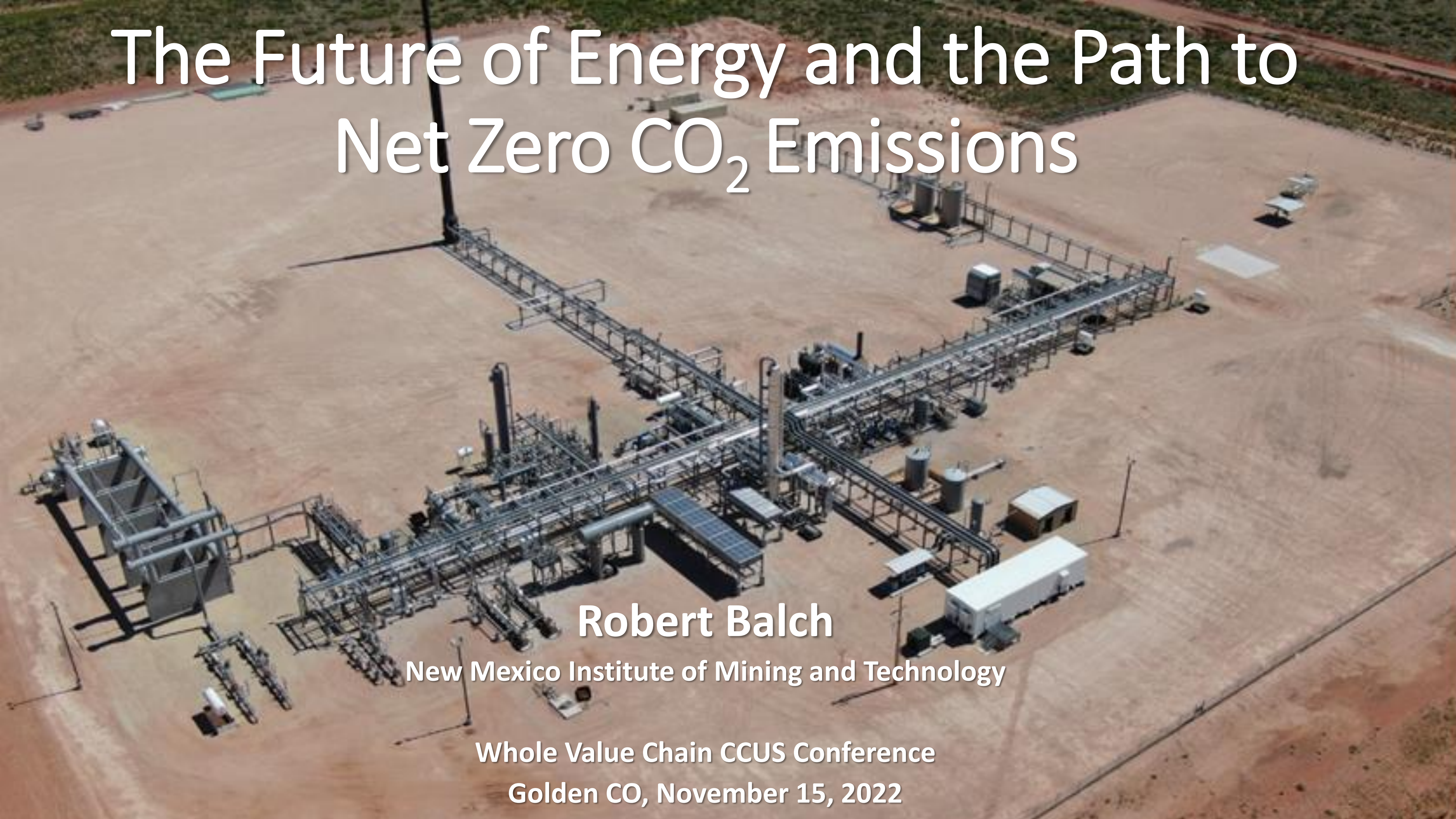

The Future of Energy and the Path to Net Zero CO_2 Emissions

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Whole Value Chain CCUS Conference

Golden CO, November 15, 2022

What Do We Mean when we say Net Zero?

