OAK RIDGE National Laboratory

Driving disruptive innovation for a more sustainable energy future

Robert M. Wagner
Oak Ridge National Laboratory
wagnerrm@ornl.gov

October 24, 2023

This meeting was founded to connect international thought leaders from diverse disciplines across industry, universities, national laboratories, and the government to drive the conversation on accelerating a more sustainable energy future

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

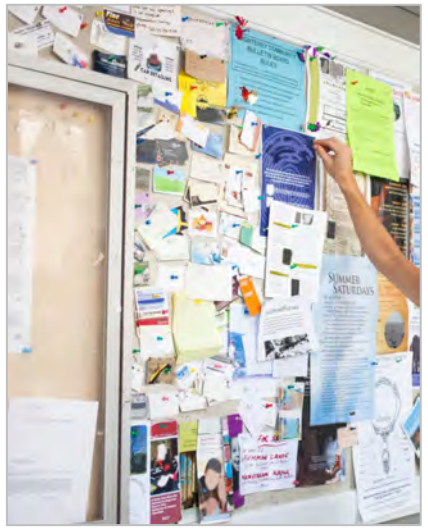
Acknowledgements

Thank you to many for valuable discussions, advice, and/or sharing of information that helped shape this presentation

- **Vivek Sujan, Scott Curran, Ron Graves, Rich Davies,** and **Josh Pihl**
  Oak Ridge National Laboratory
- **Terry Alger**
  Southwest Research Institute
- **John Farrell**
  National Renewable Energy Laboratory
- **Venkat Srinivasan**
  Argonne National Laboratory
- **John Eichberger**
  Transportation Energy Institute
- **And many more …**

A lot can happen in 30 years …. disruptive innovations have changed our way of life

Reflecting on the state of technology when I arrived at ORNL as an undergraduate student



Internship opportunity posted on a school bulletin board

No internet

All correspondence with ORNL was with postal service

No email

Travel from MO to East TN required planning with a road atlas

No GPS

Communication back home was on a public pay phone

No cell phone

My computer was a 386DX 33-mhz with no internet capability

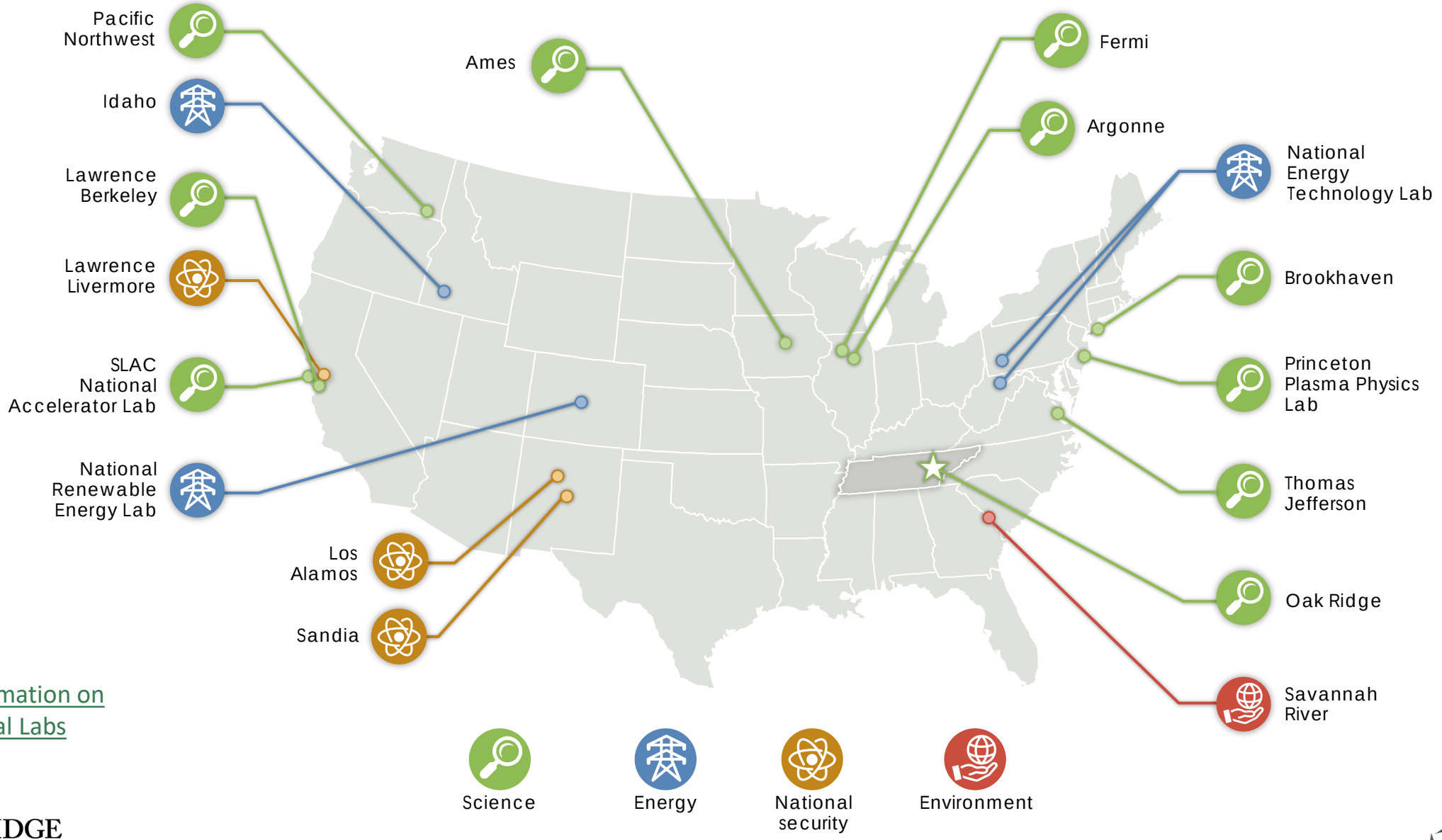
Computer was nice

What will we see in the next 30 years?

OAK RIDGE National Laboratory

SMOKY MOUNTAINS

My perspective is from a career with the national laboratories



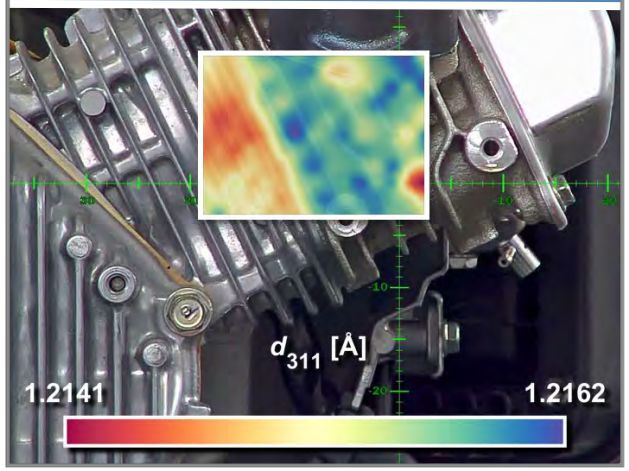
More information on the National Labs

OAK RIDGE National Laboratory

SMOKY MOUNTAINS

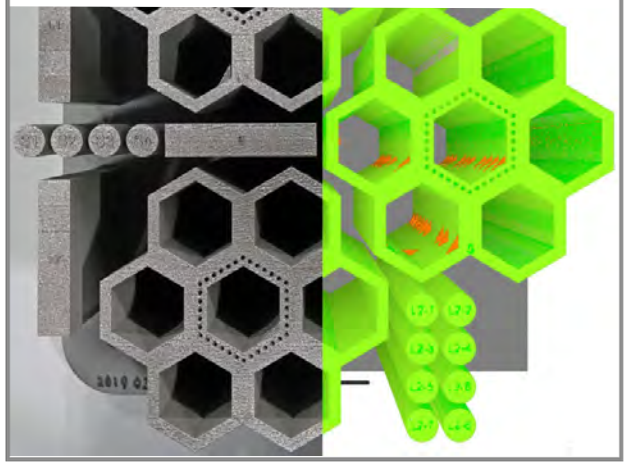
My experiences have taught me that **nothing is impossible** with a strong and passionate team from diverse fields

See the unseeable



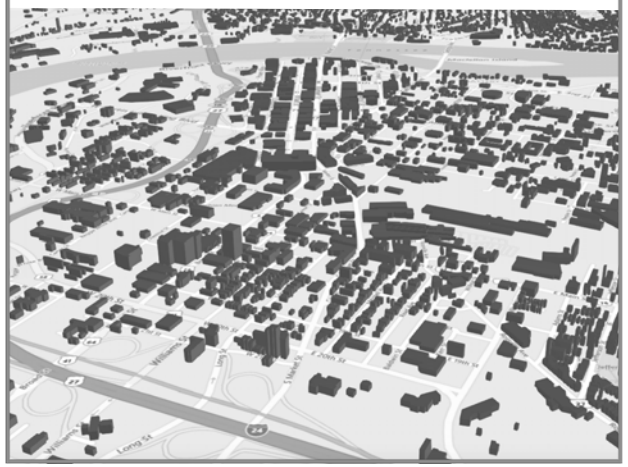
Example. **Neutrons** for temporal and spatial measurements in a running engine

Build the unbuildable



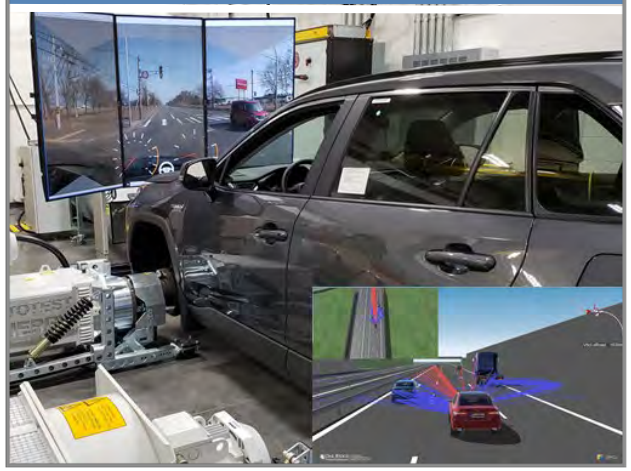
Example. **3D printing** of materials for harsh environments to accelerate design innovations

Solve the unsolvable



Example. **Super computers** to calculate energy usage of every building in the U.S.

Control the uncontrollable



Example. **Artificial intelligence** to control autonomous vehicles and complex systems

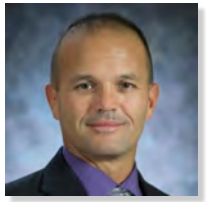
OAK RIDGE National Laboratory

SMOKY MOUNTAINS

What does it mean to be sustainable?

A challenge is that *sustainability* means different things to different people with different interests, knowledge, and agendas

2023 SMMC Speakers and Panelists


Dr. Terry Alger


Dr. Inalvis Alvarez


Hugh Blaxill

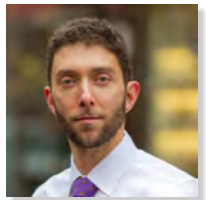

Dr. Zoran Filipi


Dr. Tim Frazier


Richard Hampo


Dr. Joe Hoagland


Harry Husted


Ari Kahn


Kurt Niebuhr


Dr. Sreekanth Pannala


Daniel Pickett


Jeff Purdy


Dr. Giorgio Rizzoni


Ann Rundle


Reuben Sarkar


Dr. Bulent Sarlioglu

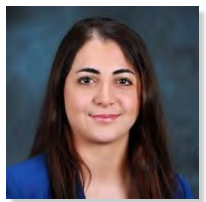

Dr. Mina Sartipi


Alex Schroeder


Dr. Brad Taylor


Dr. Robert Wagner


Kirk Waltz


Helia Zandi


Alexis Zubrow

Sustainability is important for energy security and independence

President Carter created the Department of Energy [1977] with the goal of promoting energy conservation and developing alternative sources of energy. He wanted to not be dependent on foreign oil and reduce the use of fossil fuels.

