive Materials for Energy Systems

Integrated Energy Pathways

Generation, Storage, and Integration
System Security and Resilience
Advanced Mobility

Electrons to Molecules at NREL

Hybrid Approaches to CO_2 Reduction and Electrons to Molecules at NREL
Reactive Carbon Capture and Conversion
Novel Electricity-Driven Processes for Industrial Manufacturing

Current Programs are necessary, but not sufficient for the Challenge

INDIVIDUAL TECHNOLOGY BASED PROGRAMS

a. Energy ICORP
b. Tech. Com. Fund (TCF)
c. DOE Loan program
d. FOAs
e. Multi-lab/Industry/academia (e.g.; DuraMAT)
f. Initiatives (e.g.: Grid Modernization Initiative)

NREL

a. Wells Fargo innovation Incubator (IN2)

b. Shell Game Changer

c. Global power system transformation (G-PST) consortium –system operators and partners from around the world

Final Comments

I. Progress toward addressing the challenge: current status

Must increase the breadth of the strategy, the scale of the activities, accelerate progress, more reliable funding and permitting mechanisms

II. Many viable pathways, each involving *electrification and energy storage*

Dictated by competing factors: Science/technology/innovation/ manufacturing, policy, sociological preferences, environmental/health, economics, funding (government, corporate, private equity)

III. DOE has a variety of partnering mechanisms that have been very effective over the years. Some will have to be revised to ensure that they can meet the administration's goals