The reduction and/or removal of CO_2 across all sectors and nations to a value which adds up to zero globally

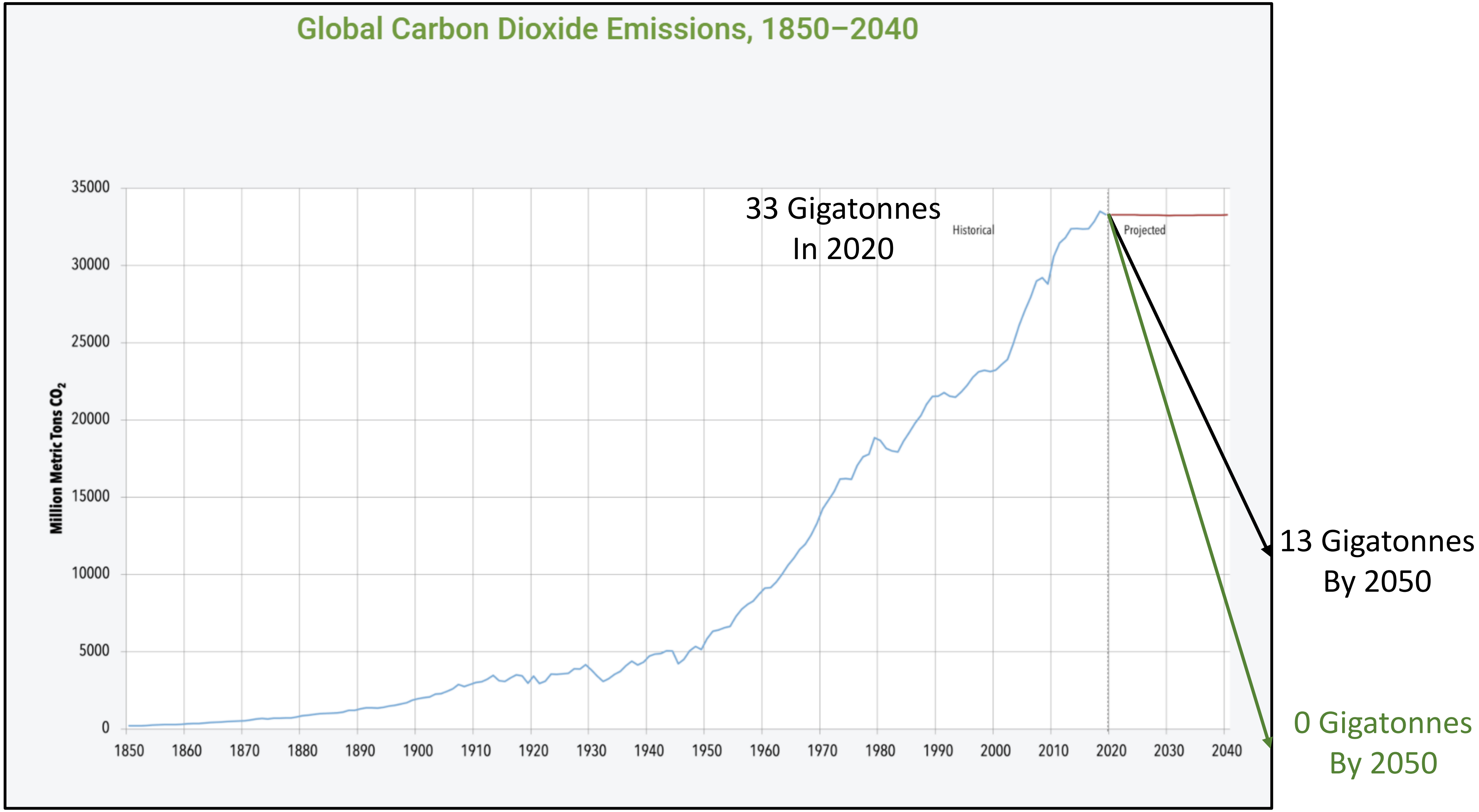
Scale Matters: It is simpler for a single person, industry, city, or state to accomplish this than it is for the entire world to do so simultaneously

Timing Matters: The Paris Accord says we have until 2050 to reduce to 40% of current emissions, yet still have a 1.5^{o}C change. 100% reduction is required to further minimize impacts. Time is running out

Why is Net Zero Important?