Source: Wikipedia, United States Department of Energy

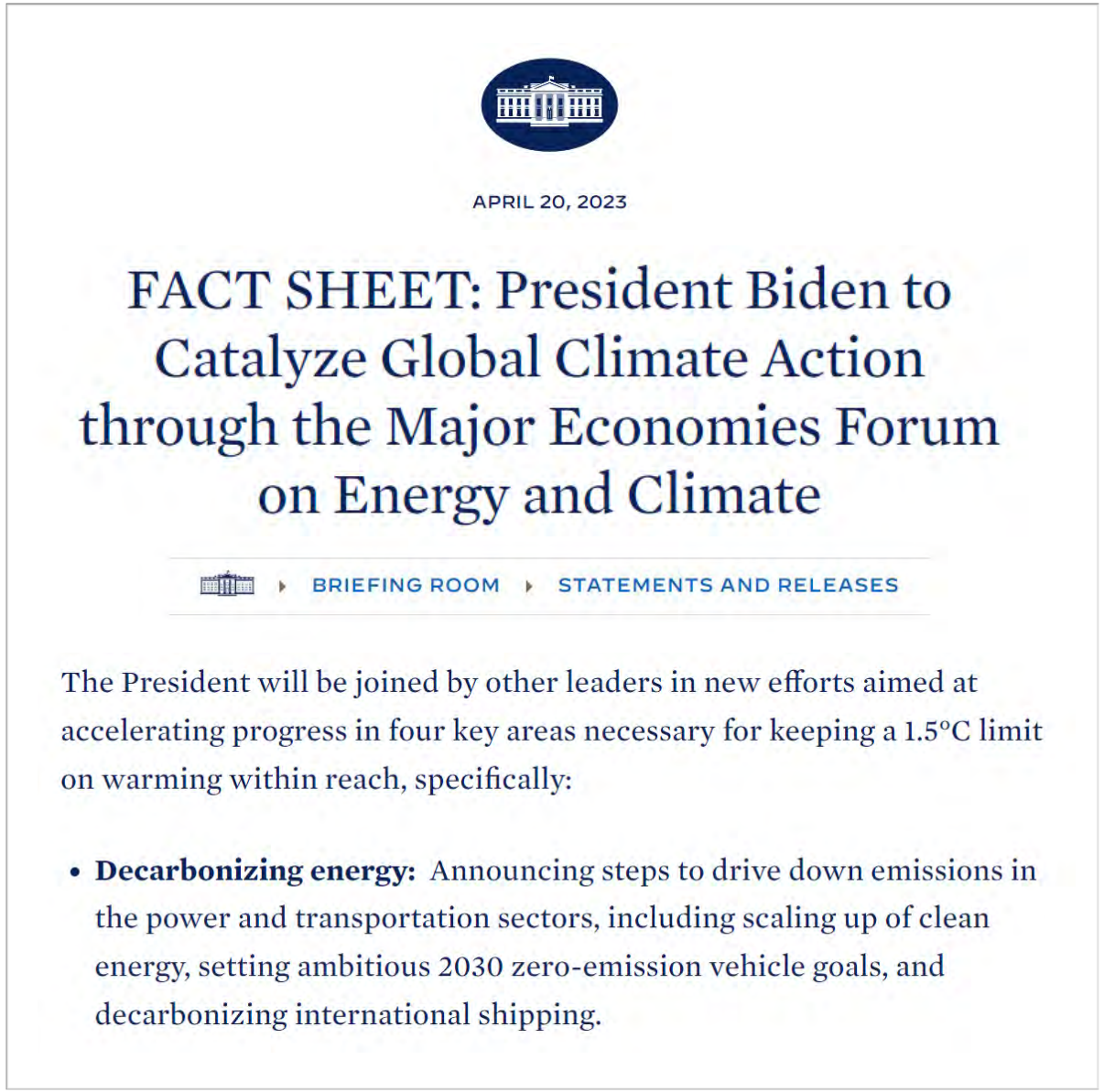
We are now able to focus more on long-term energy sustainability, and renewables further add to our energy security and independence

Market acceptance needed to accelerate a sustainable future

> "… make sure to define sustainability as more than just low CO2 – we need sustainable profits for companies, satisfying products at reasonable prices for sustainable sales, etc. – if we are going to make this work in the long term."
>
> – Dr. Terry Alger
> Executive Director, Sustainable Energy and Mobility Directorate
> Southwest Research Institute

From a personal email exchange with Dr. Terry Alger on June 8, 2023

There has been a push for global climate action as being critical to a more sustainable future



APRIL 20, 2023

FACT SHEET: President Biden to Catalyze Global Climate Action through the Major Economies Forum on Energy and Climate

BRIEFING ROOM ▸ STATEMENTS AND RELEASES

The President will be joined by other leaders in new efforts aimed at accelerating progress in four key areas necessary for keeping a 1.5°C limit on warming within reach, specifically:

- **Decarbonizing energy:** Announcing steps to drive down emissions in the power and transportation sectors, including scaling up of clean energy, setting ambitious 2030 zero-emission vehicle goals, and decarbonizing international shipping.

Excerpt from the Fact Sheet which is available here

This push has led to much discussion, debate, and regulation …


REUTERS®

Environment

Lead EU lawmaker pushes zero-CO2 trucks target for 2040

By **Kate Abnett**

June 21, 2023 1:09 PM EDT · Updated 2 months ago


FROM politico PRO

It's 100 percent or bust for efforts to cut EU truck emissions

The Commission's plan to revisit truck CO2 standards has set off a frenzy of lobbying.


THE WALL STREET JOURNAL.

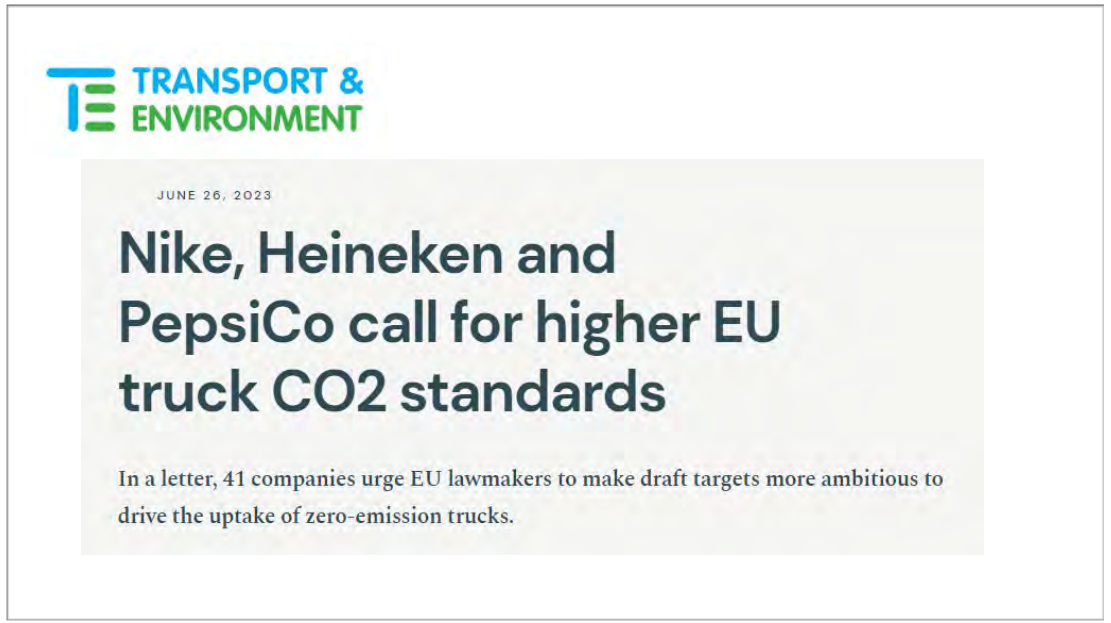
BUSINESS | ENERGY | JOURNAL REPORTS: ENERGY

Commercial Trucks Are a Key Part of EV Adoption. What's Holding Them Back?

Battery-powered trucks face hurdles that electric cars don't. Among them: They can cost more than three times as much as a similar diesel model

By Bart Ziegler

July 23, 2023 10:00 am ET


TRANSPORT & ENVIRONMENT

JUNE 26, 2023

Nike, Heineken and PepsiCo call for higher EU truck CO2 standards

In a letter, 41 companies urge EU lawmakers to make draft targets more ambitious to drive the uptake of zero-emission trucks.

OAK RIDGE National Laboratory

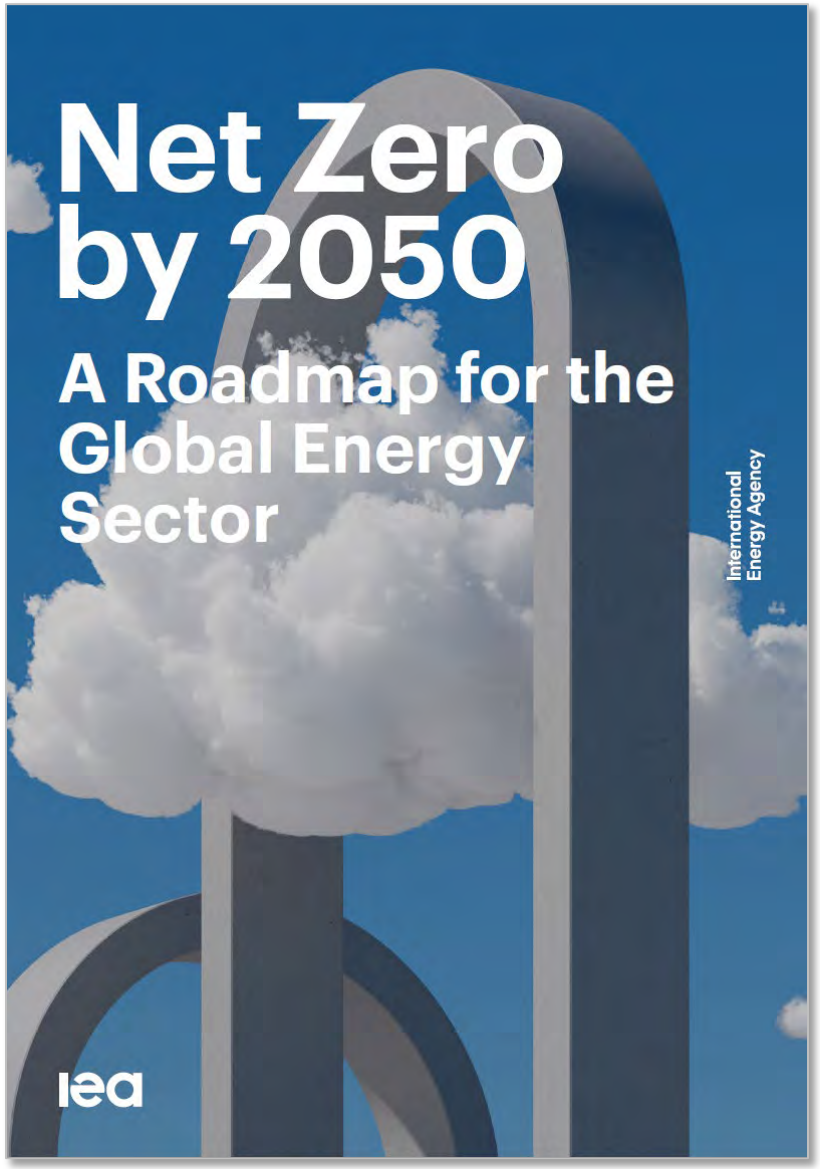
SMOKY MOUNTAINS

> Achieving net zero emissions by 2050 will require nothing short of the complete transformation of the global energy system

"It [electricity] will play a key role across all sectors, from transport and buildings to industry. Electricity generation will need to reach net zero emissions globally in 2040 and be well on its way to supplying almost half of total energy consumption. This will require huge increases in electricity system flexibility – such as batteries, demand response, hydrogen-based fuels, hydropower and more – to ensure reliable supplies."

