Life Cycle Carbon: Estimates and Outlook

Municipal and State Energy Forum

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IRESN

June 28, 2023

Introduction

Toward a circular renewable energy economy

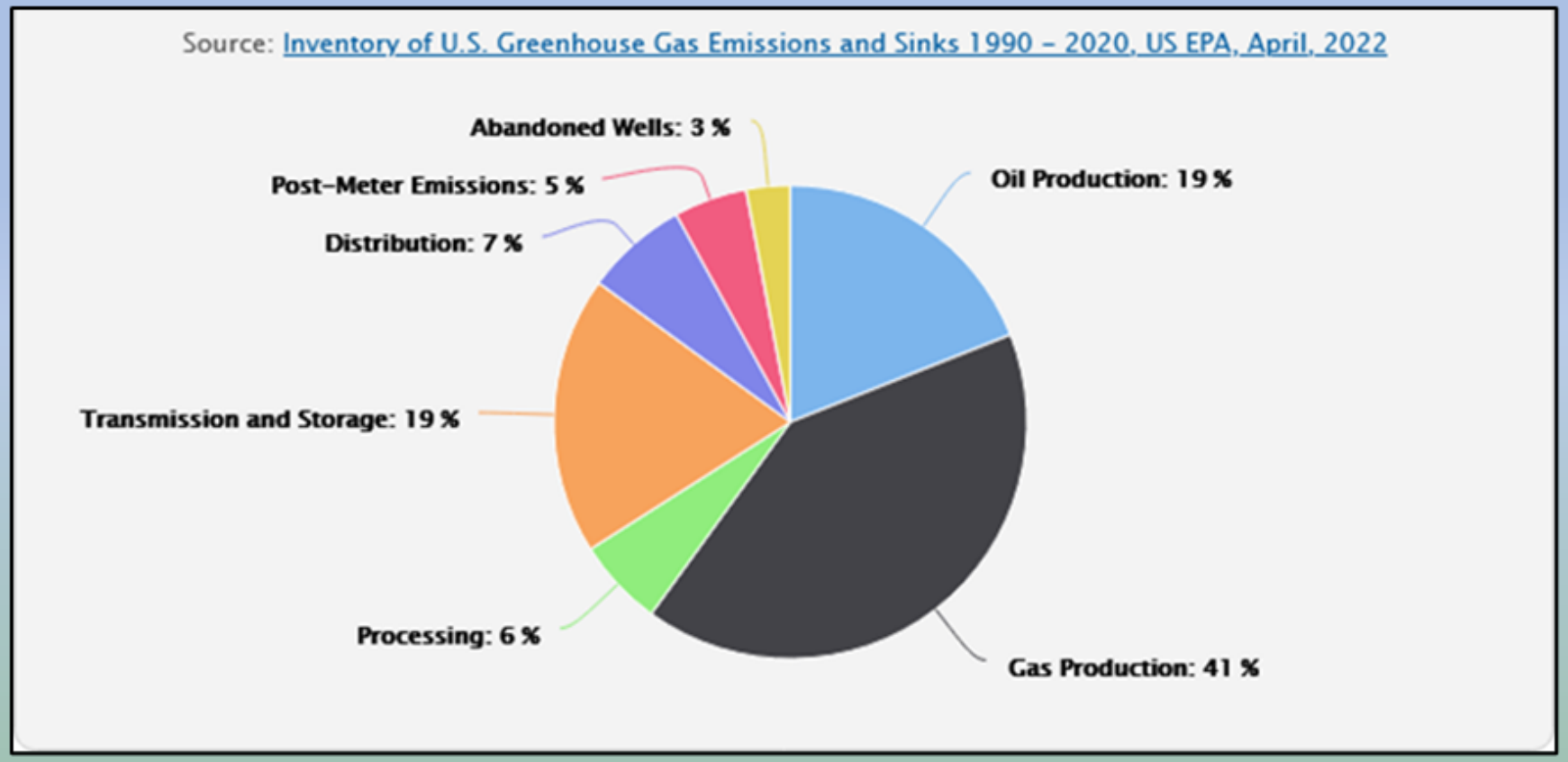
Energy payback and carbon payback

Definitions and metrics

- Buildings
  - Upfront carbon (tons of CO2-eq)
    - **Embodied carbon**
    - **Embedded carbon**
  - Operating carbon (tons of CO2-eq)
- Energy Systems and Products
  - **Life cycle carbon (grams of CO2-eq/kWh → tons of CO2-eq per year)**