- World carbon emissions from human activities is ~33 Billion Tonnes of CO_2 per year as of 2020
  - Increased from ~2 billion tonnes of CO_2 per year in 1900
- World leaders meet periodically to assess the hazards of these emissions and make agreements about what can be done to mitigate the effects
  - Paris Accord, Kyoto Protocol, are two prominent examples
- Reduction to pre-industrial levels would mitigate the effect of humanity on the Earth's climate
- Climate impacts are unpredictable and may have broad consequences for life on the planet

Paris Accord: A Steep Challenge



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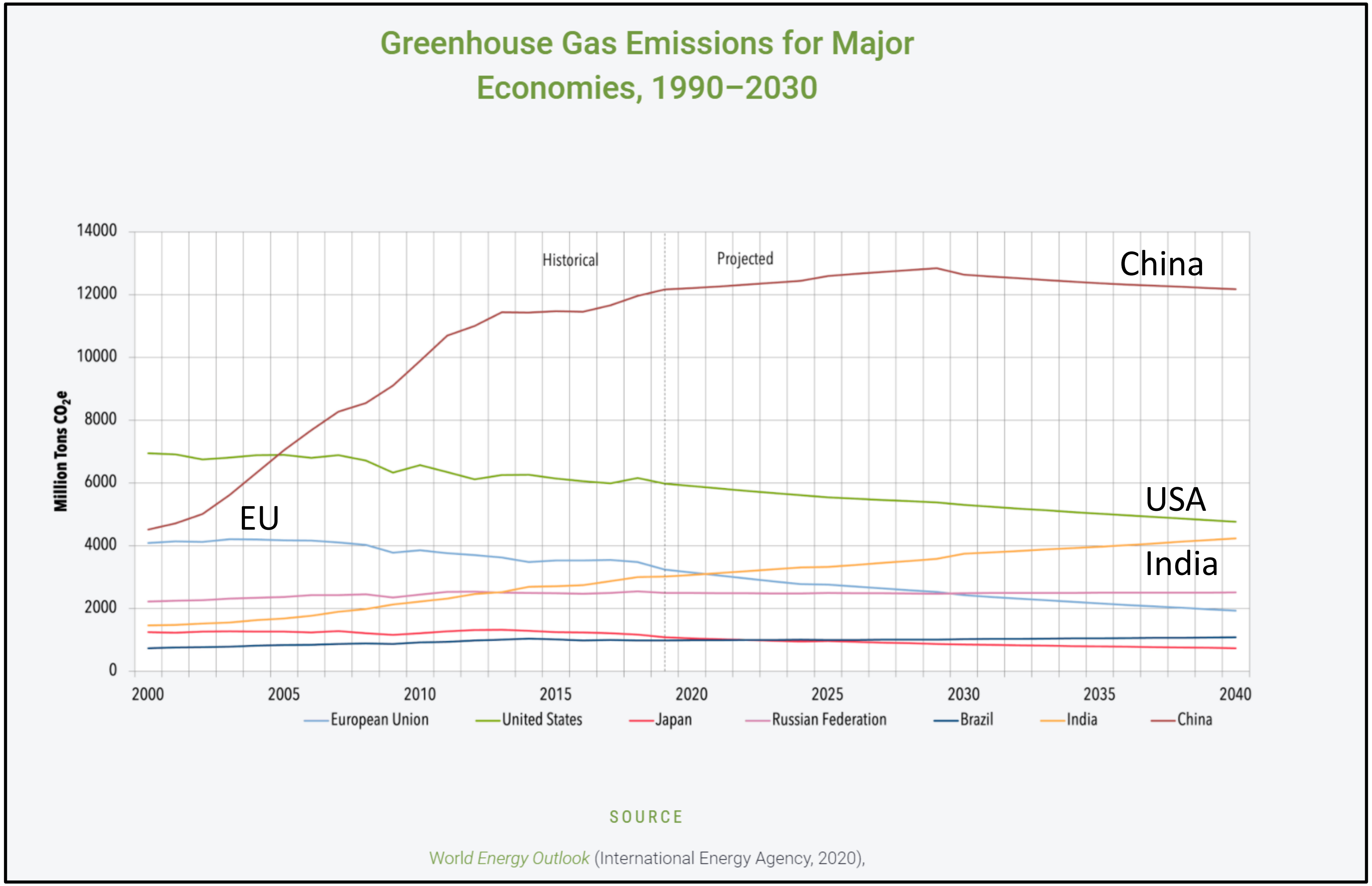
Paris Accord – Projected Progress

Projected drops in CO_2 emissions fail to meet Paris Accord goals for industrialized countries

USA projected to drop CO_2 emissions by 35% in next 30 years from 6.8 Gigatonnes today to 4.4 Gigatonnes

Good news! But is it enough?