International Energy Agency

Net Zero by 2050 report



OAK RIDGE National Laboratory

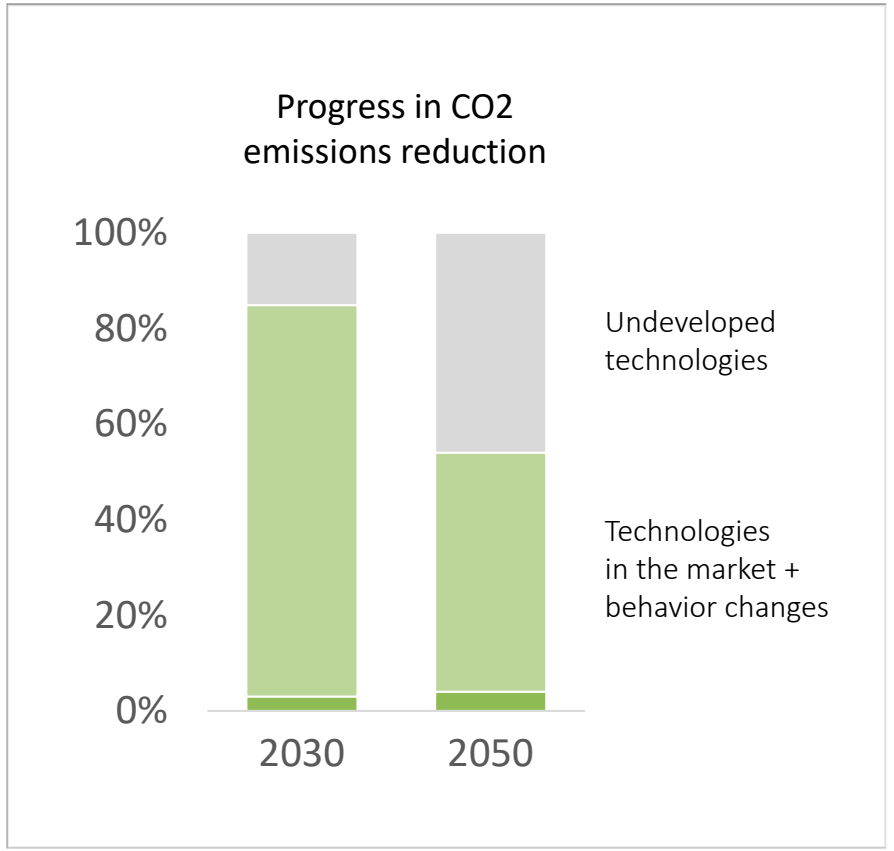
SMOKY MOUNTAINS

Many technologies needed to get us to a net-zero 2050 are undeveloped

"Most of the reductions in CO2 emissions through 2030 come from technologies already on the market today. But in 2050, almost half the reductions come from technologies that are currently at the demonstration or prototype phase. Major innovation efforts must take place this decade in order to bring these new technologies to market in time."

International Energy Agency

Net Zero by 2050 report



OAK RIDGE National Laboratory

SMOKY MOUNTAINS

An energy transition in the United States

U.S. transportation by the numbers … the scale is simply unimaginable (at least to me)

U.S. Annual **Vehicle Miles Traveled**[1] (approximate)	**3300** **Billion Miles** All on-road	**300** **Billion Miles** Commercial vehicles
U.S. Annual **Energy Consumption**[2] (approximate)	**27** **Quads** All transportation	**7** **Quads** Commercial vehicles
U.S. Annual **CO2 Emissions**[3] (approximate)	**1019** **MMmt** Motor gasoline	**457** **MMmt** Diesel

How "fast" is billions of miles per year?

How much energy is a Quad?

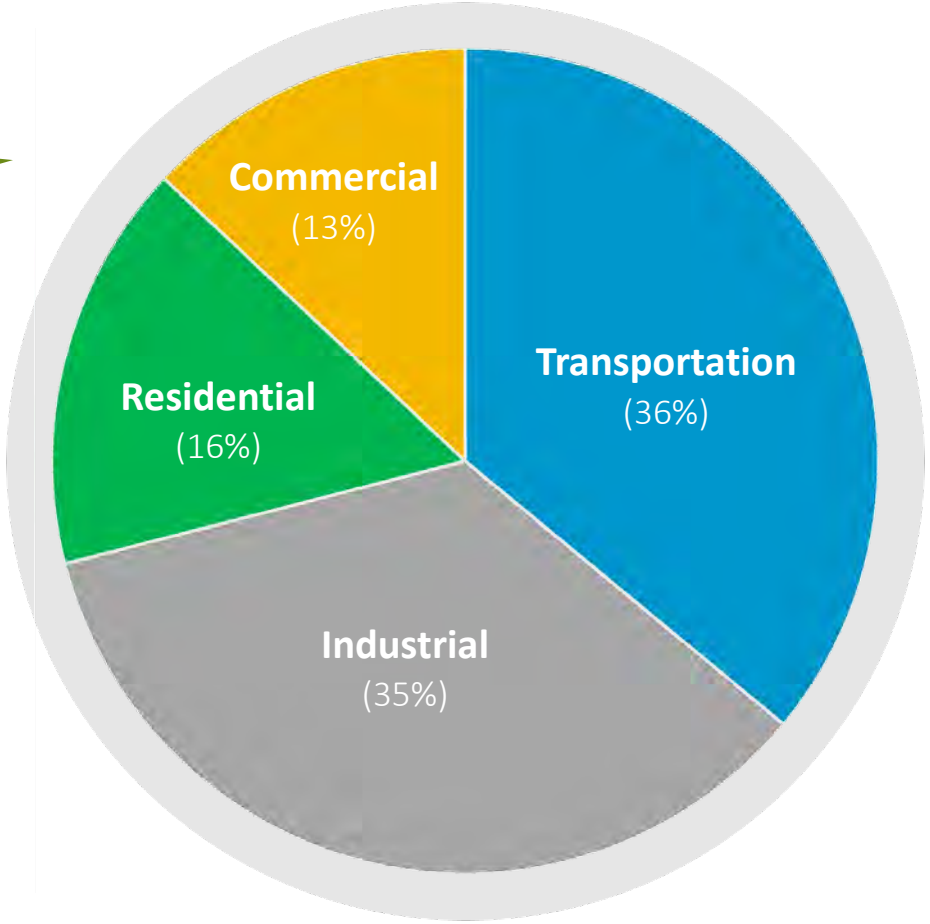
How much is a million metric tons (MMmt)?

OAK RIDGE National Laboratory

1 Bureau of Transportation Statistics, 2019 | 2 U.S. Department of Energy, 2021 | 3 U.S. Energy Information Administration, 2022

SMOKY MOUNTAINS

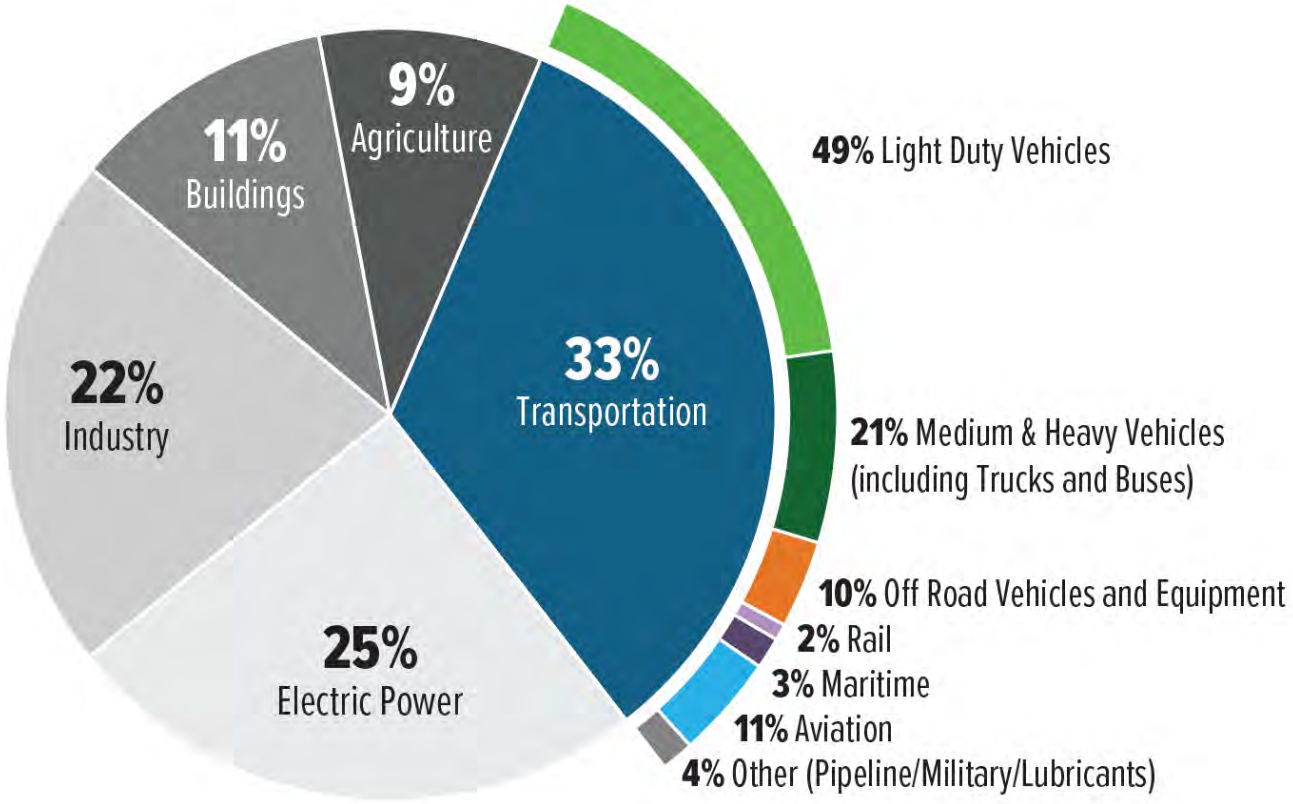
A transition requires coordination of all energy use sectors – not just transportation



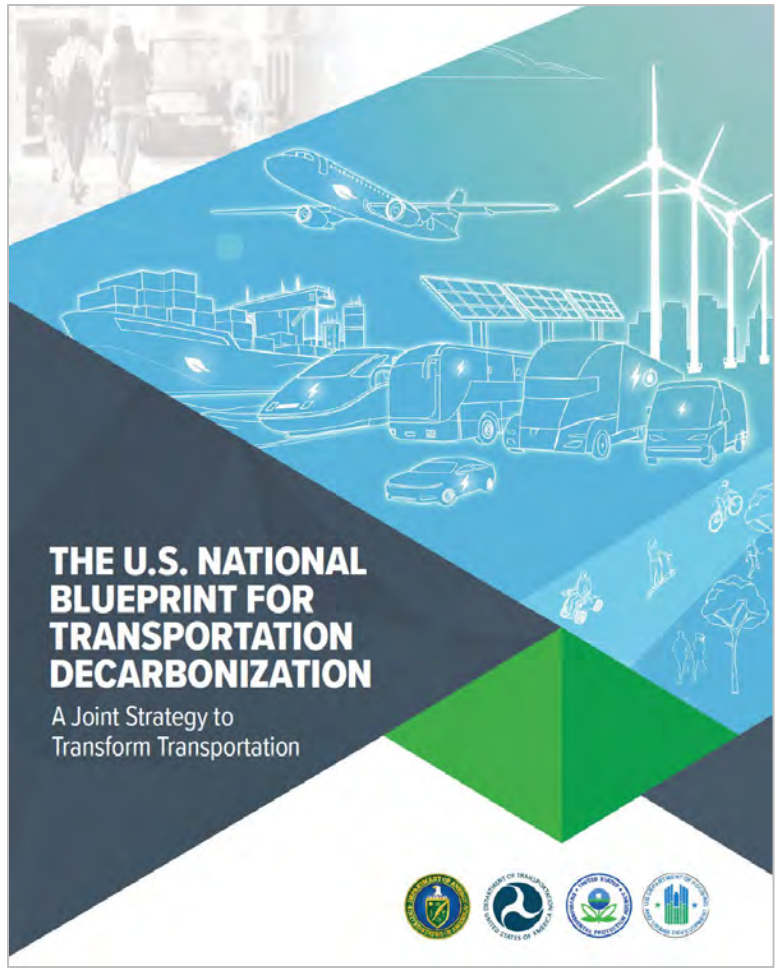
100.3 quads U.S. energy consumption in 2022

(sources LLNL and EIA)

Transportation accounts for one-third of greenhouse gas emissions in the U.S.