Fugitive Methane Emissions Analog

2020 Oil and Gas Methane Emissions by Segment (~211 million metric tons CO2-eq)



Renewable Electrification

- Substitution of materials, equipment and low carbon fuels for high carbon fuels is underway in some countries and in some economic sectors.
- Renewable electrification is a key substitution strategy intended to bring operating carbon under control.
- Global annual energy-related carbon dioxide emissions rose to 36.3 and 36.8 billion metric tons of CO2-eq in 2021 and 2022.
- To what extent will life cycle carbon emissions off-set the effect of substituting renewable energy for fossil fuel use? What might cause life cycle carbon emissions to escalate or exceed current estimates? What can be done to minimize life cycle carbon emissions?

Renewable Electrification and Decarbonization

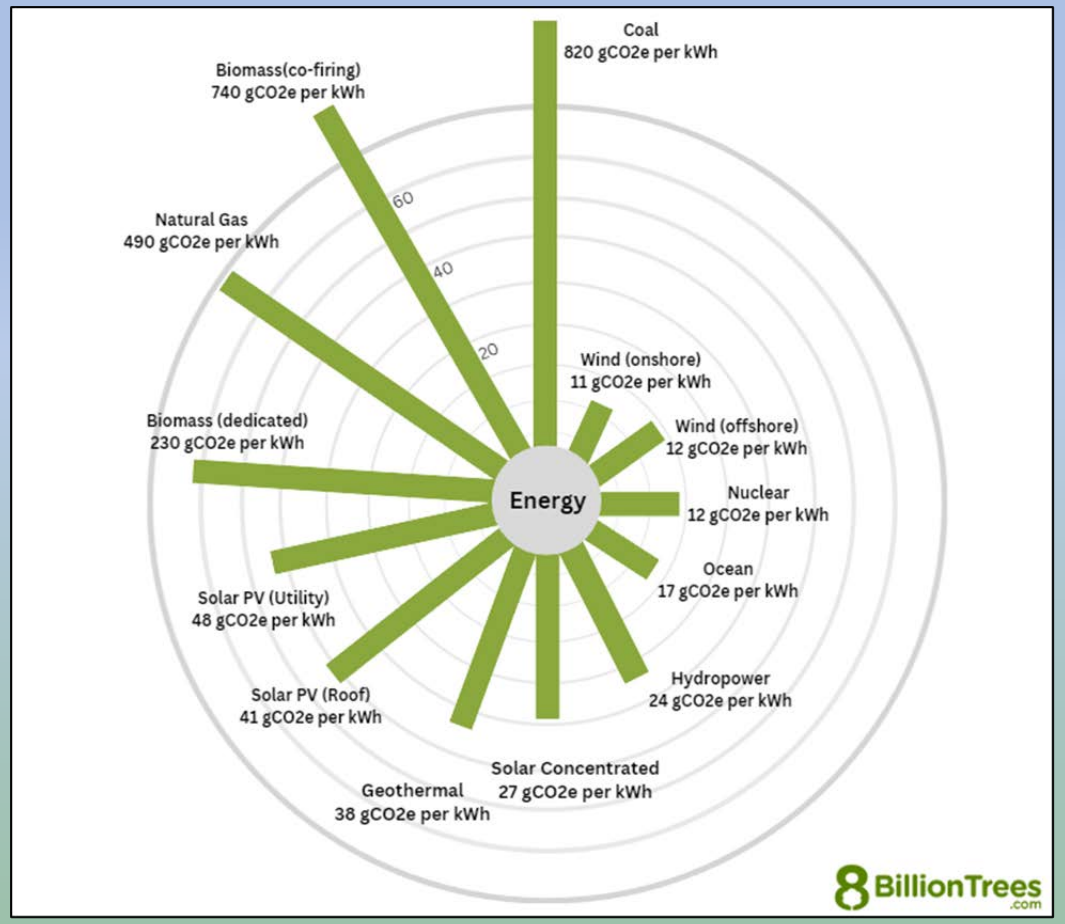
- Life cycle carbon emissions accompanying substitution are additive to historical and on-going emissions.
  - Solar and wind projects
  - Vehicle and stationary storage batteries charged with renewable electricity
  - Heat pumps that use renewable electricity for refrigeration, cooling or heating
  - Refrigerants - high GWP gases that enable heat pumping
  - Renewable electricity storage and transport losses
  - Renewable heat and fuels
    - Space and water heating
    - Process heating
    - Renewable hydrogen

