Challenges for Energy Transitions, and the Path to Net Zero

Robert Balch

New Mexico Institute of Mining and Technology

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Why Am I talking about This?

I was asked to give an invited talk showing the path to net zero for an SPE conference in 2021

- Whether you personally agree or disagree with current climate science, leaders and influencers have made the issue an important and often divisive topic
- When presented with a problem, I like to draw a box around it, and understand relevant inputs and outputs
  - **Energy and mass balances are important!**
- We are presented with many different, and often completely opposed views
  - **News is personal in the 21st century, your phone will send you articles that affirm your demonstrated beliefs as mined from your previous search activity**

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 from legacy emissions. 100% reduction is required to further minimize impacts. For more than 2 decades regular international meetings have found that the previous agreements have not been widely achieved

Cost is an Issue: Current annual spending on green energy is about $1.4 Trillion, to meet Paris accord $131 Trillion is needed between 2021 and 2050, which comes to about $4.5 trillion per year* spending will need to be subsidized in developing world (Global GDP in 2022 was $100 Trillion)

*Nature Journal, 15 May 2023

Net Zero may be an Insufficient Descriptor

- What is our air made of?
  - Nitrogen 78.08%
  - Oxygen 20.95%
  - Argon 0.93%
  - CO_2 0.04 %
    - 0.28% pre-industry
    - 4.0% dangerous to humans
  - When CO_2 is in the atmosphere it is a gas, and can trap heat much like a greenhouse
- **True Net Zero likely needs to includes an additional 7.2 gT per year**

- Direct human related CO_2 emissions **were 41.6 billion metric tonnes** in 2024
  - Electricity generation
  - Industrial processes
  - Transportation fuels
- Land use changes also affect CO_2 Emissions
  - **4.2 billion tonnes** in 2024
- When we breathe we also exhale CO_2!
  - About **3 billion tonnes** per year
- Plants, animals, volcanoes and other natural processes move about **780 billion tonnes** of CO_2 per year

What Is an Energy Transition?

An energy transition is a broad shift in technologies and behaviours that are needed to replace one source of energy with another (Jacard, 2020)

Has this happened before?: Sort of. Around 1750 the industrial revolution started in England, Biomass began to give way to coal. However... We still use biomass today, and in fact some coal power plants are being converted back to biomass

Arguably there has been only one Energy Transition which is still progress!

Biomass > Coal > Oil/Gas > Hydro > Wind > Nuclear > Solar PV > Modern Renewables

Pre 1750 1750 1850 1891 1895 1951 1951 1980

All of these power sources are still in use today

Energy Transitions are long-term processes, usually resulting from finding something better or cheaper: Early shifts in primary energy source driven by economics and capacity demand

So… What Is the Current Energy Transition (ETA)?

A global or local shift in the world energy sector from Fossil based fuels to renewable [or carbon neutral] power sources.

Where is this occurring: Some countries have already established ETA goals, primarily in the US, Europe, Australia, and parts of Asia (OECD Countries)

While some countries and US states are very aggressively changing policies to pursue these goals, often with phased approaches, many more are taking a much softer approach

Politics Matter: The most aggressive policies are at times outpacing the ability for renewables to be deployed, without full consideration of economics, materials, and energy balances

What are the Challenges for reaching Net Zero?

Four major issues provide significant challenges to reaching Net Zero on a global scale:

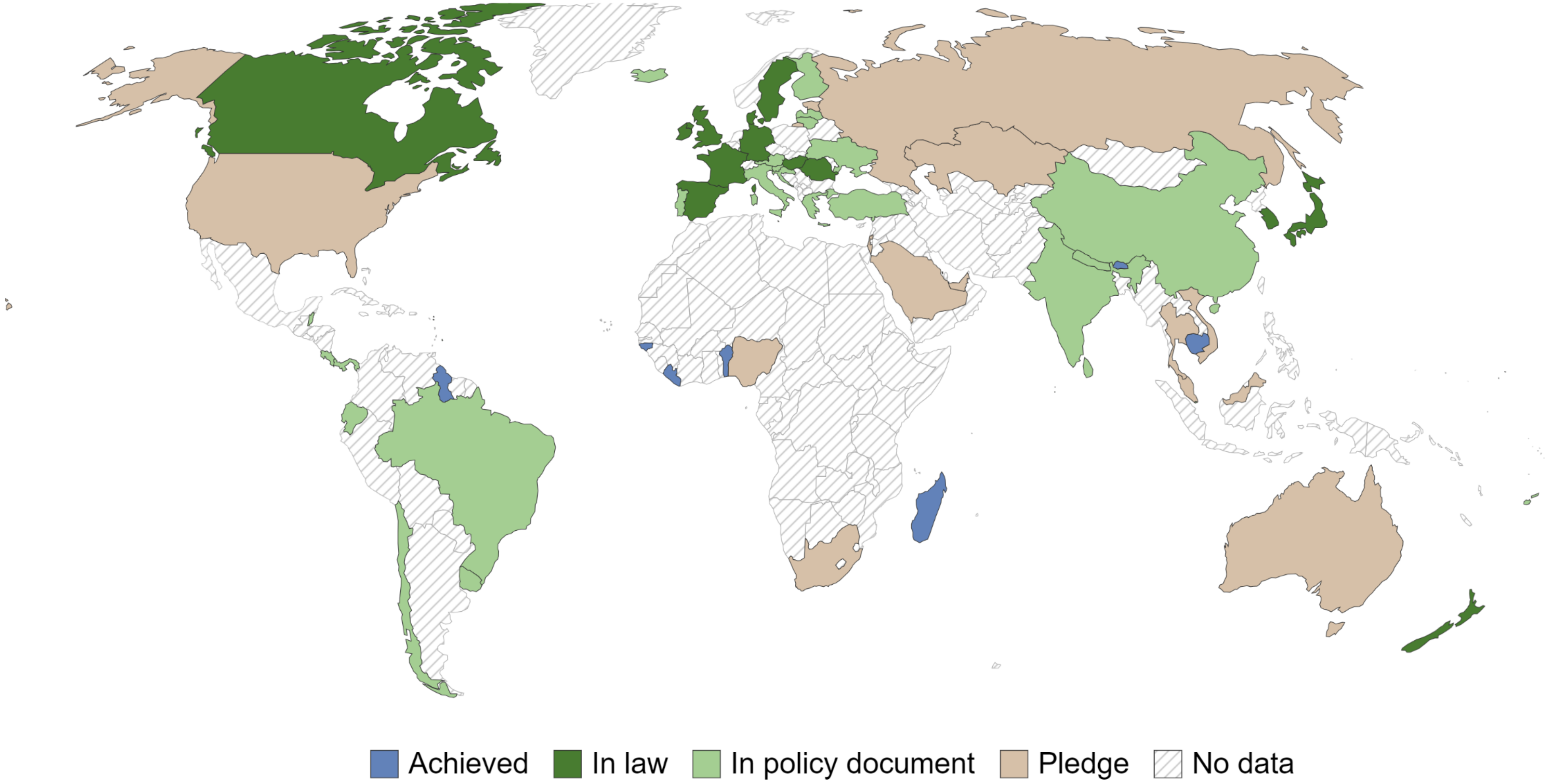
1. Energy Demand vs. Supply
2. Critical Building Materials
3. Strategic Minerals
4. Geopolitics