What about the Rest of the World?



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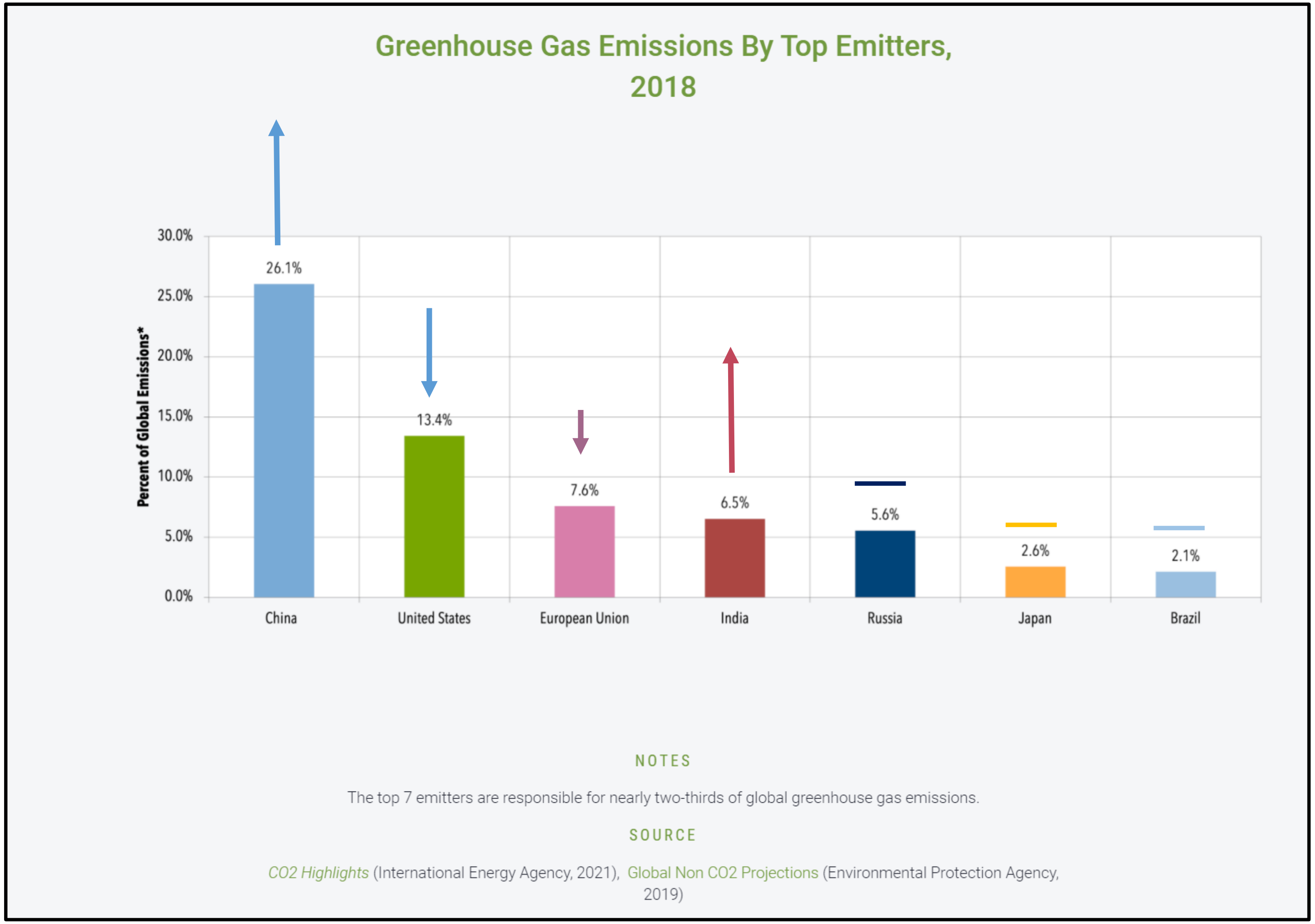
Where Do We Stand?