Life Cycle Carbon Emissions by Energy Source

- Life cycle carbon emissions resulting from solar and wind deployment in the current decade will equal 15 percent of current annual global GHG emissions.

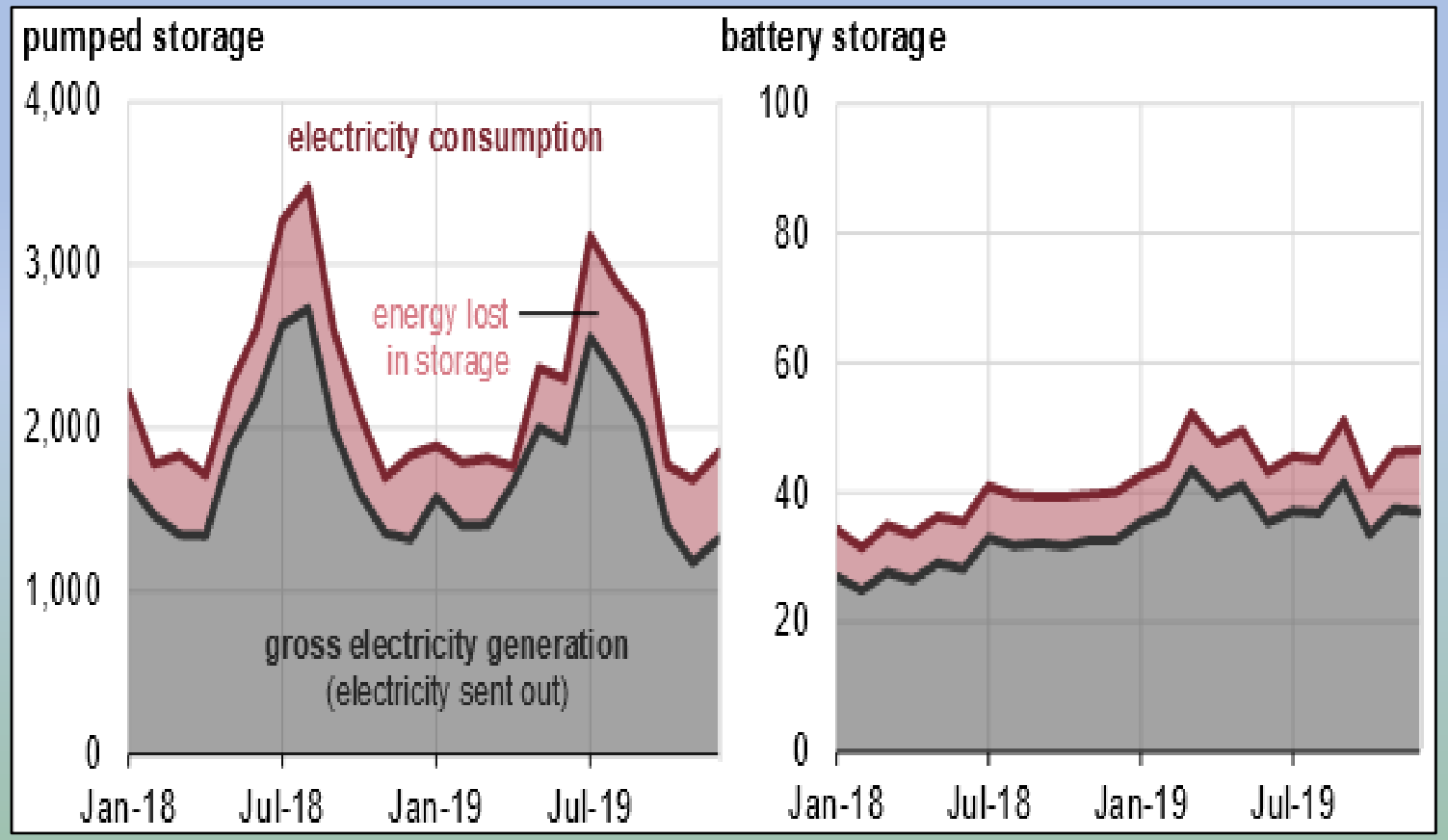
Comparisons and concerns:

- On-shore vs. off-shore wind
- On-site vs. power plant solar
- Operating lifetimes
- Energy storage life cycle carbon strategy and management



Renewable Electricity Losses

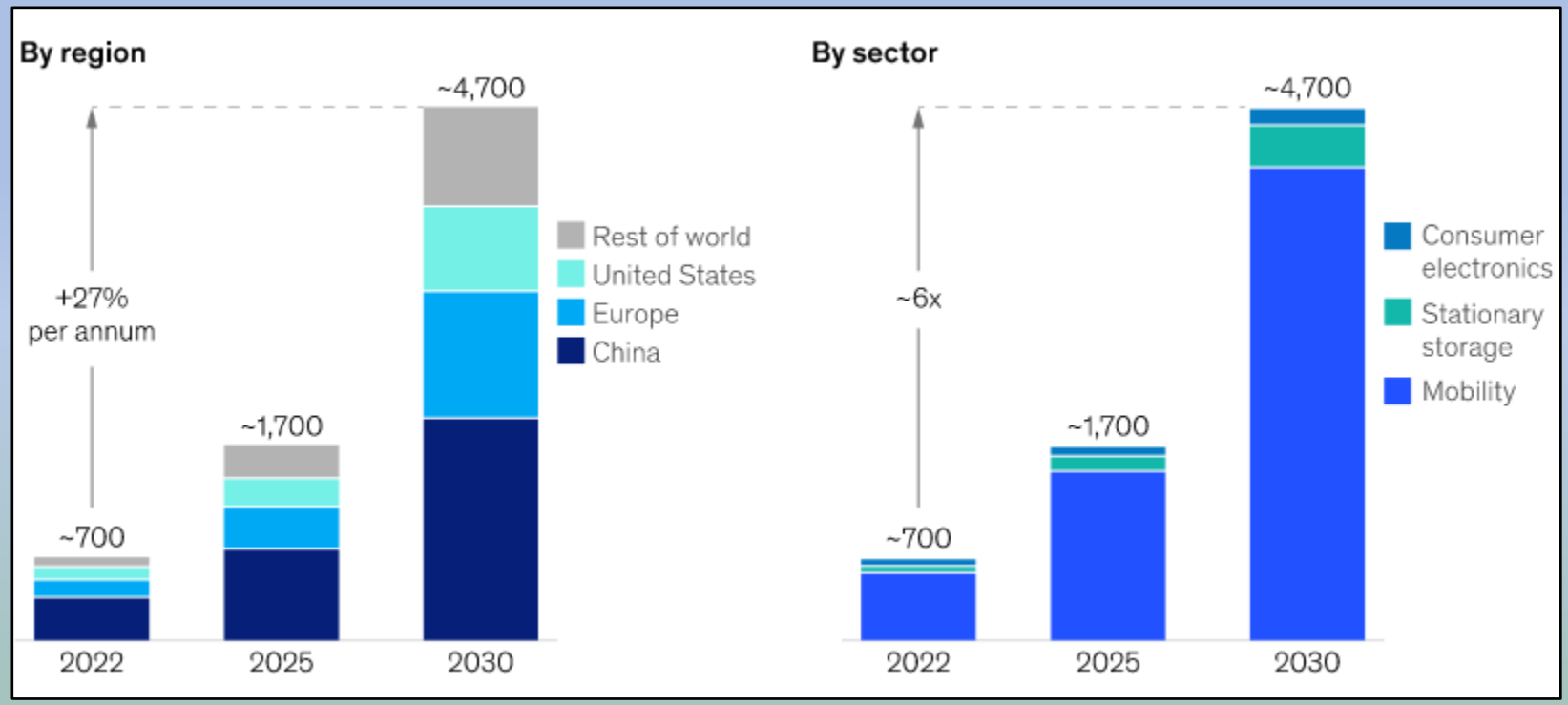
- Five percent of electricity generated in the US is lost during transport, and twenty percent of stored bulk electricity is “lost” due to pumping losses, initial battery self-discharge and higher rates of self-discharge at elevated ambient temperatures.
- Direct use of solar electricity avoids transport and storage and reduces life cycle carbon emissions.