U.S. National Blueprint for Transportation Decarbonization



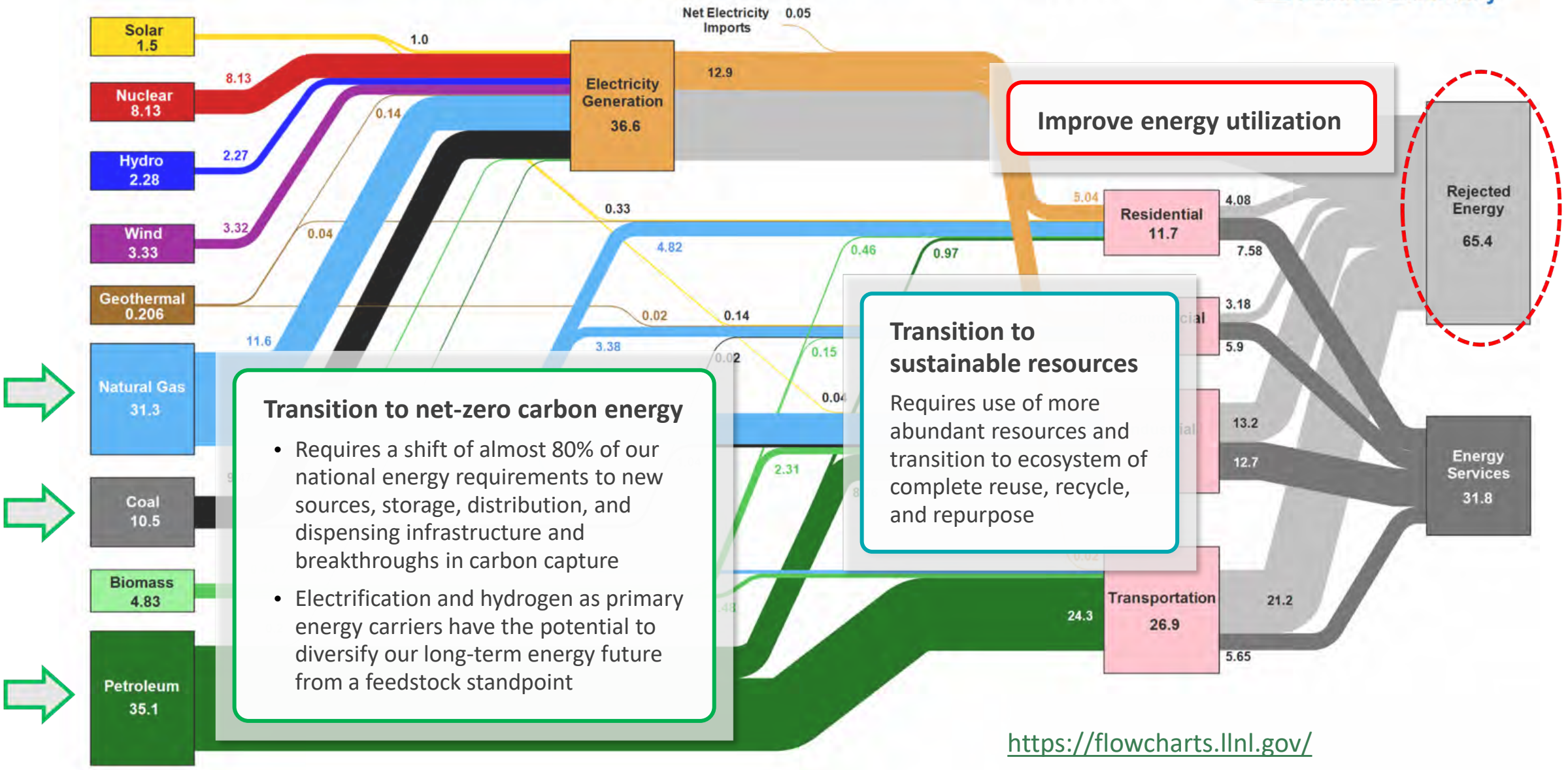
6,340 million metric tons U.S. annual CO2 emissions in 2021 (Source EPA)

OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Estimated U.S. Energy Consumption in 2021: 97.3 Quads

Lawrence Livermore National Laboratory



Improve energy utilization

Transition to net-zero carbon energy

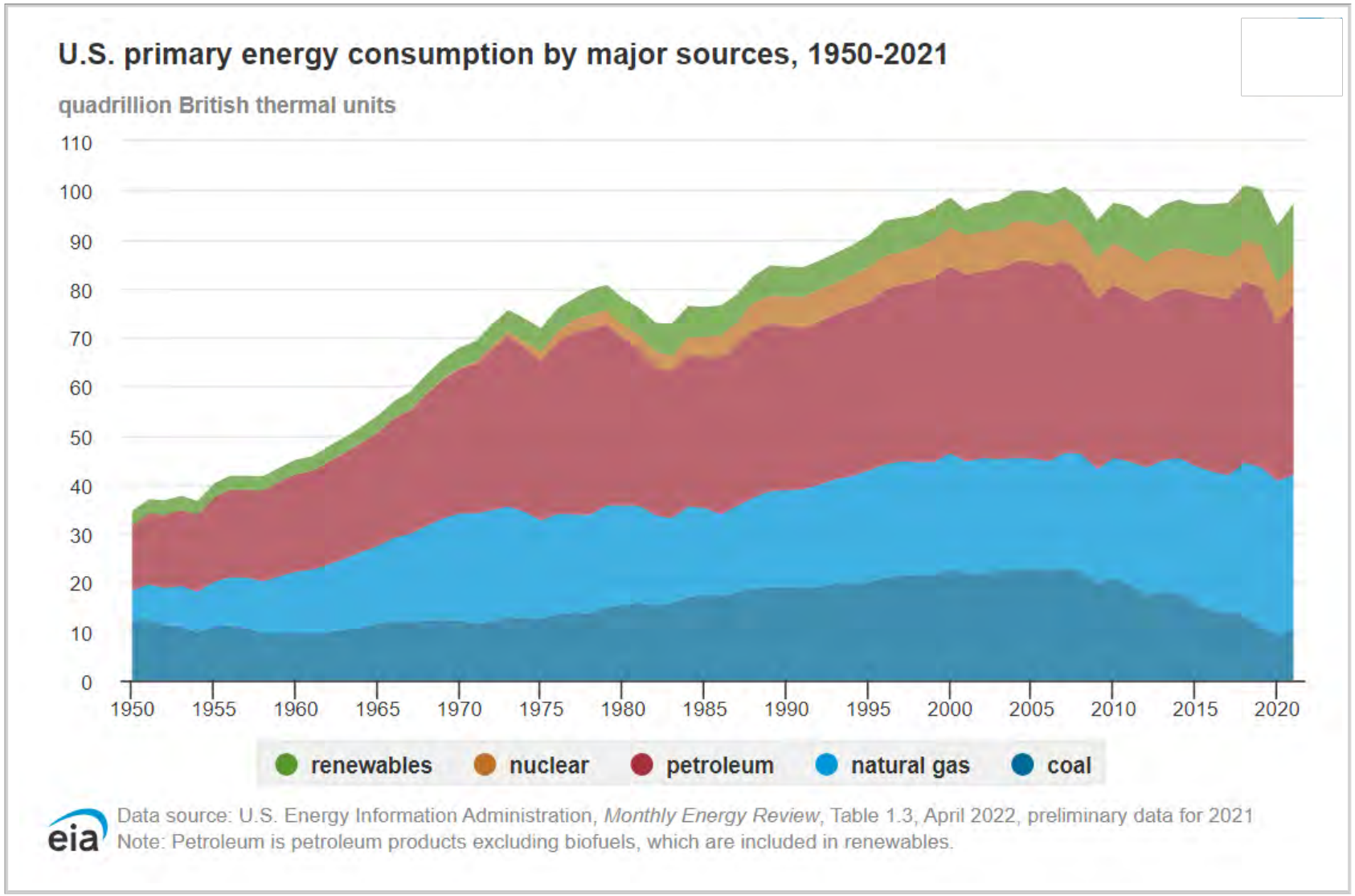
- Requires a shift of almost 80% of our national energy requirements to new sources, storage, distribution, and dispensing infrastructure and breakthroughs in carbon capture
- Electrification and hydrogen as primary energy carriers have the potential to diversify our long-term energy future from a feedstock standpoint

Transition to sustainable resources

Requires use of more abundant resources and transition to ecosystem of complete reuse, recycle, and repurpose

https://flowcharts.llnl.gov/

Renewable energy continues to increase with technology improvements



Renewable Progress
2012–2022 (quads)

Source	2012	2022
Solar	0.156	1.87
Hydro	2.63	2.32
Wind	1.34	3.85
Geothermal	0.212	0.214
Biomass	4.52	4.81
Renewables	**8.86**	**13.06**

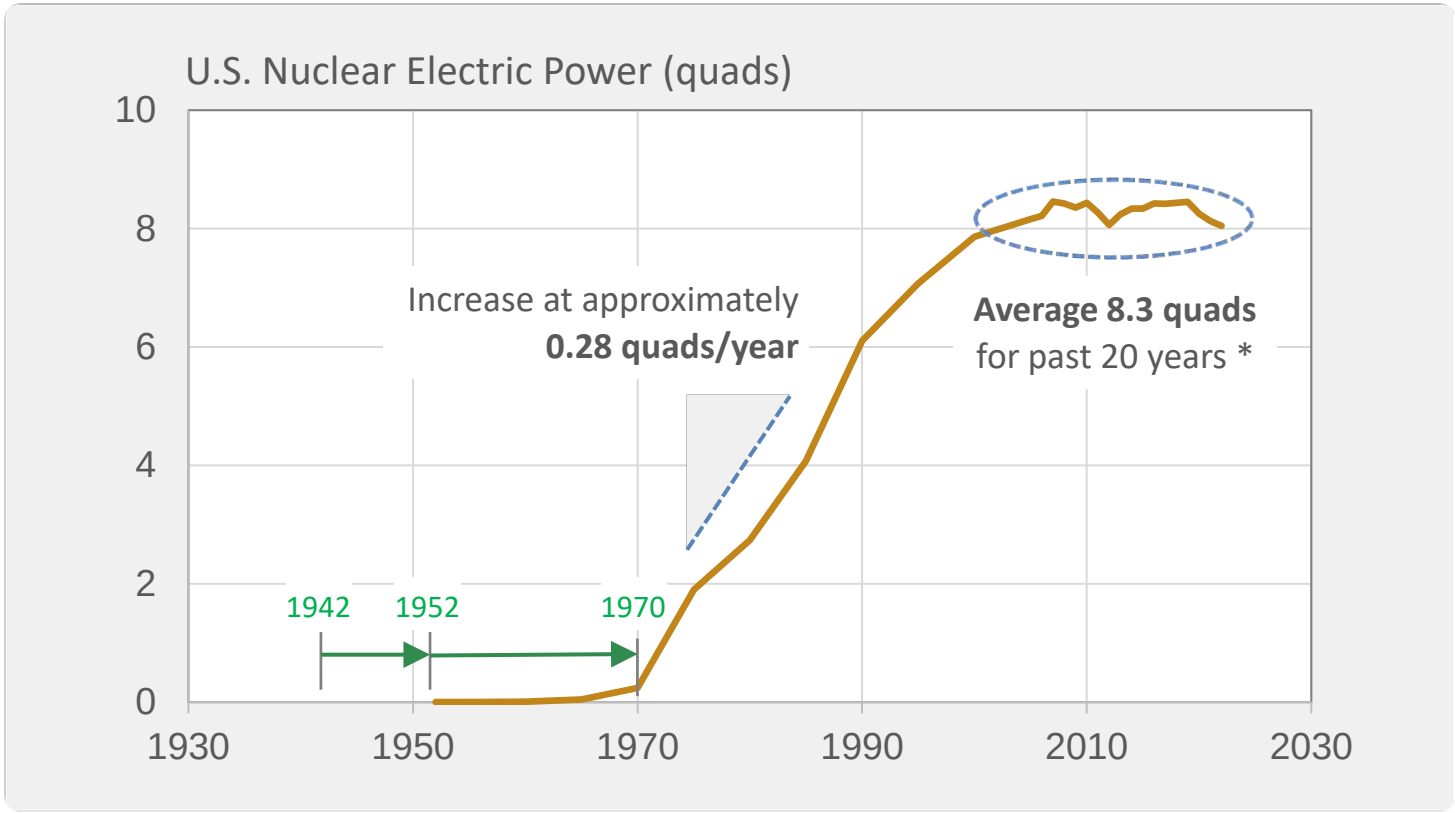
Data source: US EIA, July 2023

Multi-quad increases in solar and wind over 10 years

Overall, renewable energy increased at approximately **0.42 quads/year**

Renewable energy continues to increase with technology improvements

Renewable energy growth in last decade similar to nuclear energy growth in the 1980s