And two other categories requiring DAC also needs to be addressed

5. Unmitigated future emissions from the developing world
6. Legacy Emissions – more than 1 trillion tonnes since 1750

Lets Draw Some Boxes…

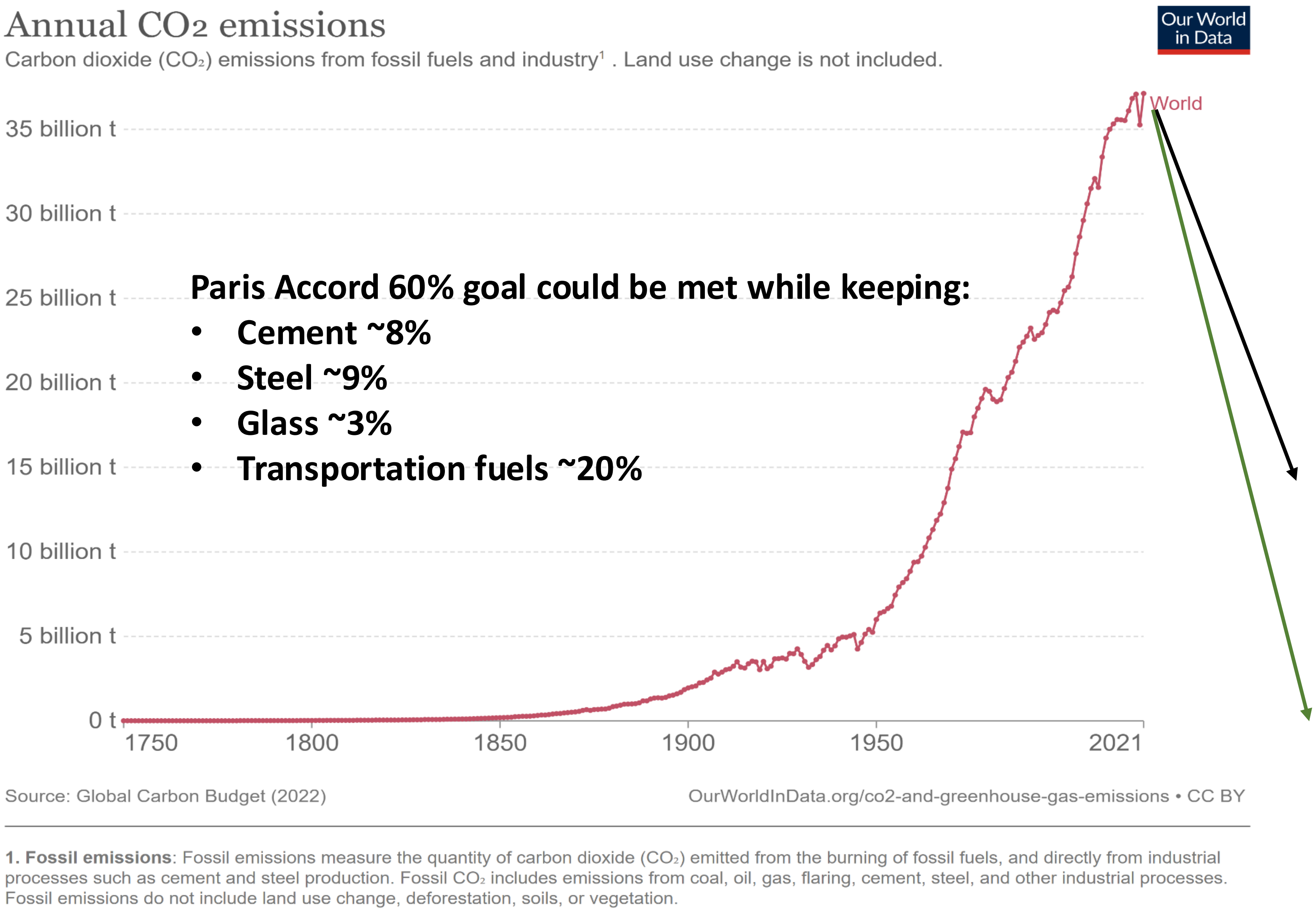
Is Anyone Net-Zero?



