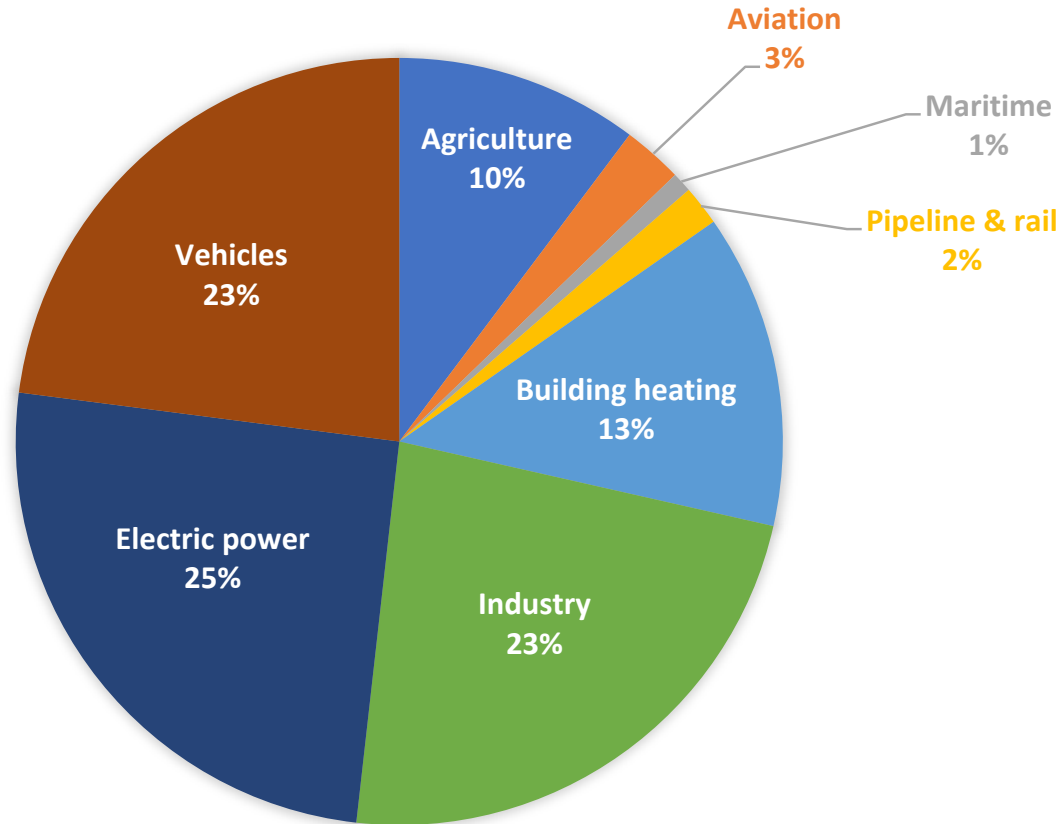


**Which Energy for Which Use:
Electricity, Hydrogen or Biofuel?**

Part of the Hydrogen Tech Brief Series

Which Form of Energy Is Right for Each Use?