Electric Vehicle Batteries

- Most EV batteries (around 80 percent of the global total) are currently manufactured in China where coal is the dominant energy source.
- Building a new EV can produce ten metric tons of CO2-eq - 80% more emissions than building a comparable gas-powered car.

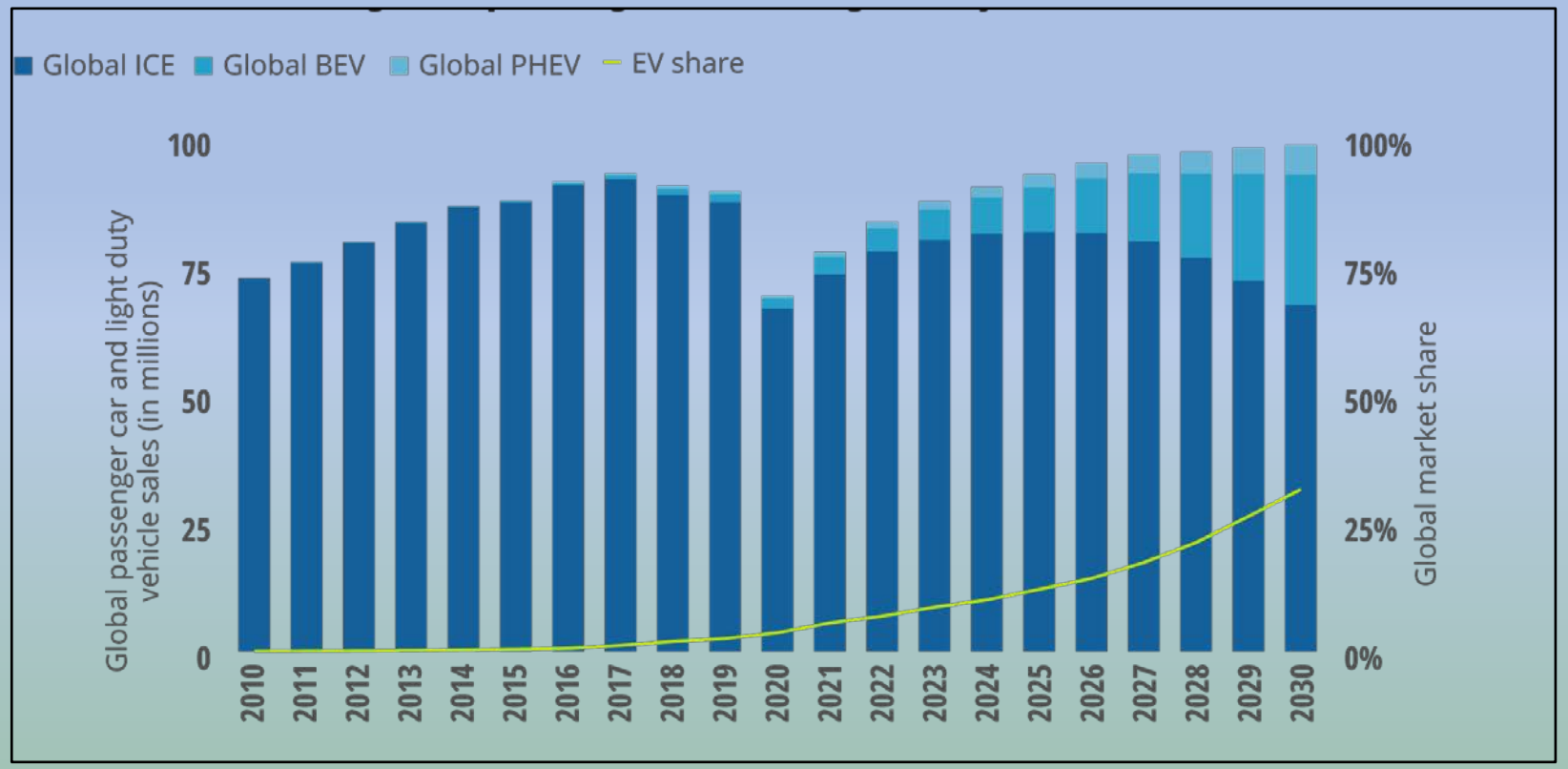
Annual Global Li-ion Battery Demand Forecast (GWh) – Base Case