Source: Net Zero Tracker. Energy and Climate Intelligence Unit, Data-Driven EnviroLab, NewClimate Institute, Oxford Net Zero. Last updated: 2nd November 2021.
OurWorldInData.org/co2-and-greenhouse-gas-emissions • CC BY

* Our World in Data

The Paris Accord: A Steep Challenge



Paris Accord 60% goal could be met while keeping:

- **Cement ~8%**
- **Steel ~9%**
- **Glass ~3%**
- **Transportation fuels ~20%**

37.12 Billion Tonnes in 2021

41.6 Billion Tonnes in 2024…

13 Gigatonnes
By 2050

0 Gigatonnes
By 2050

* Our World in Data

World Emissions– Who Emits the Most CO_2?

Actively Decarbonizing

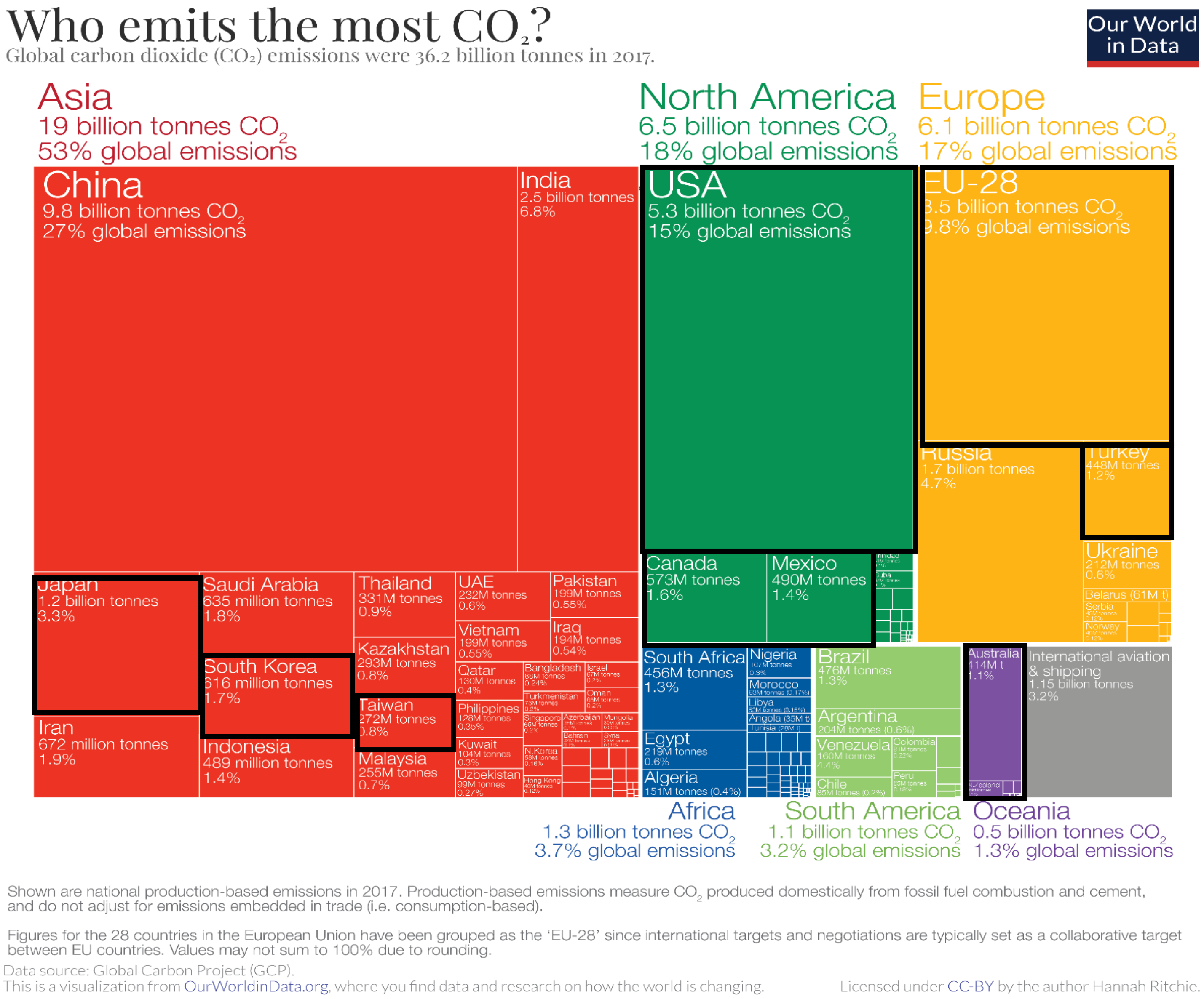
USA 5.3Gt (15%) and EU 3.5Gt (9.8%) are actively reducing their emissions

What about the Rest of the World?