US Total emissions are ~6.8 Gigatonnes per year today

EU Total emissions are ~2.51 Gigattones per year today

To meet Paris Accord US needs to drop to 1.4Gigatonnes per year, and the EU to 0.5Gigatonnes per year, by 2050

Net Zero requires both to drop to zero in the same 28 year period



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How Do We Achieve Net Zero?

Simply stated this is an immense challenge

- **Hydrocarbon Energy:** Is pervasive and impacts every aspect of modern life
  - Coal-fired power (~30% of world CO_2 emissions)
  - Natural gas (~22%)
  - Vehicle Fuel (~9%)
- **Critical Building Materials:** Drive economic development
  - Cement (~8% world emissions)
  - Steel (~9%)
- **Strategic Minerals are Scarce:** Relative to new demands we lack sufficient supplies to meet demand for renewables, renewable power storage, and 0 emissions vehicles

While rapidly evolving, Technology may not answer all of these needs in the time we have left

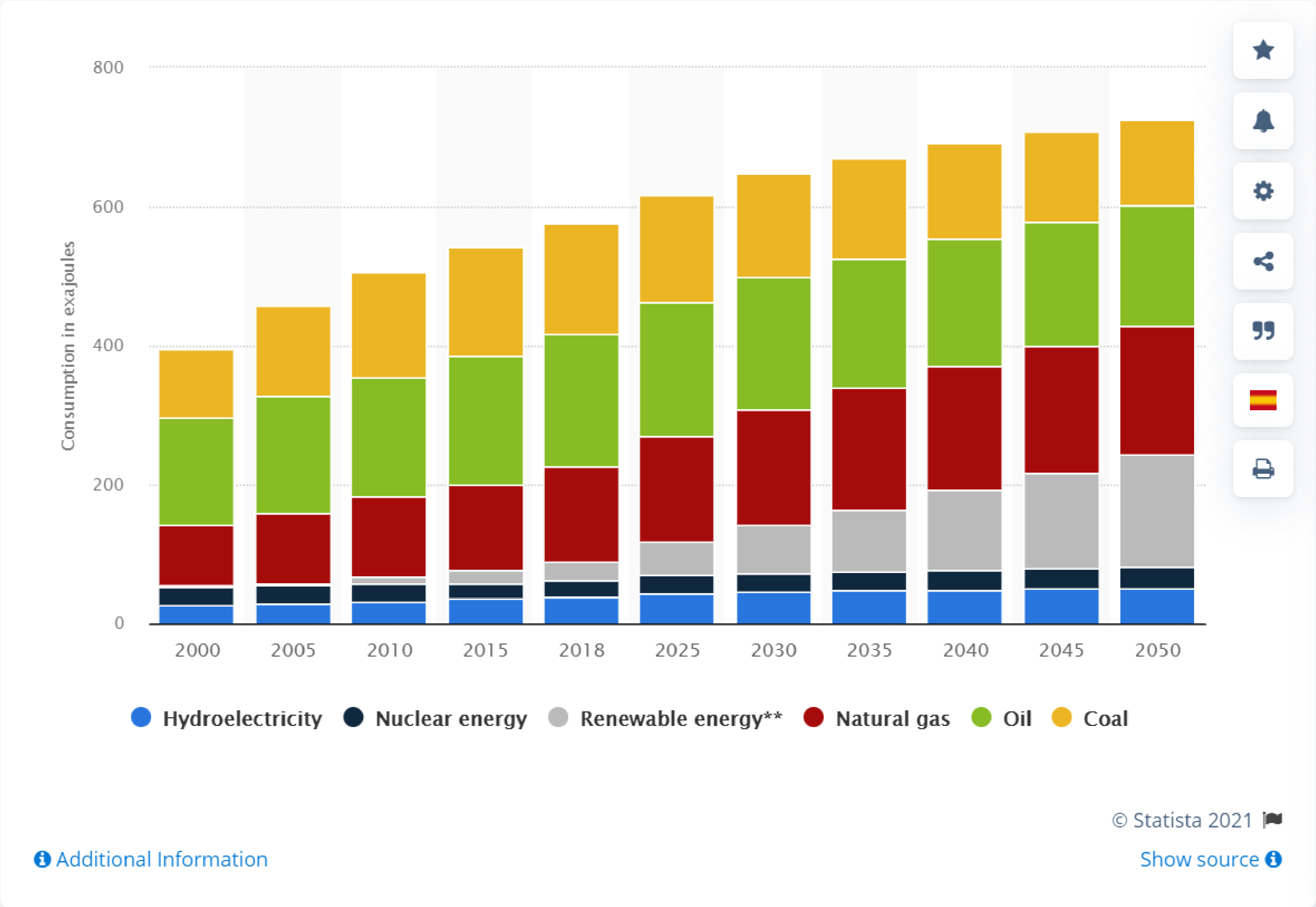
Hydrocarbons: An Uncomfortable Truth

By 2050 we will have broader adoption of renewables but it will still leave more than 60% of world energy coming from Hydrocarbons

Similar use of Coal/Oil/Natural Gas in 30 years, as we have Today

Hydrocarbon energy emits CO_2

Carbon Storage is not only a good idea but is necessary to meet climate goals



Critical Building Materials

- Work is being done on reducing emissions from these sources, but these solutions are in the realm of **Science**, not **Engineering**

- These are difficult materials to replace and are also essential for renewables
    - Wind Tower materials include (NREL):
        - 71-95% steel and Iron by mass (150 metric tonnes
        - 11-16% fiberglass resin or plastic by mass (950 barrels of oil)
        - Concrete (400 m^3)
        - Copper for turbines (1% by mass)
        - Does not consider fuel for trucking and manufacturing

Likely need to mitigate rather than eliminate most of these emissions

Strategic Minerals

- Materials needed for generators, catalysts (hydrogen), and batteries to build and store energy from renewables
- Minerals used include (futures prices):