Disruptive innovation example – 10 years from the first self-sustaining, controlled nuclear chain reaction (1942) to nuclear-generated electricity on the grid (1952)

Renewable Progress
2012–2022 (quads)

Source	2012	2022
Solar	0.156	1.87
Hydro	2.63	2.32
Wind	1.34	3.85
Geothermal	0.212	0.214
Biomass	4.52	4.81
Renewables	**8.86**	**13.06**

Data source: US EIA, July 2023

Multi-quad increases in solar and wind over 10 years

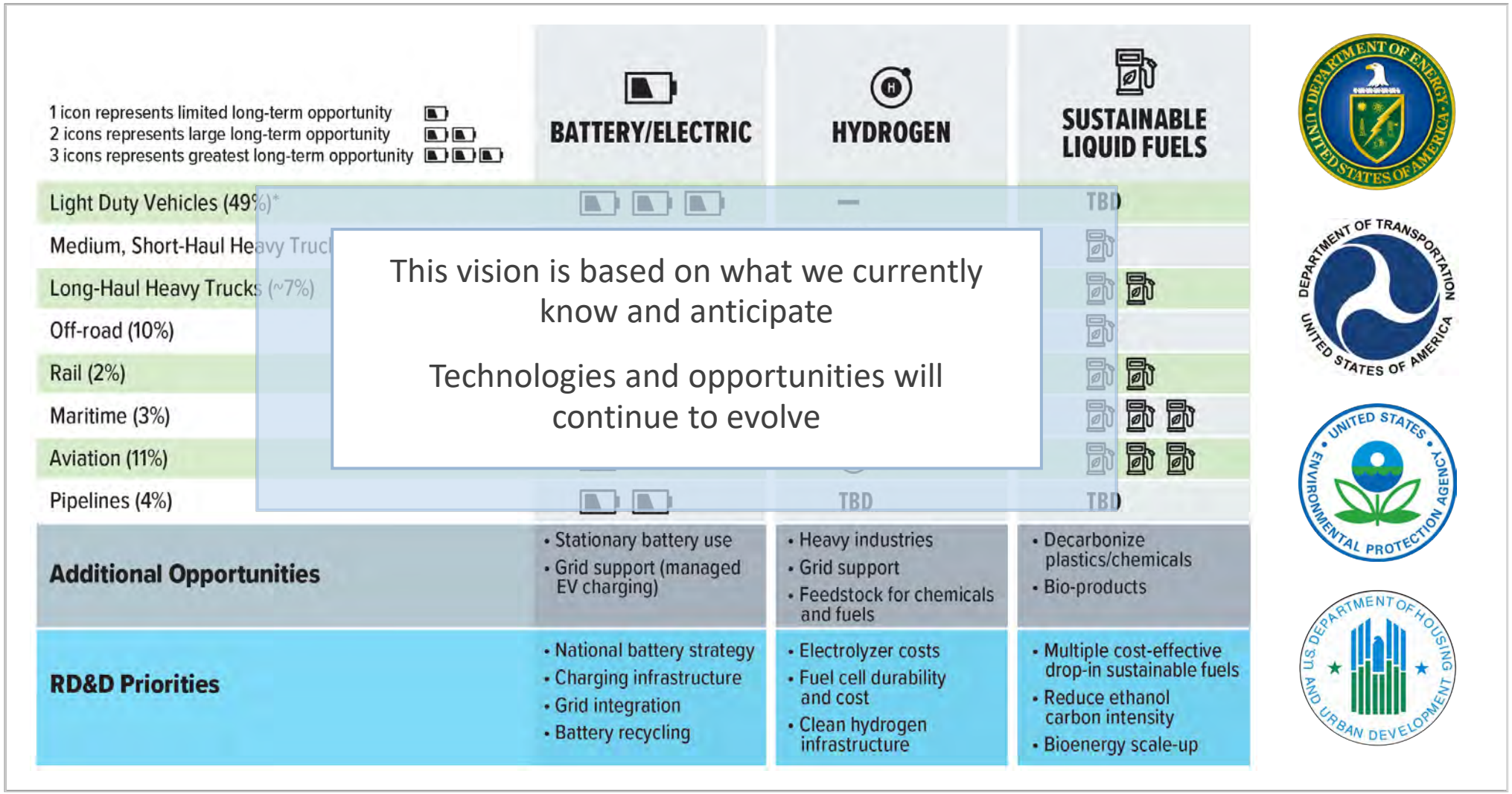
Overall, renewable energy increased at approximately **0.42 quads/year**

* Important to note that nuclear power generation did not plateau due to technical readiness limitations but other reasons which is a completely different discussion

Moving forward

Important to keep in mind that new technologies must scale for real-world impact

National Blueprint of opportunities and priorities from four federal agencies



U.S. National Blueprint for Transportation Decarbonization

OAK RIDGE National Laboratory

SMOKY MOUNTAINS

New **vehicle technologies** span electrification, hydrogen, and liquid fuels

- **Transition from well-accepted technologies** to new technologies with many unknowns will take time
- **New vehicle technologies** have new challenges and unknowns in durability, safety, and security
- **Solutions will require even more intentional collaboration** across diverse disciplines from ideation to deployment
  - For example, chemistry, material science, manufacturing, thermal science, controls, artificial intelligence, …

Image credit: Josh Bauer

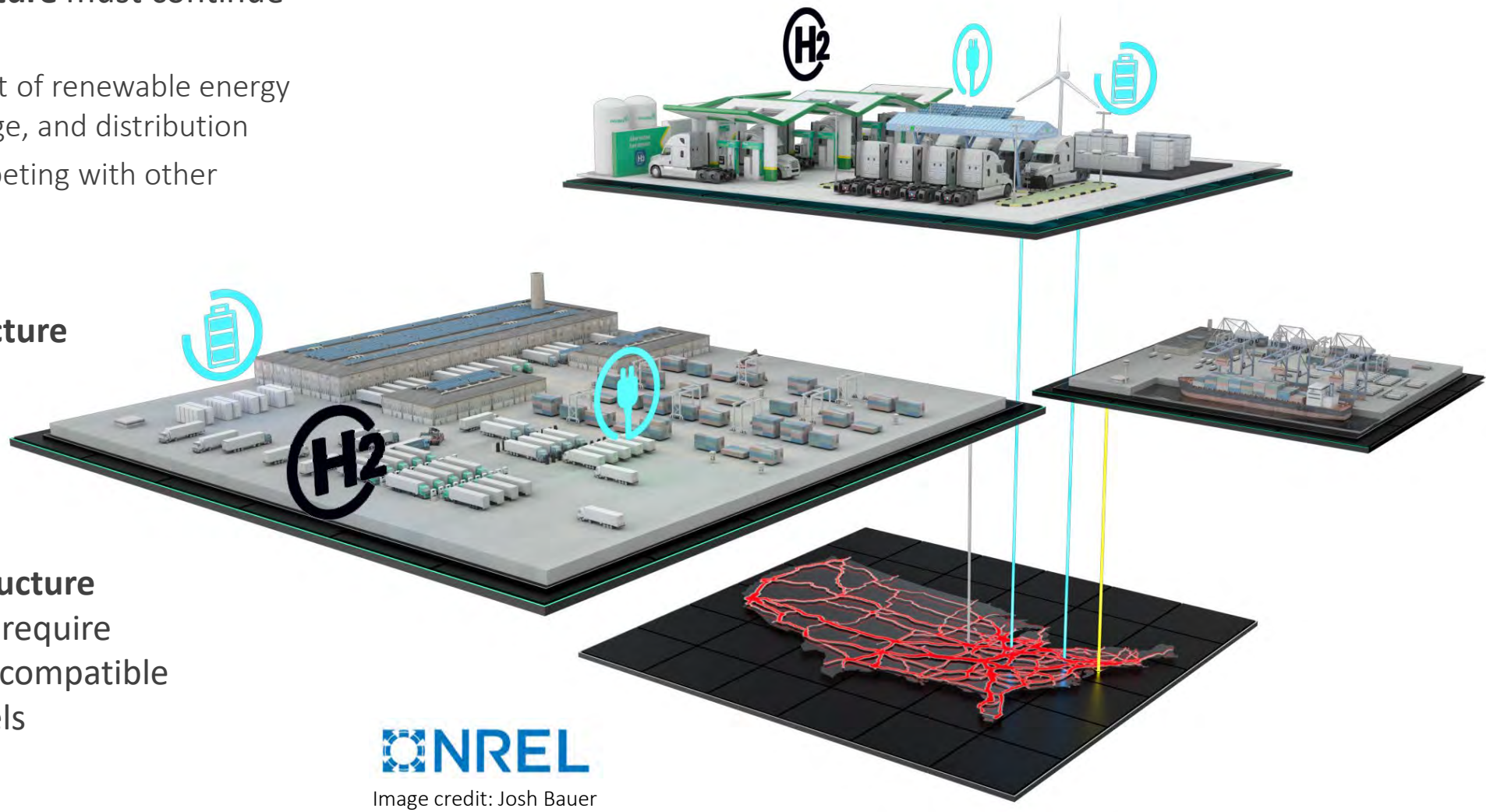
Energy infrastructure development underway for future demand of net-zero

Electrical infrastructure must continue to evolve

- Requires build-out of renewable energy generation, storage, and distribution
- Sharing and competing with other energy users

Hydrogen infrastructure is underway but build-out will take time

Liquid fuels infrastructure is extensive but will require modifications to be compatible with sustainable fuels



NREL

Image credit: Josh Bauer

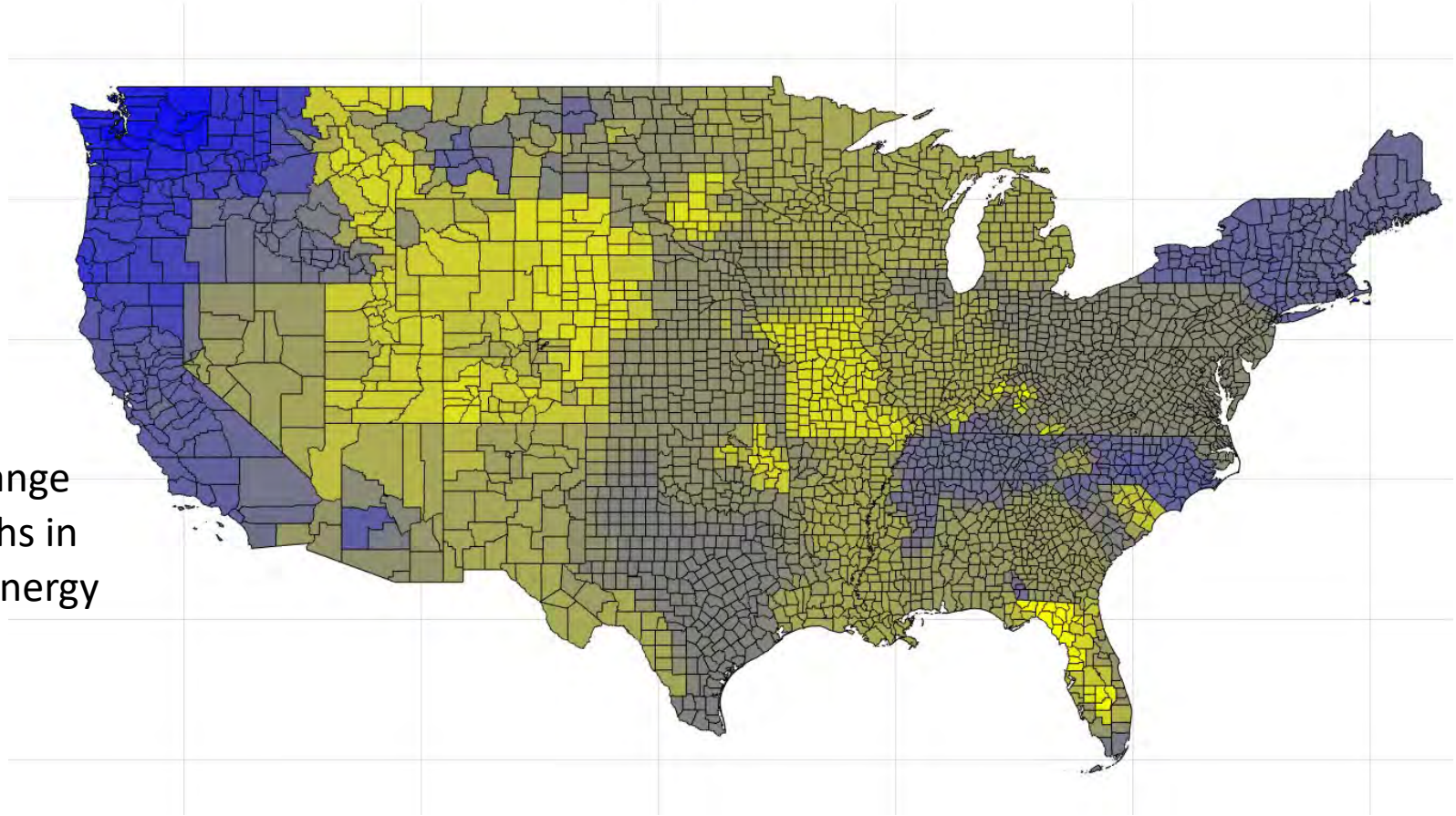
OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Significant regional variations in electricity CO2 intensity (2022)