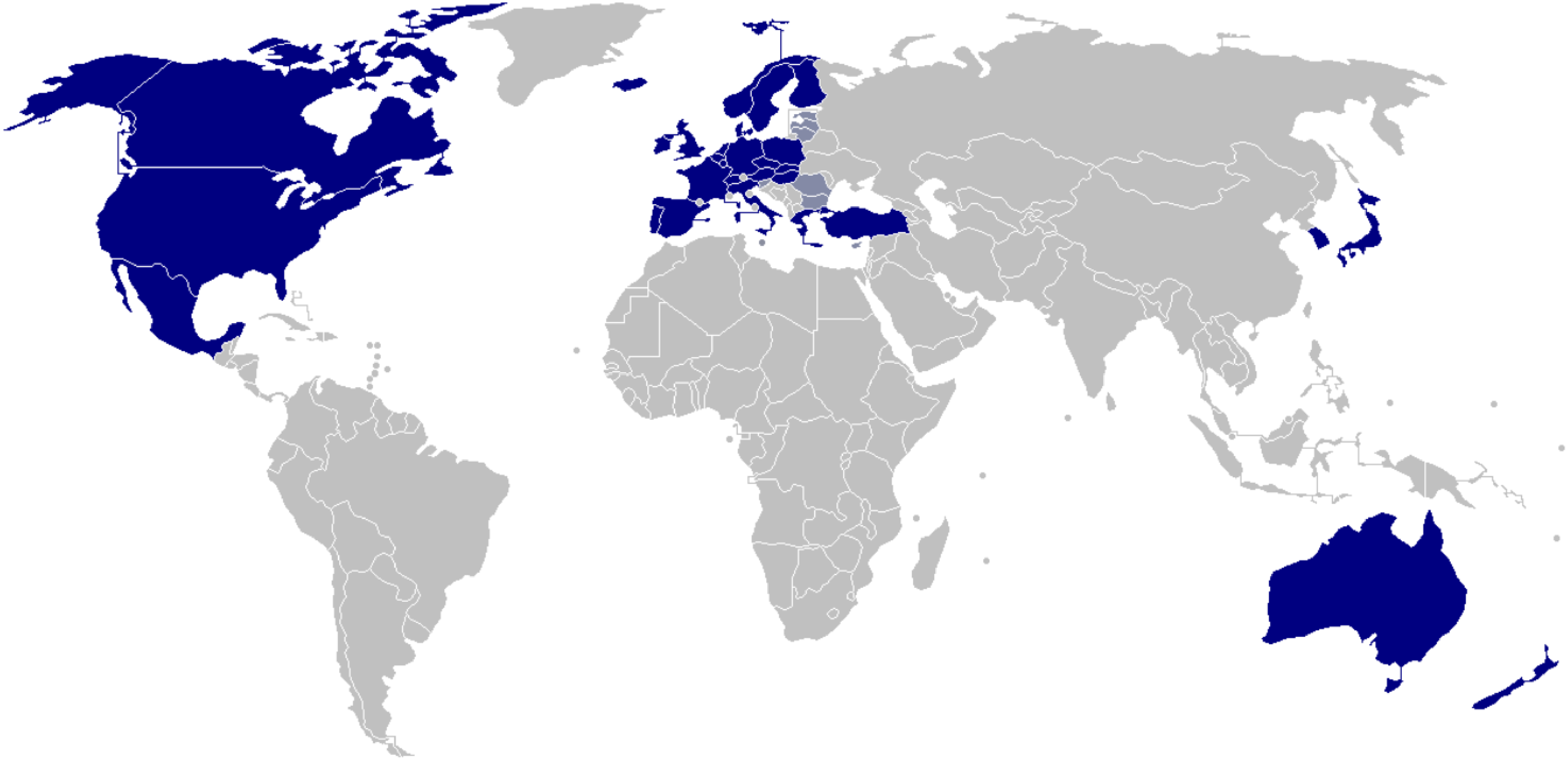
China 9.8GT (27%) and India 2.5GT (6.8%) are ***actively growing*** their emissions

- China will increase emissions into the 2030's before declining to present levels in 2050

Africa (3.7%) and South America 1.1%) are poised to grow their economies and thus their energy requirements



Two world Orders: OECD Countries



Wikimedia – Map of Organization for Economic Cooperation and Development

Two world Orders: China Debtors (Belt and Road)