  - **Copper** ($2.10 per lb in 2016, $4.48 per lb in February **2X**)
  - **Cobalt** ($16,205 per ton in 2016, $81,360 per ton in April **5X**)
  - **Nickel** ($7,148 per ton in 2016, $48,436 per ton in March **7X**)
  - **Rare Earths** (varies but typically has gone up **3-4X**)
  - **Lithium** ($83,054 per tonne in 2017, $468,500 in June **6X**)
  - **Silver** ($4.72 per oz in 2016, $21.91 per oz in May of 2022 **5X**)
- Batteries need vast quantities of materials
  - To electrify all 285 million vehicles in USA would require
    - 4 years of world annual Copper production
    - 8 years of world annual Lithium production
    - 15 years of world annual Cobalt production

Other countries and Industries also need these materials!

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And Then There is Geopolitics…

- Major emitting countries that are most likely to pursue Net Zero (USA/EU) do not produce the bulk of these materials because mining has major environmental concerns!
- **Where do these minerals come from?:**
  - **Copper** top 5 : Chile, Peru, ***China, DR Congo***, USA
  - **Cobalt** top 5 : ***DR Congo, Russia***, Australia, Phillipines, ***Cuba***
  - **Nickel** top 5: Indonesia, Phillipines, ***Russia***, Caledonia, Australia
  - **Rare Earths** Top 5: ***China,*** USA, Myanmar, Australia, Thailand
  - **Lithium** top 5: Australia, Chile, ***China***, Argentina, Brazil
  - **Silver** top 5: Mexico, Peru, ***China, Russia***, Poland
- Also there are social costs:
  - Democratic Republic of Congo – Child Labor, dangerous conditions, lack of environmental protections
  - China – Rare earths sourced from Myanmar devastating jungle ecosystems, forced labor by ethnic minorities to build solar panels in Western China
  - Russia – Norilsk, most polluted city on Earth due to smelting of Copper, Cobalt, Nickel
  - Chile – Atacama desert, hydrologic system of several million years severely disrupted by Lithium mining

Renewables, Hydrogen, and associated new infrastructures, all need much more strategic minerals than are mined today, this means many new mines

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So,How Do We Achieve Net Zero?