EV Market Growth and Life Cycle Carbon

- An EV's carbon debt is repaid by the time it has been driven 20K miles, less or much more where charging electricity is zero or high carbon.
- Batteries in under-utilized vehicles take many years to repay their carbon debt.
- Lithium-ion battery self-discharge increases with age, cycling and elevated temperature.

Outlook for Annual Global Passenger-car and Light -duty Vehicle Sales



Battery Energy Storage Systems

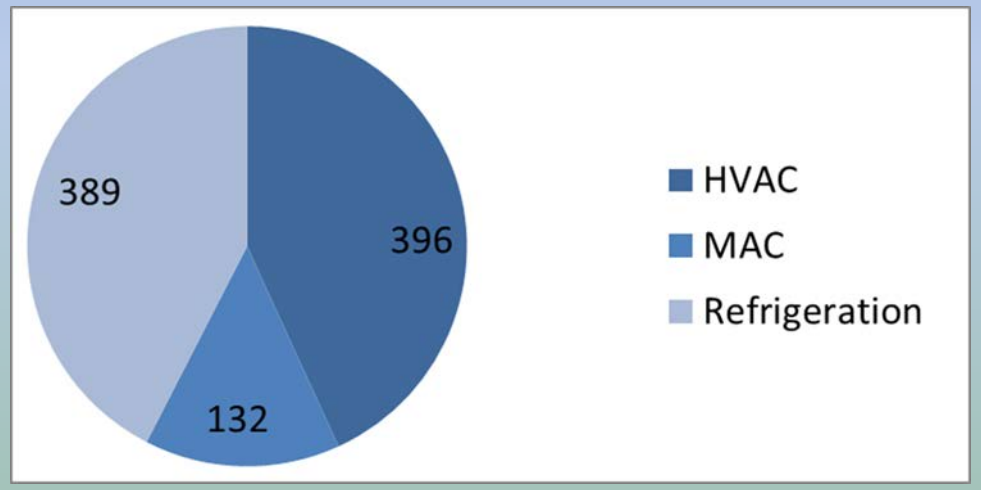
- Deployed by utilities, self-generators and charging station owners
- Flexible capacity being added as thermal power plants are retired
- Currently in California, 2kW of battery plant capacity for each 1kW of solar power plant capacity may increase to 5-10 kWh per kW.
- Fast (EV) chargers require BESS capacity to avoid demand charges.
- Large scale battery recycling focuses on materials recovery vs. cell second use.
- Redundant V2X and BESS Li-ion battery capacity is a long-term life cycle carbon concern.