Newsweek – Map of countries that owe money to china

Paris Accord – Projected Progress

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

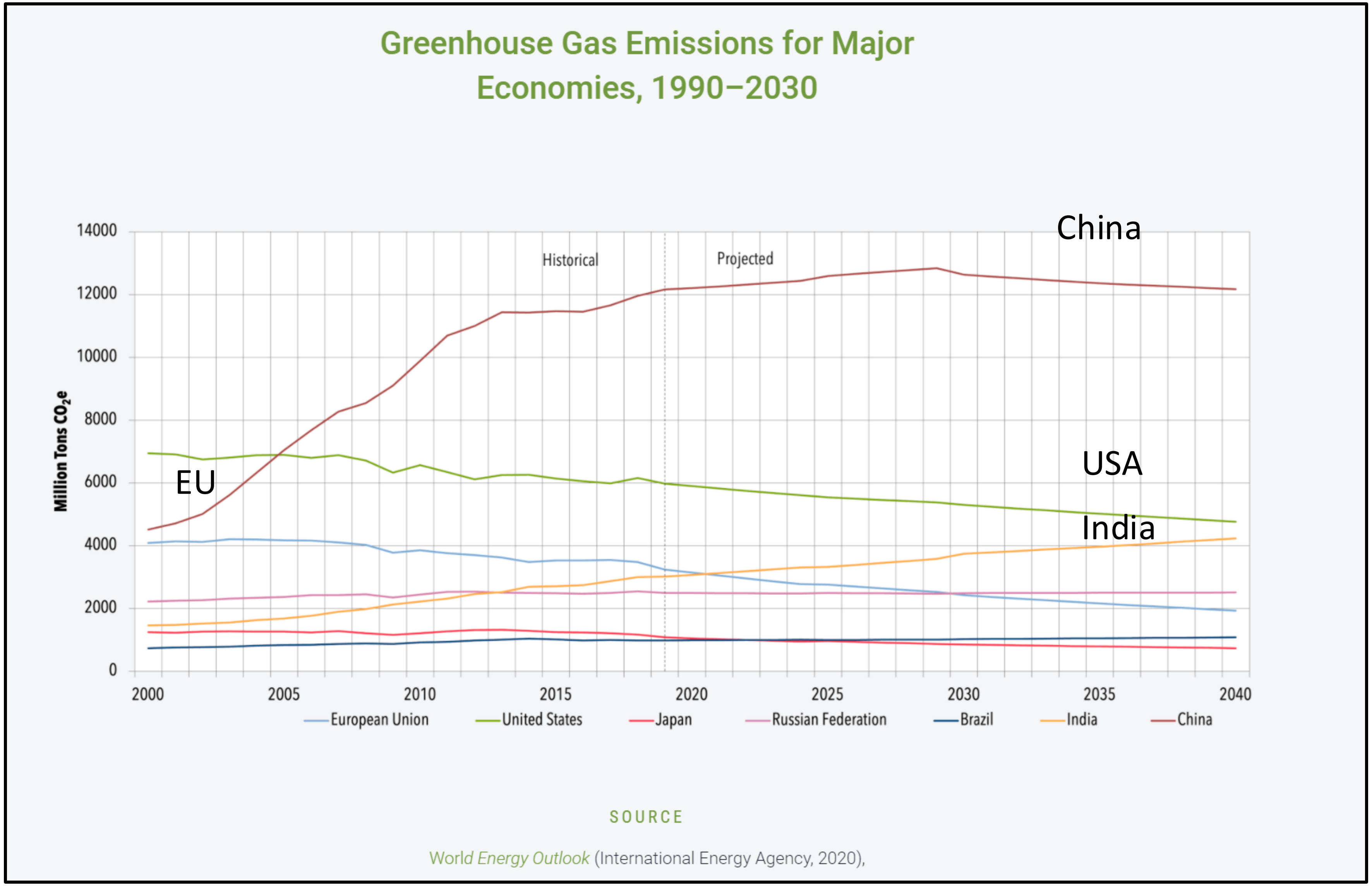
USA and Europe projected to drop CO_2 emissions by ~35% in next 30 years

Is it enough?

Not really.

China and India actively growing emissions

Developing countries and regions needs cheap energy



* World Energy Outlook, IEA, 2020

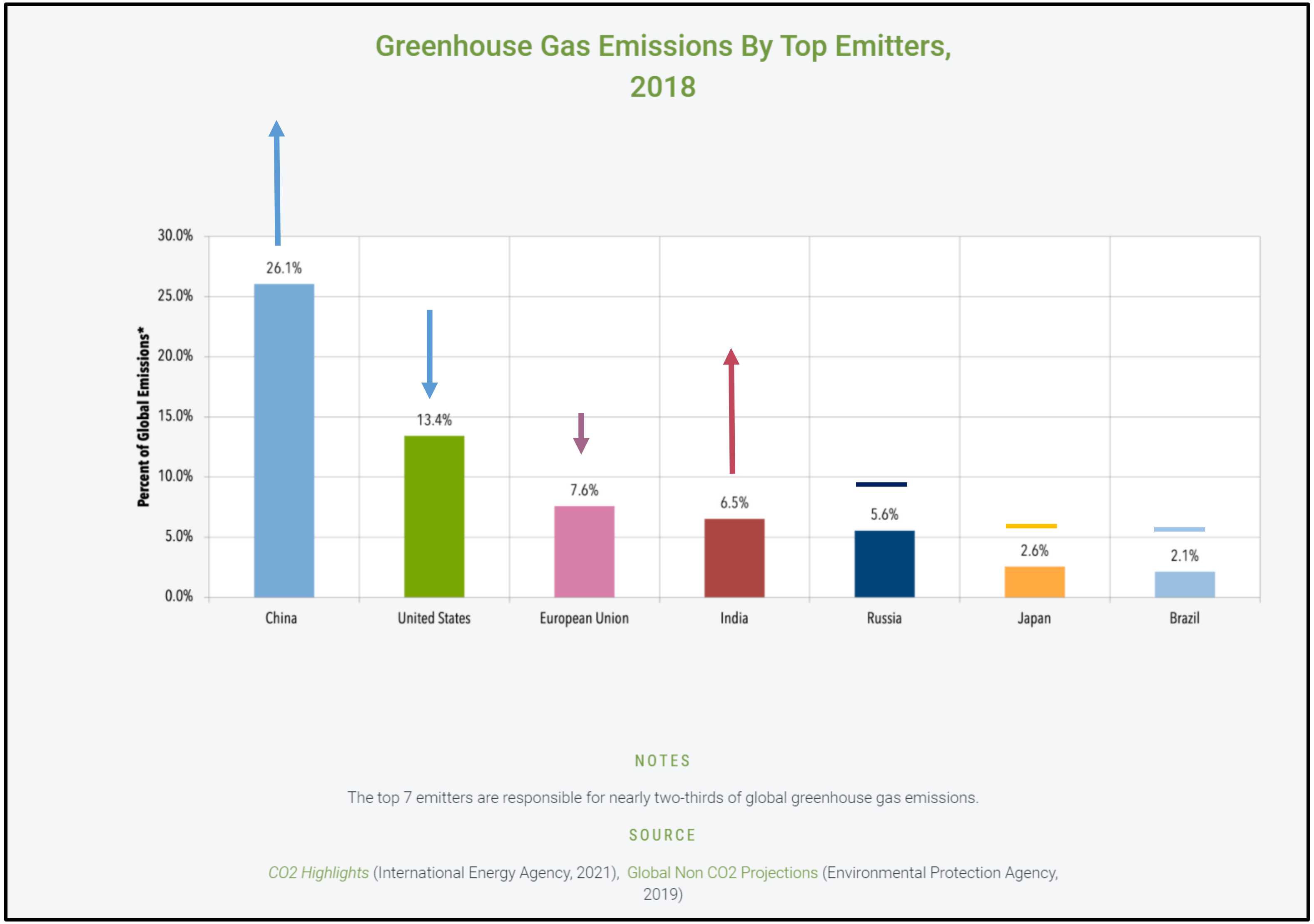
Where Do We Stand?