- Switching completely to renewables is a multi-generational change, and we only have a generation to accomplish this
  - Need major advances in Energy storage, Grid Management, and Power Electronics
  - Huge infrastructure ask, solar panels to power the US would completely cover the states of NM and AZ, and would require Terawatt sized batteries with longer cycle times than current Lithium-Ion
  - Need to rapidly develop new sources of strategic minerals or alternate technology to use more common materials
- Will need to be able to use existing energy sources while this transition is made
- Mitigation (storage and reductions by efficiency)will have to dominate the near term to buy time for new technology to be developed
- Fortunately we can leverage existing energy assets and subsurface experience, with a highly trained workforce of energy workers

Emission Penalties (Stick) and Tax credits like 45Q in USA (Carrot) are impactors

Is There a Path to Net Zero?

- **Locally, yes.** Communities, Cities, States, even Countries could conceivably do this with a healthy mix of:
  - Increased efficiency
  - Use all types of decarbonized powers depending on local needs
  - Carbon capture and storage from fixed emission sources
  - Direct Air Capture will still likely be needed to compensate for some sectors that are decentralized
- **Cost is an issue**
  - Cannot work in a vacuum when it comes to costs of global commodities
  - Significant portions of GDP will be required
  - Will become non-competitive with neighbors who do not, or cannot afford to, pursue these goals as aggressively

Is There a Path to Net Zero?

- **Globally, not on present path.** most countries cannot afford the costs of these technologies
  - Technologies once developed have to be given away to countries that cannot afford to develop those technologies on their own
  - ***Carbon storage from fixed emission sources is the cheapest and has the lowest cost of entry in both technology and materials***
- **Cost is a major issue**
  - Carbon problem in India is that they don’t have enough coal
  - Developing countries will not handicap themselves economically to solve what for them is a “First World Problem”
  - ***Hydrocarbons are very cost-effective, and will only become more so as some countries and regions stop using them***

How Can We Best Address Climate Goals Then?

Think of all-inclusive and regionally relevant solutions

- Need to embrace *"Engineering Solutions"* available today, while we continue to work on *"Science Solutions"* for the future.
- **With current technology**:
  - Need to accelerate and embrace nuclear power
    - **Traditional, Thorium reactors, standing wave reactors, etc**
  - Develop renewables to the extent we can fully utilize them
    - **Adapt to intermittent power use to get better utilization**
  - Hydrocarbons are very cost-effective, and will continue to be used in vast quantities
    - **Those emissions must be captured and geologically stored**

Ultimately, we must be prepared to adapt to some climate change, as goals are not likely to be met, even at Paris Accord levels in the 1-2 generations we have left

This Brings us to CC(U)S

Carbon Capture: The process of capturing CO_2 from power generation, other industrial processes, or by Direct Air Capture (DAC)

- Coal, natural gas, cement, steel, fertilizer, ethanol, many other processes

Utilization: Making use of the captured CO_2 in some manner that secures the CO_2 from release to the atmosphere over very long time periods (990 years or more)

- Enhanced Oil Recovery, biogenic processes, advanced cements, others

Storage: The process of placing the captured CO_2 into long-term storage (990 years or more)

- Geologic storage in deep saline aquifers, depleted oil reservoirs, basalt formations

Mature Technologies / Common Materials

Very mature technology

- Enhanced Oil Recovery with CO2 has been going on for more than 5 decades in the US and Canada
- USA and Europe have spent Billions of Dollars on this technology focusing on capture and storage technologies over the last 20 years
- USA spending additional $43 Billion in next decade

Common Materials

- All materials used for CCUS are presently available, use common materials and are already in supply chains
- Pipes, compressors, amine solutions
- Ready workforce of oil and gas workers can deploy these technologies today

Take-Aways

- **The world needs hydrocarbons to support renewable growth**
  - Plastics
  - Lubricants
  - Road building
- **The world needs abundant energy and hydrocarbons will fill this need for decades to come**
  - No projected change to hydrocarbons use by 2050
  - This is what most countries can afford to fuel their development
- **De-carbonization of Hydrocarbons is possible with todays technologies**
  - **Enhanced Oil Recovery**
  - **Carbon storage to mitigate emissions**
  - **Lowest cost of entry to reach climate goals**

Questions?