Refrigerants - Introduction

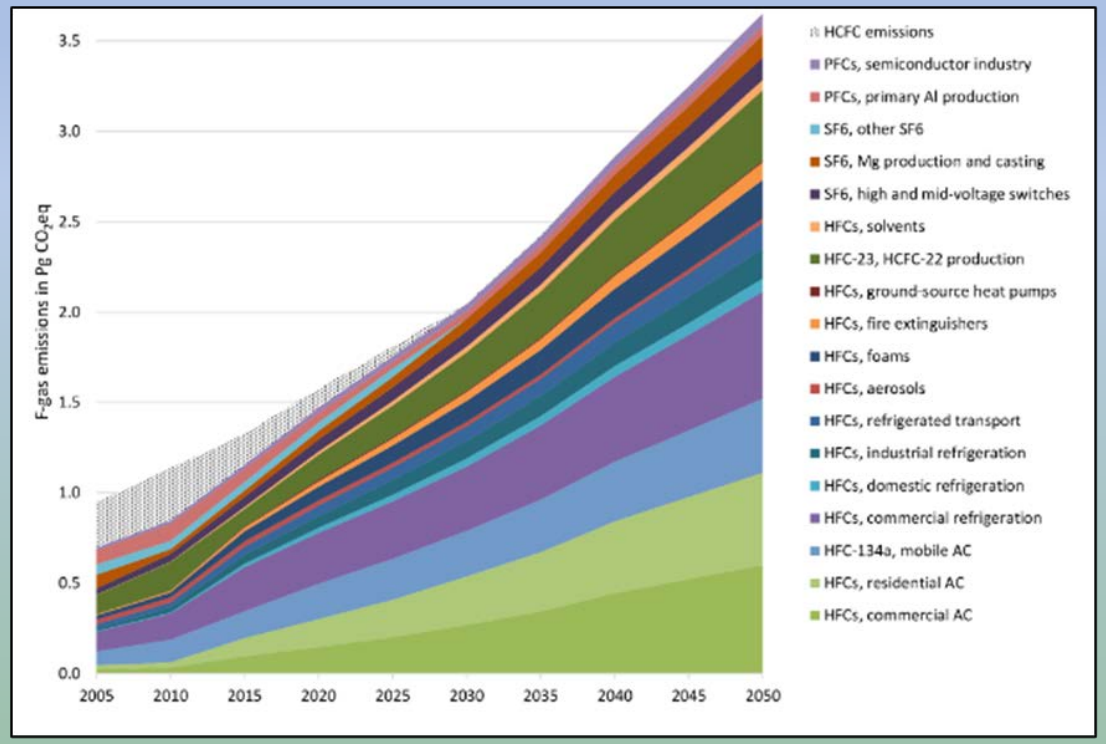
- Ozone depleting substances being phased out and replaced by hydro-fluorocarbons (HFCs)
- Between 2020 and 2030, HFCs released from discarded cooling equipment will contribute about 4% of total global energy related greenhouse gas emissions – 15 billion tons of CO2-eq.
- Thanks in part to new markets for heat pumps, HFC usage is increasing at about 10 to 15% per year and, absent remediation, will account for 10 to 20 percent of total GHG emissions by 2050.
- Annual refrigerant reclamation in the US is five percent of annual production. The percentage is declining.