US Total emissions were ~6.8 Gigatonnes per year in 2018, and have dropped to 4.4 Billion tonnes in 2022 (Coal to Natural Gas power)

EU Total emissions were ~3.1 Gigattones per year in 2018 and were 2.73 Gigattonnes in 2022

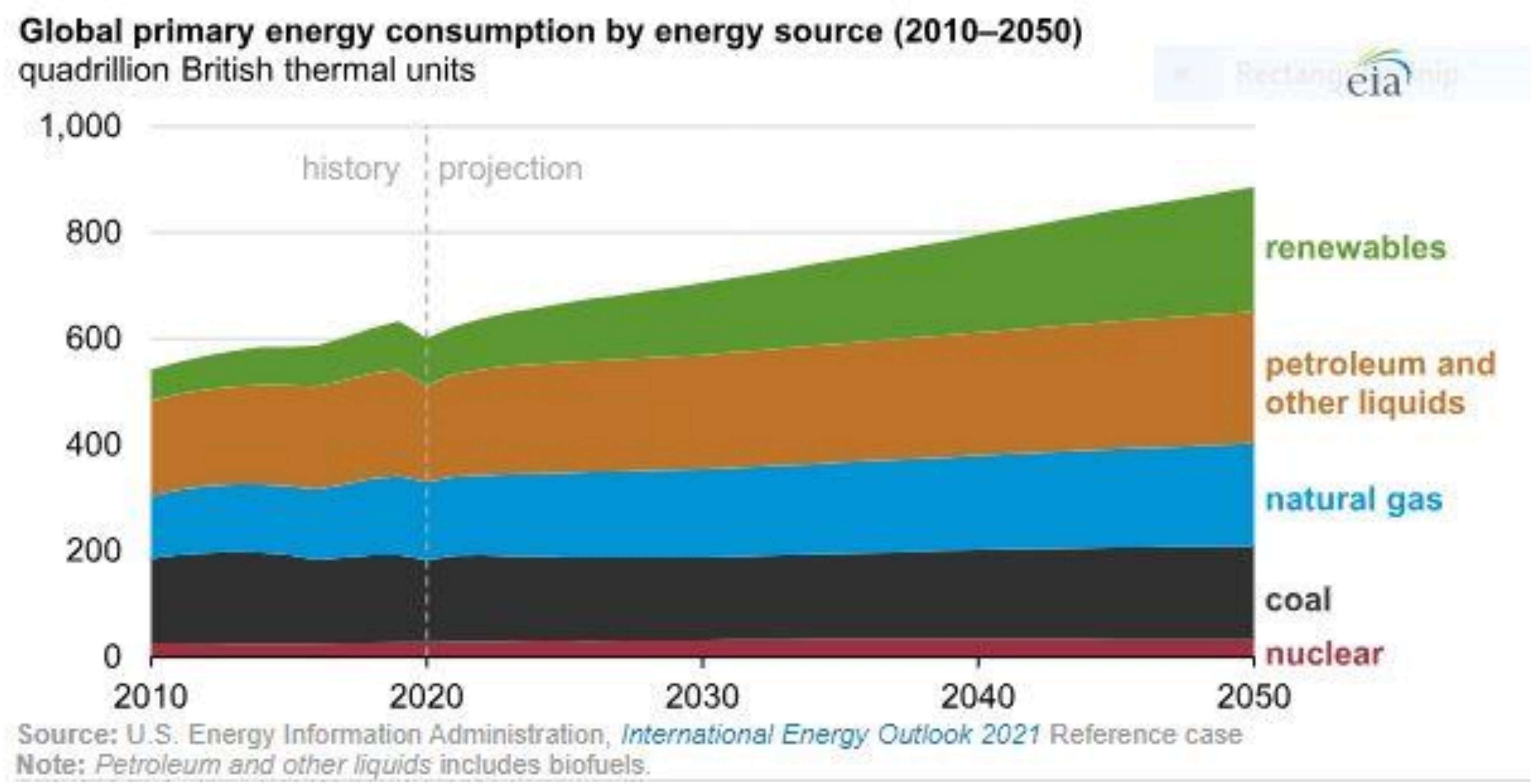
To meet Paris Accord US needs to drop to 1.4 Gigatonnes per year, and the EU to 0.5 Gigatonnes per year, by 2050

Net Zero requires both to drop to zero in the same 27 year period



* Center for Climate and Energy Solutions

1. Global Energy Mix in 2050



- Renewables are the fastest growing category (45%)
- However, world energy demand is expected to grow by 50% in the same time period.
- Renewables are displacing, in part, new hydrocarbon demands, but all energy sources are increasing by 2050

2. Critical Building Materials

- Work is being done on reducing emissions from these sources, but many of 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