Differences may drive near-term regional “best” technology solutions from a CO2 perspective

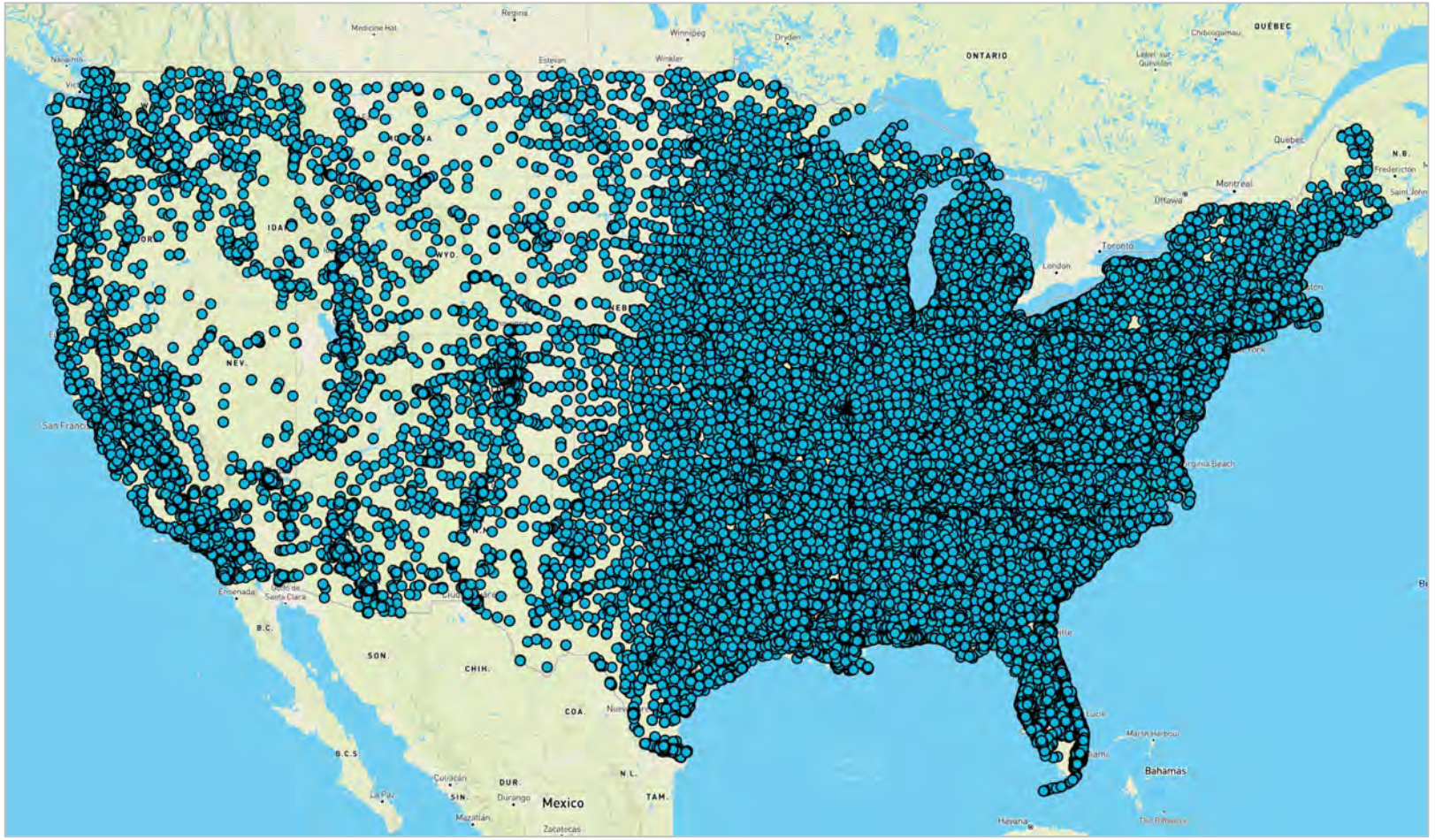
Long-term “best” solutions may change with breakthroughs in local renewable energy technologies



Source: Dr. Vivek Sujan (sujanva@ornl.gov) based on EIA open data and custom tool G-CIE (Grid Carbon Intensity Estimation)

Our current liquid fuel infrastructure is significant

CStores shown represent about 80% (NACS, TDLinks)

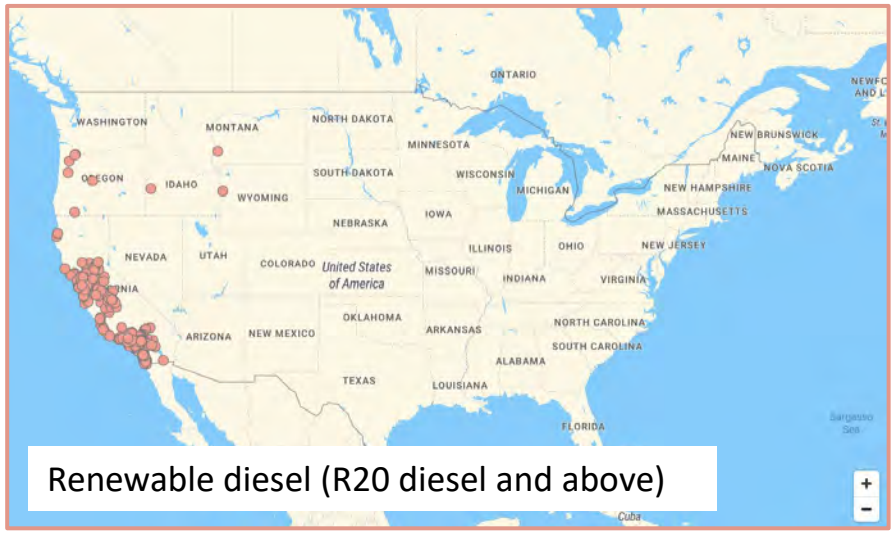


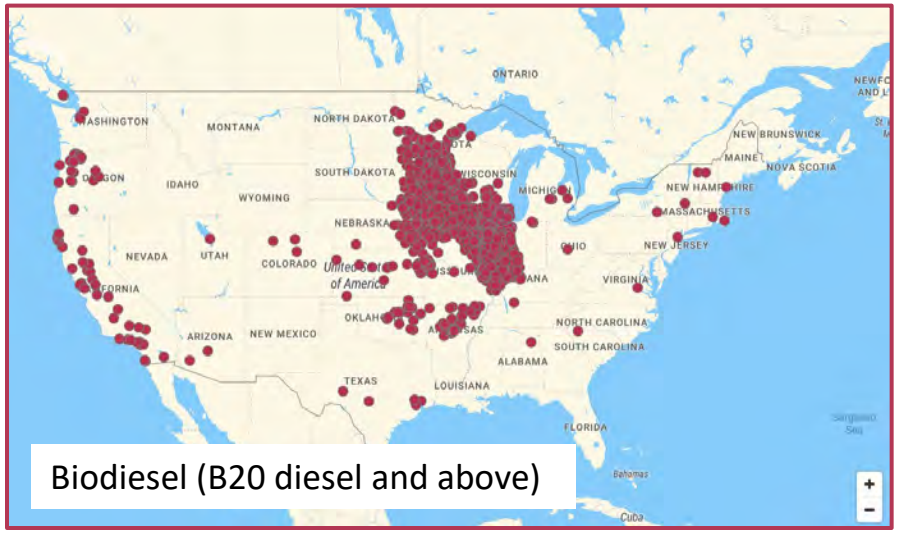
Source: John Eichberger, Transportation Energy Institute

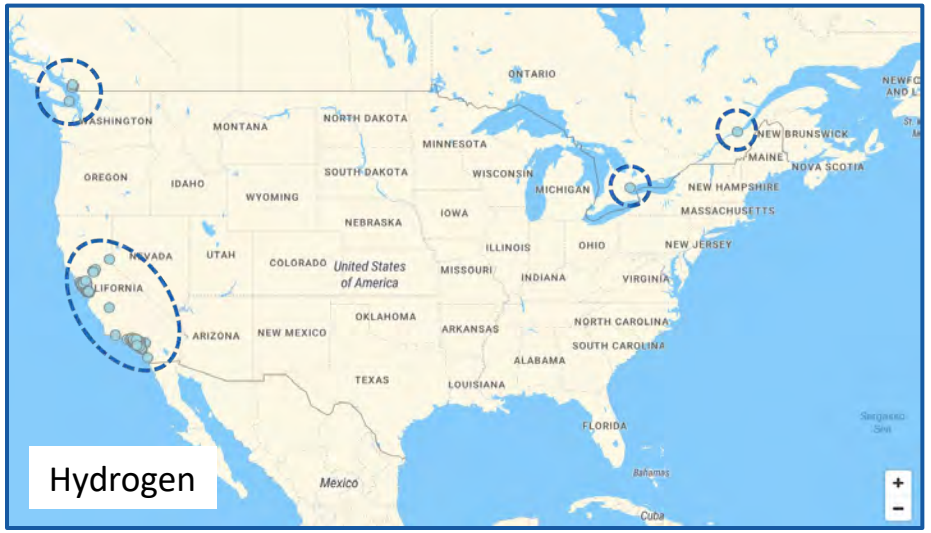
OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Sustainable fuel infrastructure is under development (DOE Alternative Fuel Station Locator)





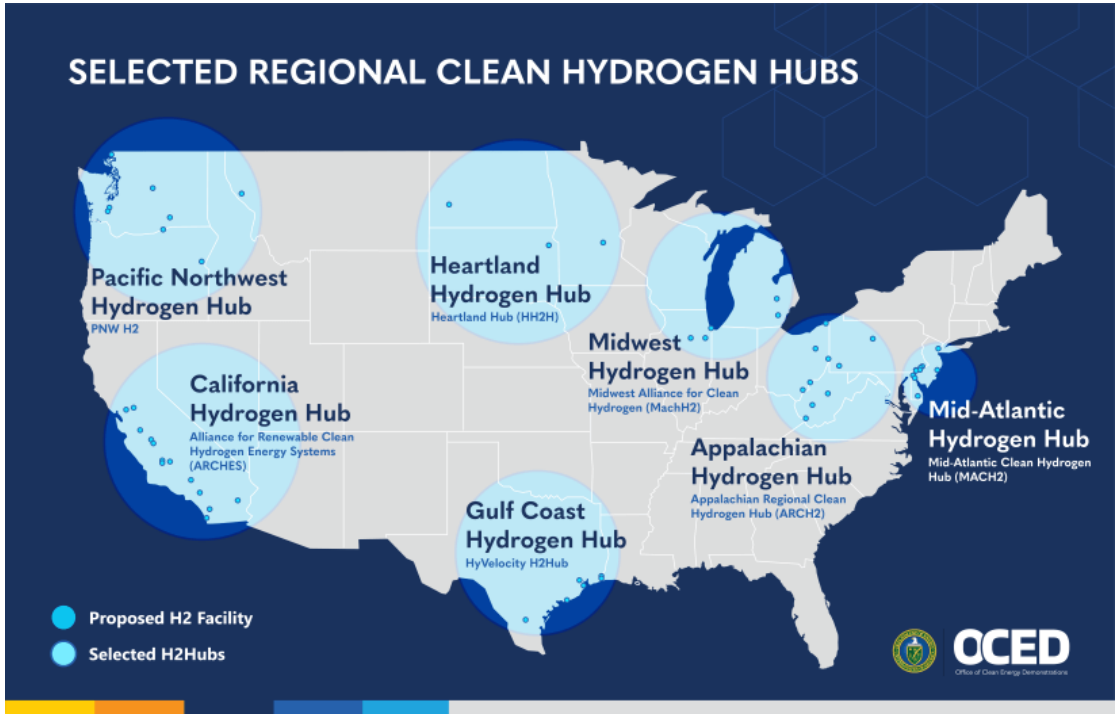


Significant government investments to accelerate breakthroughs

ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

"Earthshots™ will accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade. They will drive the major innovation breakthroughs that we know we must achieve to solve the climate crisis, reach our 2050 net-zero carbon goals, and create the jobs of the new clean energy economy."