Refrigerants – Usage and Emissions

Global Vapor Compression Use of Refrigerants, in kilotons

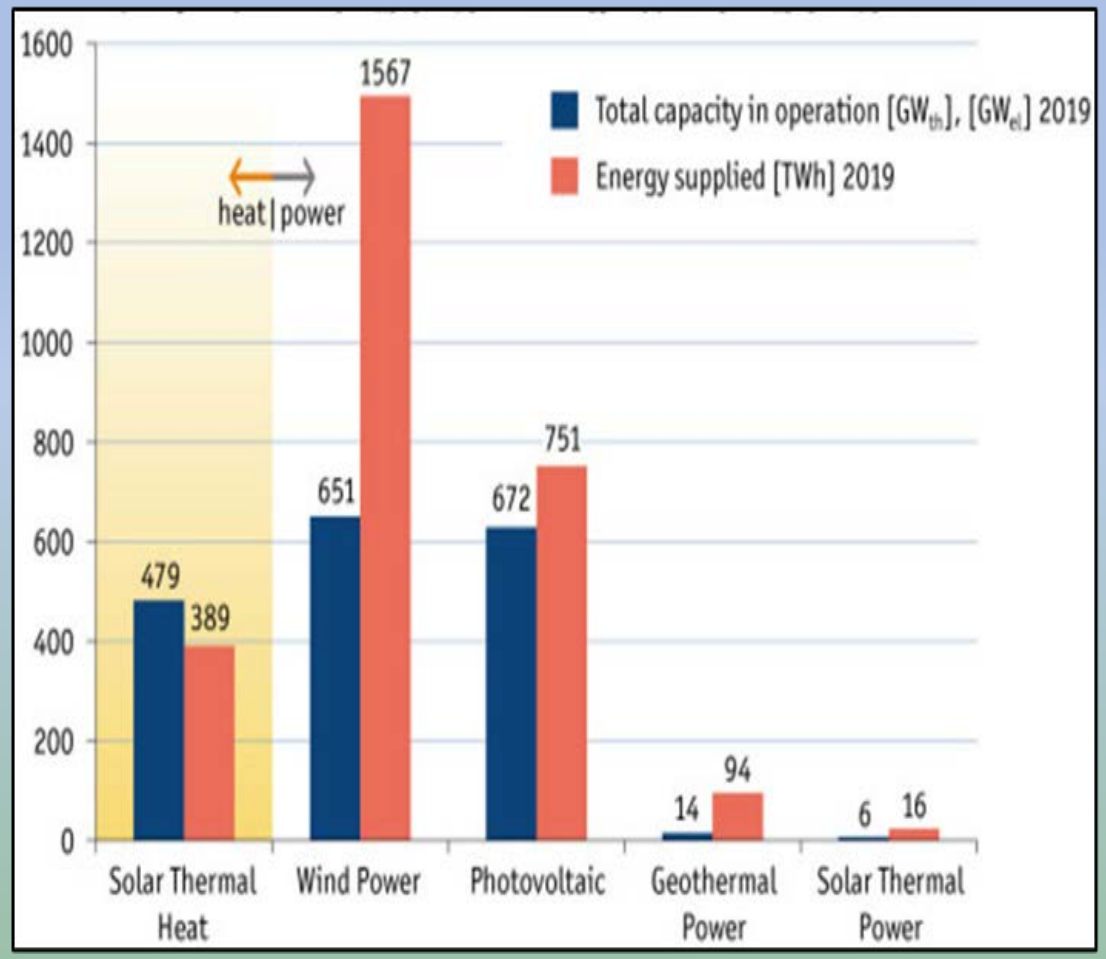


Baseline Emissions of Fluorinated Gases by Source Sector



Renewable Heat and Fuels

- Substitution of solar heat for fossil heat is underway and expected to continue but lacks effective and pervasive policy support.
- In the US and Brazil ethanol is being blended and substituted for gasoline.
- Substitution of renewable hydrogen for petroleum in the transportation sector and use as a seasonal electricity storage medium now has significant policy support in the US and other industrial countries.



Life Cycle Carbon Emissions Estimate

Estimated Global Renewable and Refrigerant Equipment Life Cycle GHG (Carbon) Emissions (2020-2029) (billions of tons of CO2-eq)	
Renewable Electricity Generation	**6**
Electric Vehicle Battery Storage	**>10**
Renewable Electricity Storage and Transport Losses	**4**
Refrigerants	**15**
Solar Water and Space Heat	**0.1**
High Temperature Solar Heat	**<< 0.1**
Renewable Vehicle Fuel - Bio-ethanol and Bio-diesel	**< 0.1**
Renewable Vehicle Fuel - Hydrogen	**<< 0.1**
Renewable Hydrogen Energy Storage	**<< 0.1**
Total	**>35**

Near Term Life Cycle Carbon Mitigation

- Focus on major sources
  - Reward recovery of high GWP refrigerants
  - Prioritize high usage EVs
- Plan for circularity
  - National plan
  - Local climate action plans
  - State support of local circularity investments and operations
- Increase battery longevity and avoid end of life losses
- Specifically account for life cycle carbon in GHG inventories
- Proportionate policy attention

Conclusion

Cumulative global renewable and refrigerant life cycle carbon emissions account for about ten percent of current energy related GHG emissions.

The percentage is likely to increase significantly before mitigation measures kick in.

The effect will be to off-set the impact of investments that directly reduce “operating carbon” emissions.

Therefore, life cycle carbon emissions increases merit timely mitigation strategies and investments and policy attention by governments at all levels.

For a Deeper Dive

- Report: Global Life Cycle Carbon Emissions – Estimates and Outlook
- Article: Toward a More Circular Renewable Energy Economy