* US National Renewable Energy Lab

3. Strategic Minerals

- Materials needed for generators, catalysts (hydrogen), and batteries to build and store energy from renewables
- Minerals used include (futures prices):
  - **Copper** ($1.95 per lb in 2016, $4.03 per lb in 2023 **2X**)
  - **Cobalt** ($13,486 per ton in 2016, $51,826 per ton in 2023 **4X**) **– 2022 spike was over $80k/tonne**
  - **Nickel** ($6,201 per ton in 2016, $20,539 per ton in 2023 **3X**) **– 2022 spike was over 48k/tonne**
  - **Rare Earths** (varies but typically has gone up **3-4X**)
  - **Lithium Carbonate** ($137,980 per tonne in 2017, $493,028 in 2023 **3.5X**)
  - **Silver** ($13.5 per oz in 2016, $24.279 per oz in 2023 **2X**)
- Batteries need vast quantities of materials
  - To electrify all 3 billion estimated vehicles in the world in 2050
    - Would require **all** of the proven reserves of lithium on the planet
    - Leaves nothing for grid scale batteries
    - Or your Smart Phone…

Other countries and Industries also need these materials!

Tradingeconomics.com

4. Geopolitics and Social Costs

- 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**, **Philippines, Cuba**
  - **Nickel** top 5: **Indonesia, Philippines, 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**

OECD

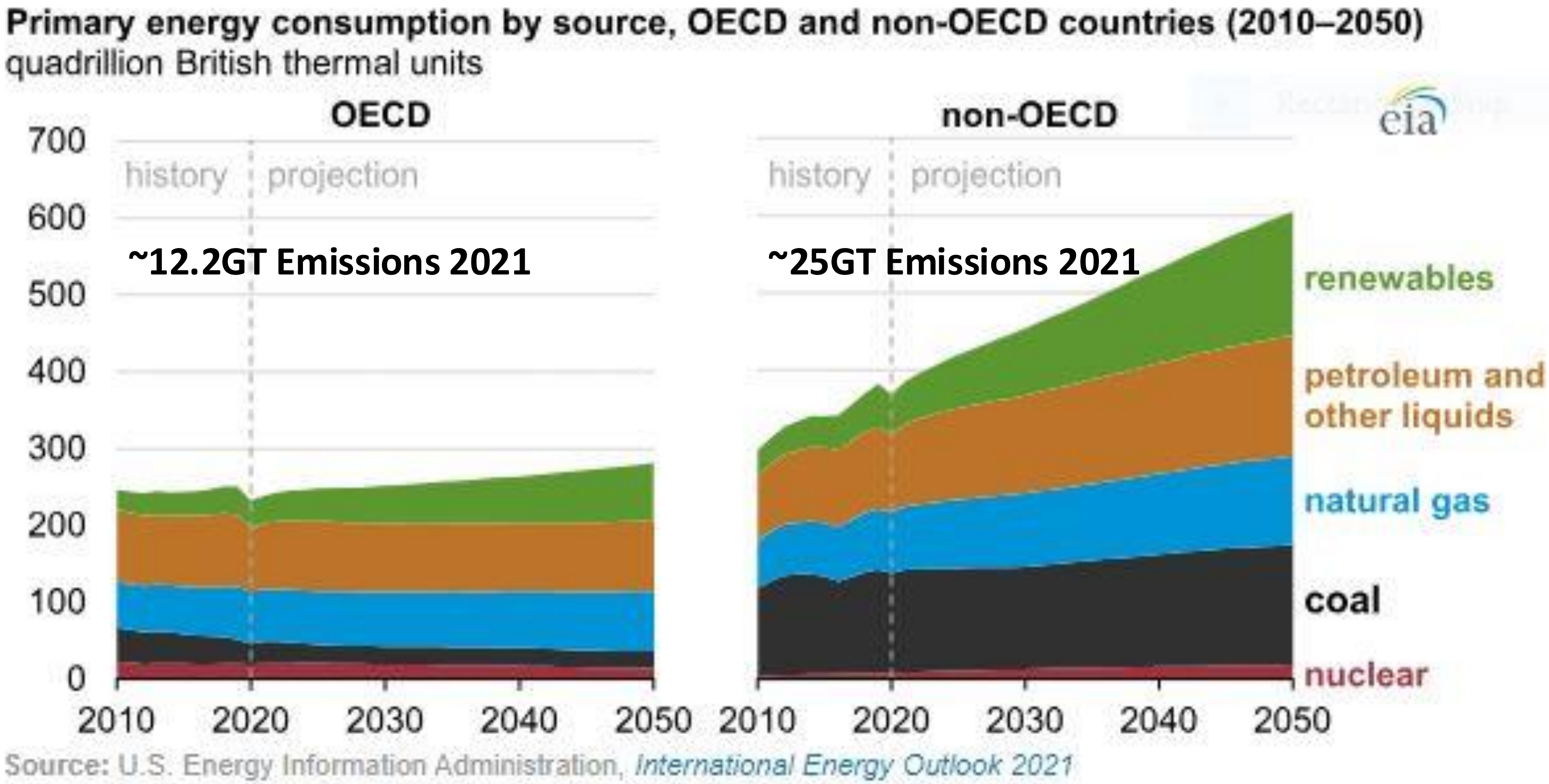
Non-OECD

- 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, Argentina** – Atacama desert, hydrologic system of several million years 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 are needed

Tradingeconomics.com

5. Unmitigated Emissions: Developing world



OECD Countries: Primarily Europe, North America, Far East Asia are expected to slightly reduce Hydrocarbon use by 2050, and have modest growth in demand covered by renewables