- Carbon Negative Shot™
- Clean Fuels & Products Shot™
- Enhanced Geothermal Shot™
- Floating Offshore Wind Shot™
- Hydrogen Shot™
- Industrial Heat Shot™
- Long Duration Storage Shot™
- Affordable Home Energy Shot™



The Regional Clean Hydrogen Hubs (H2Hubs) will kickstart a national network of clean hydrogen producers, consumers, and connective infrastructure while supporting the production, storage, delivery, and end-use of clean hydrogen.

Accelerating solutions requires continued collaboration and government engagement

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

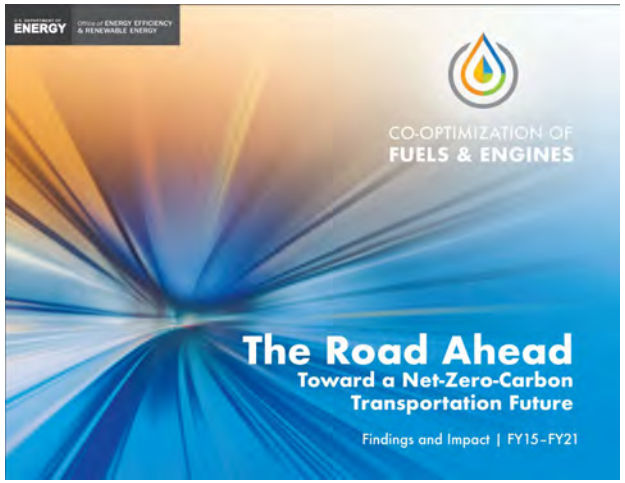
A few examples of DOE-driven collaborations

H2@Scale U.S. Department of Energy

EVs@Scale

BATTERY500 CONSORTIUM

SUPERTRUCK



21st CENTURY TRUCK PARTNERSHIP SM

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

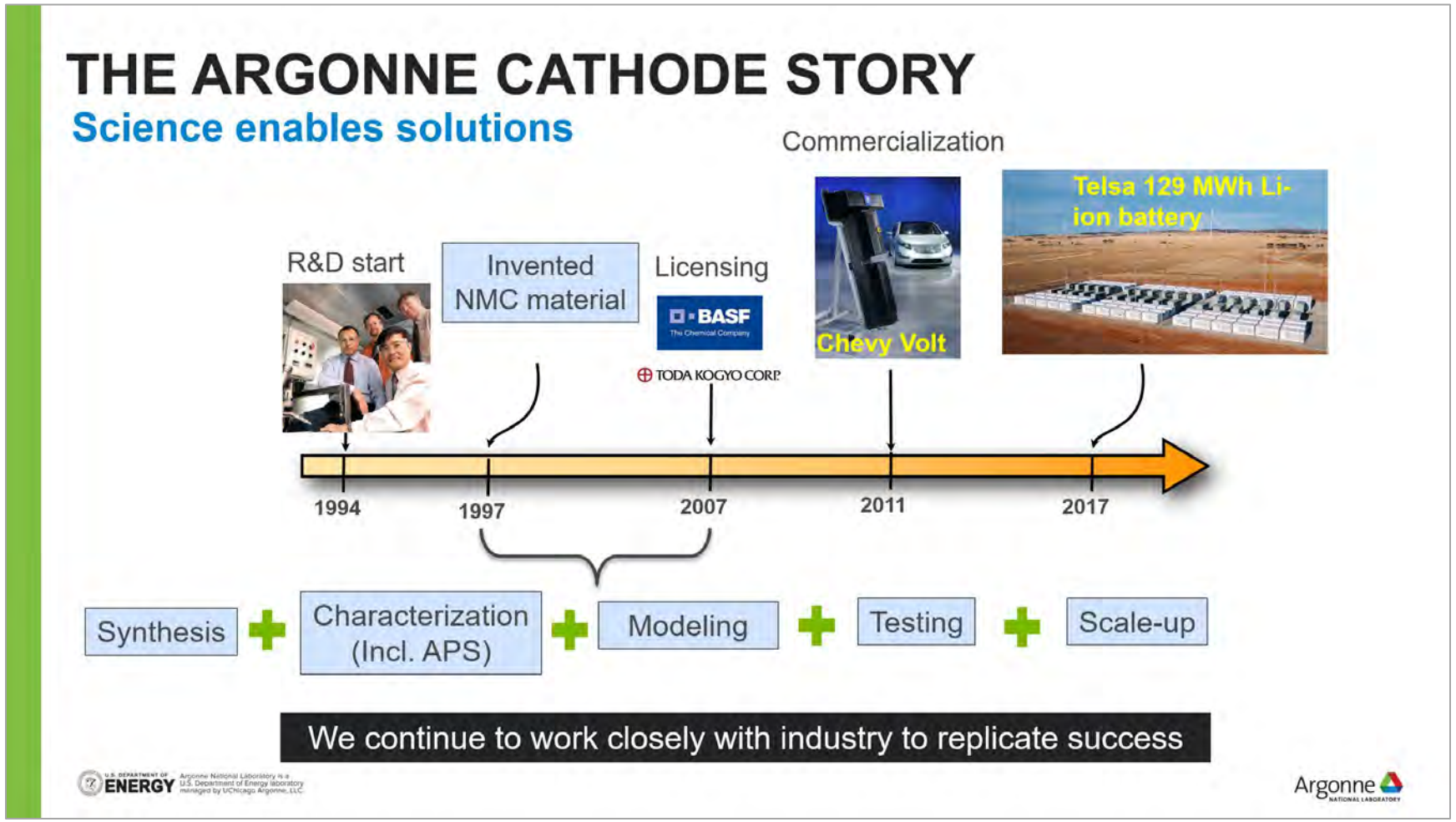
OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Science and collaboration has and will continue to enable necessary breakthroughs

"This was an invention that pulled together the expertise of the labs – from domain scientists to user facilities, with experimentalists and theorists – that led to commercialization and licensing."

– **Dr. Venkat Srinivasan**
Director, Argonne Collaborative Center for Energy Storage Science (ACCESS)



OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Another science example – development of materials for harsh environments

- **DOE VTO Powertrain Materials consortium** leverages world-class resources to accelerate scientific understanding for rapid design, development, and deployment
- **Breakthroughs in materials for combustion and electrification technologies**
  - Aluminum alloys for higher strength and higher temperature
  - Steels for higher temperature pistons and valve seats
  - Steel and aluminum alloys for additive manufacturing
  - Ultra-conductive composites
  - High strength lightweight conductors
- **Significant industry engagement with multiple R&D 100 awards**

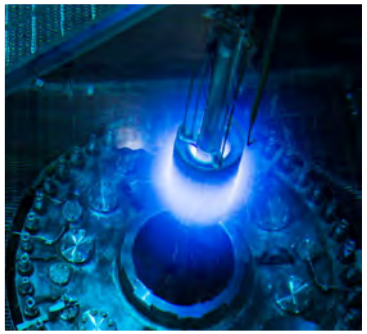
Argonne NATIONAL LABORATORY

Advanced Photon Source

Pacific Northwest NATIONAL LABORATORY

Environmental Molecular Sciences Lab

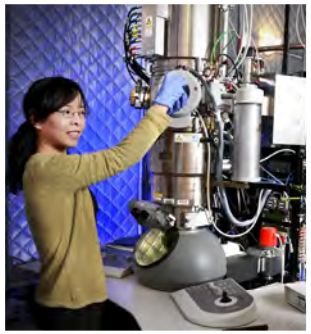
OAK RIDGE National Laboratory



High Flux Isotope Reactor

Spallation Neutron Source

Oak Ridge Leadership Computing Facility

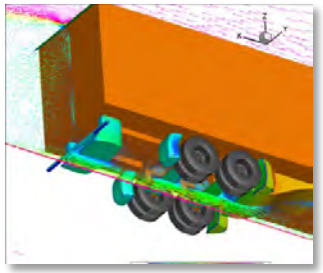


Center for Nanophase Materials Sciences

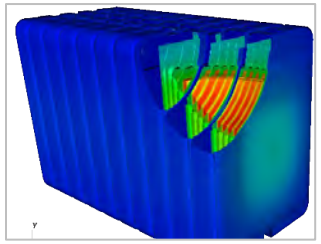
National Transportation Research Center

Manufacturing Demonstration Facility

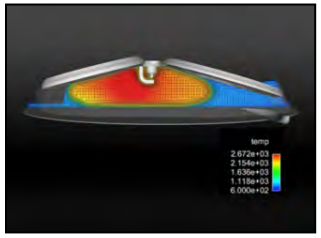
Another science example – knowledge discovery through high performance computing



Long-haul truck fuel efficiency
Simulations reduced by 50% the time to develop a unique system of add-on parts that increase fuel efficiency by 7–12%

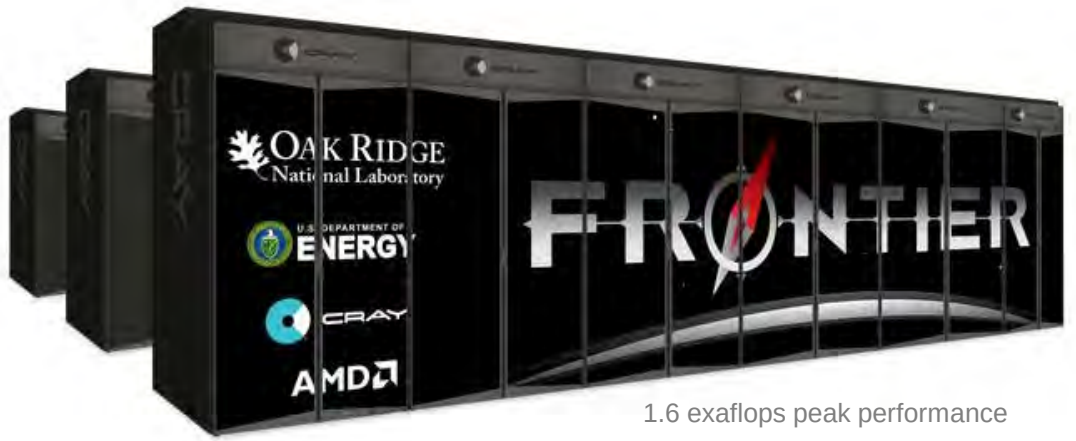


Batteries
High-fidelity models to help find new ways to safely increase the energy density of batteries



Combustion
Fundamentals of cyclic variability, advanced combustion modes, knock formation, and injector optimization to accelerate more efficient engines

Virtual design and calibration
Accelerate engine design and calibration with advanced computational methods



1.6 exaflops peak performance

"The Advanced Scientific Computing Research (ASCR) program mission is to discover, develop, and deploy computational and networking capability to analyze, model, simulate and predict complex phenomena important to the Department of Energy and the advancement of science."