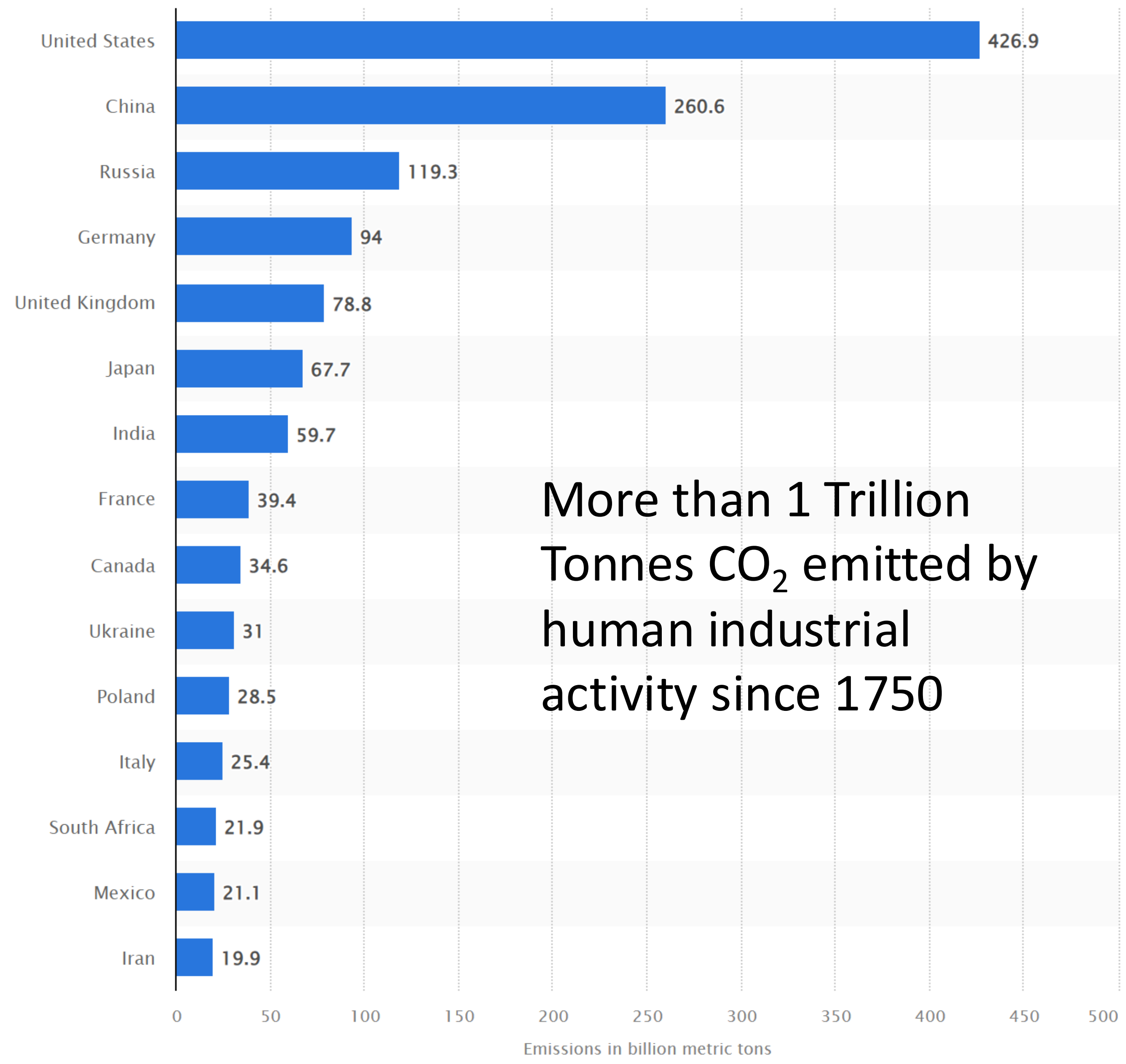
Non-OECD Countries: See rapid growth in every energy category, leading to a net increase in hydrocarbon use world-wide in 2050

6. Legacy Emissions

The problem is not just current emissions…

While China and ultimately India will surpass US total emissions, at present OECD Countries represent over 75% of all the CO_2 that has been emitted by human activities since the beginning of the industrial revolution (1750 to present)

CO_2 molecules resides in the atmosphere for an average of 990 years



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 / Transportation Fuels (~20%)
- **Critical Building Materials:** Drive economic development
  - Cement (~8% world emissions)
  - Steel (~9%)
  - Glass (~3%)
- **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

Is There a Path to Net Zero?

- **Locally, yes.** Communities, Cities, States, even Countries could 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
  - Grid stability from outside their borders
- **Cost is an issue**
  - Cannot work in a vacuum when it comes to costs of global commodities
  - Significant portions of GDP will be required
  - May become non-competitive with countries who do not, or cannot afford to, pursue these goals as aggressively.
  - May split the world into dual OECD/non-OECD economies…. IE BRICS

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 to countries that cannot afford to develop those technologies on their own
  - ***Carbon Capture and Storage from fixed emission sources is the cheapest (but still expensive!) and has the lowest cost of entry in both technology and materials***
- **Cost is a major issue**
  - The 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

Could 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 (Sticks) and Tax credits like 45Q in USA (Carrots) are impactors

How Can We 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
    - **Need better, more flexible, and cheap power storage**
    - **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 managed (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

CCUS: 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, even to support renewable growth**
  - Plastics
  - Lubricants
  - Road building
  - And the 6000+ other products we use everyday…
- **The world needs abundant today's 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**
  - **Carbon Utilization (EOR, Cement manufacturing, Plastics, etc)**
  - **Carbon storage to mitigate emissions**
  - **Lowest cost of entry to reach climate goals**


Questions?