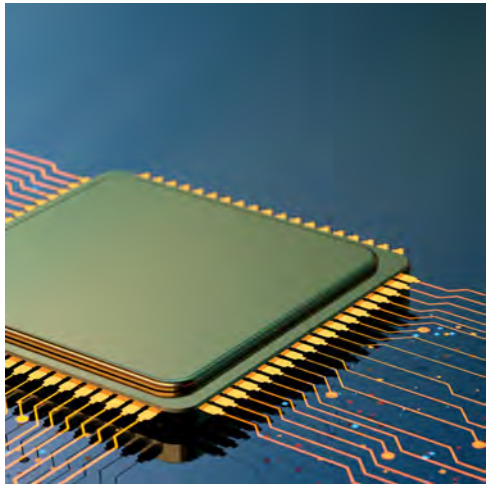
Several of the national laboratories steward and make available high performance computers

OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Disruptive surprises from diverse disciplines have changed our industry

These are breakthroughs that changed our way of life, our industry, and will continue to reshape the world in unexpected ways



Computers enable our way of life from daily conveniences to expanding our knowledge of the universe

The **internet** changed how we communicate and share information

Smart phones continue to evolve with new applications every day

GPS enabled a new era in navigation and tracking

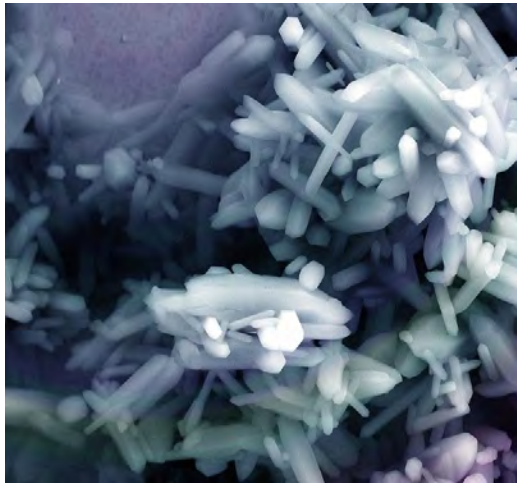
… with more disruptive surprises on the way with unimaginable impacts

These are breakthroughs that will further change our way of life, our industry, and reshape the world in unexpected ways

Artificial Intelligence from generative AI to controls to accelerating simulations

Quantum technologies spanning computing, sensing, and data security

Data management and communication continues to get bigger, faster, and more resilient



Advanced materials and manufacturing to improve energy production and efficiency

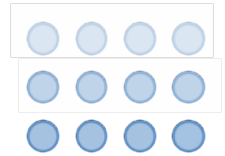
OAK RIDGE National Laboratory

SMOKY MOUNTAINS

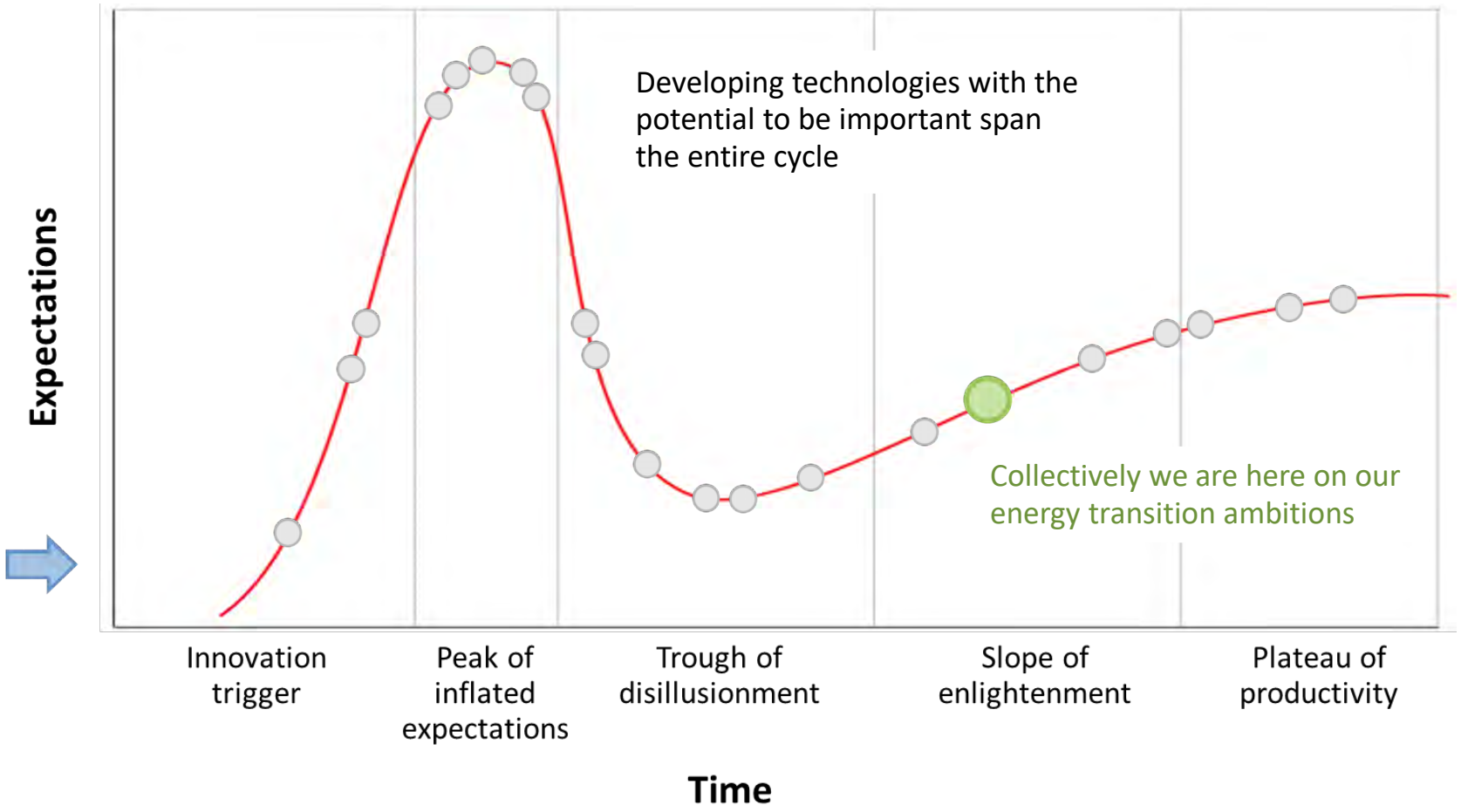
How are we doing?

From my perspective …

I often use the Gartner Hype Cycle methodology to think about technology progress



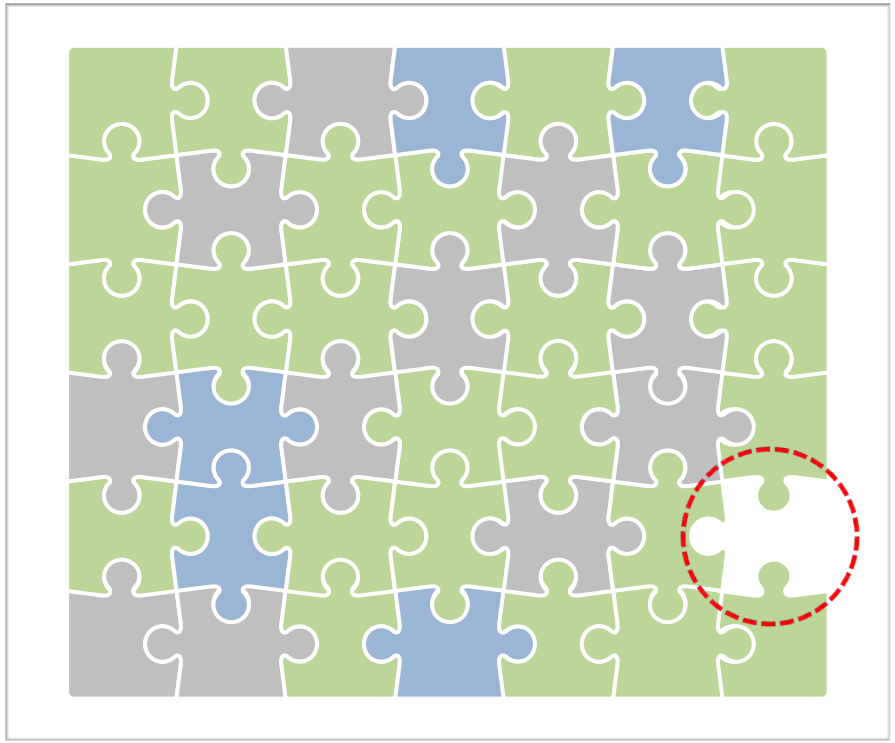
There are unknown technologies that will be important



OAK RIDGE National Laboratory

SMOKY MOUNTAINS

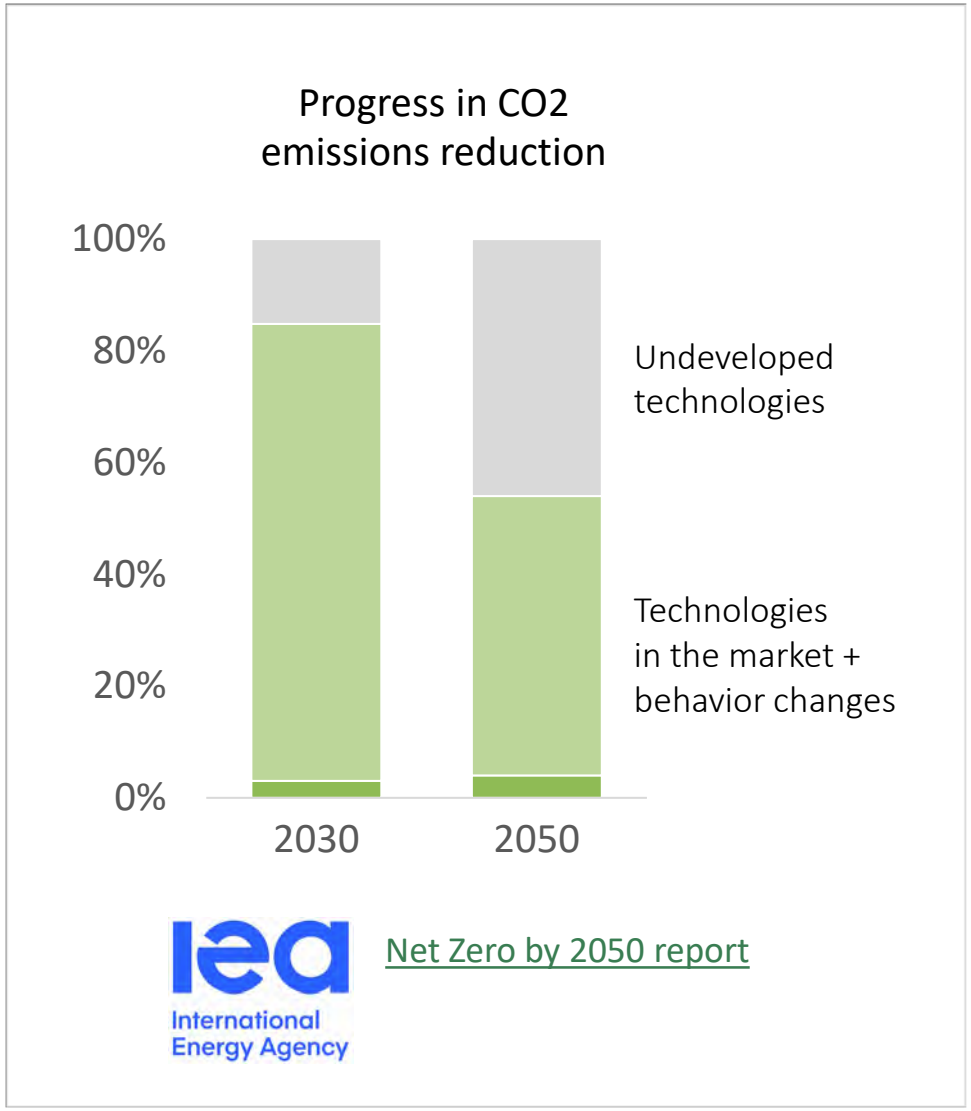
We will improve and refine our path as new technologies become available



Technologies in the market

Undeveloped technologies

Unknown technologies



OAK RIDGE National Laboratory

SMOKY MOUNTAINS

Closing takeaways

- Market acceptance is important for a long-term sustainable future
- Transportation energy will no longer be completely independent of other major energy users
- Electrification and hydrogen have the potential to diversify our energy future from a feedstock perspective, and sustainable liquid fuels will continue to be important for the foreseeable future
- Many key technologies are undeveloped or unknown at this time – these technologies must scale to meet national and global needs
- We are on path to a more sustainable future but transitioning our energy system and the vehicle fleet will take time

What got us here will not get us there – we will need new perspectives, more science, and disruptive surprises – which is happening

“Over and over again it has been demonstrated that the whole can be greater than the sum of its parts, that **good people from diverse fields working together** can make major scientific discoveries that are denied geniuses working in isolation.”

— Alvin M. Weinberg
ORNL director
1955-1973

Thank you!

Robert Wagner
wagnerrm@ornl.gov

OAK RIDGE National Laboratory

SMOKY MOUNTAINS