2021 GREENHOUSE GAS EMISSIONS



Sectors

Vehicles

Electric Power

Industry

Building Heating

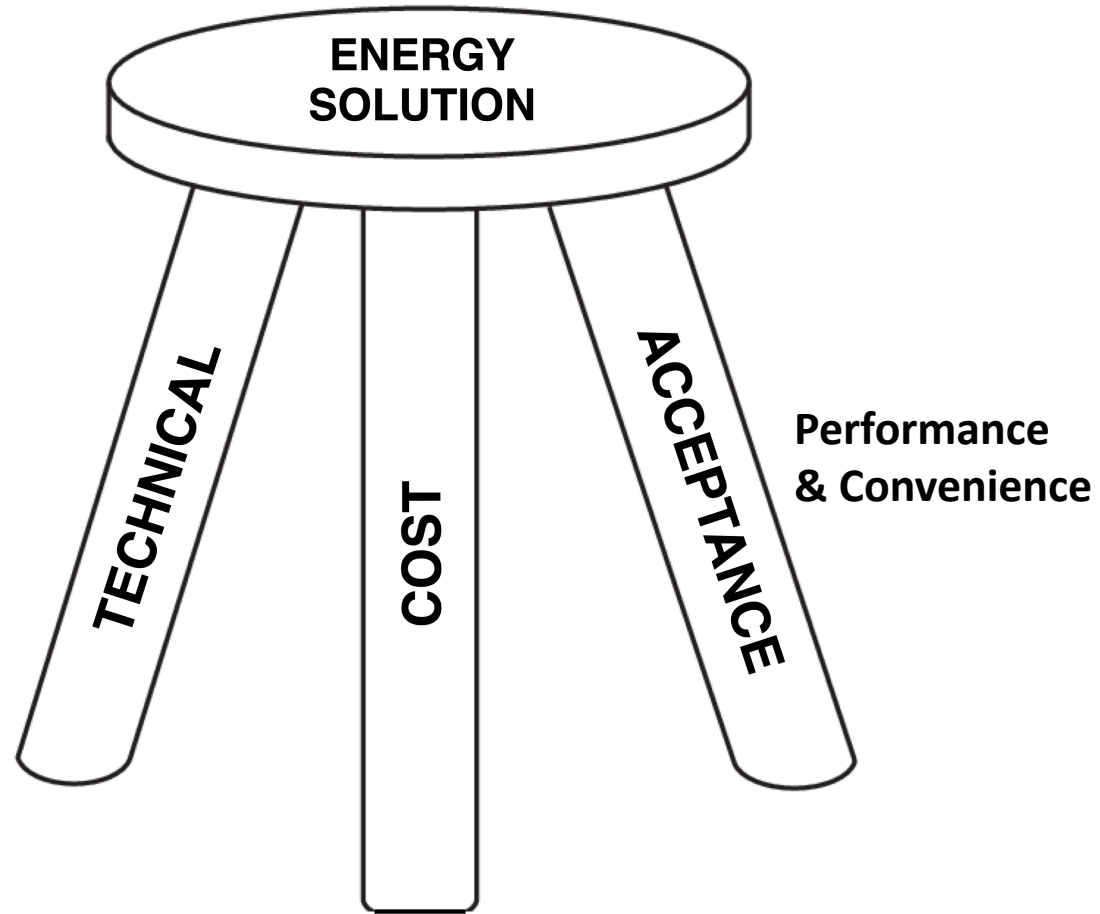
Maritime

Aviation

Agriculture

Pipeline & Rail

Which Form of Energy Is Right for Each Use?



**Energy Solutions Must Meet
Three Criteria**

Energy Source Summary

Source	Renewable	Zero GHG	GHG Neutral	GHG Negative
Wind	✓	✓		
Solar	✓	✓		
Geothermal	✓	✓		
Hydroelectric	✓	✓		
Hydrogen wells	✓	✓		
Generated Underground (GU) Hydrogen		✓		✓
Biomass or algae to biofuel	✓		✓	✓
Biomass or algae to hydrogen	✓	✓	✓	✓
Nuclear		✓		

Suitable Energy Forms for Uses

That Meet Our 3 Criteria

Use	Electricity	Hydrogen	Biofuel	Key Discriminator
Electric Grid	✓			
Transportation	✓	✓		Performance & Convenience
Industrial Heat		✓		Technical
Aviation		✓ (short haul)	✓ (Long Haul)	Technical
Building Heat	✓ (New Construction)		✓ (Existing)	Cost
Maritime			✓	Technical

Hydrogen is a Useful Fuel for Transportation

- Two types of Electric Vehicles (EV's)
 - Battery EV's – Get their energy by charging
 - Fuel Cell EV's – Get their energy by fueling with hydrogen
- Battery EV's are *different* than petroleum vehicles
 - More convenient for short distances and charged at home or work
 - Far less convenient for long range or hauling loads
- If we are to convince users to adopt something new:
 - It must provide the same performance and convenience as petroleum
 - Fuel Cell EV's provide the same user experience:
 - ✓ 3-Minute Refueling (trucks longer)
 - ✓ Light, Compact, Abundant Energy for Trucks & RV's
 - ✓ Range Undiminished by Cold Weather
 - ✓ Full Driving Range with Heavy Loads and Towing

Industrial Heat

✗ Electricity

- Inefficient

✓ Hydrogen

- Molecules are needed for some processes
 - Removing oxygen from iron oxide ($\text{FeO}_2 + \text{H}_2 \rightarrow \text{H}_2\text{O} + \text{Fe}$)
- High temperature processes
 - Steel, glass and cement making.

Aviation

- ✓ Short-haul
 - Hydrogen
 - Energy density sufficient for short-haul flights
- ✓ Long haul
 - Biofuel
 - Higher energy density than hydrogen
 - JP-4 can be made from biomass
 - Easy transport and storage.

Building Heating

- ✓ New construction, electric heat pumps are ideal
 - A heat pump is a reversible air conditioner
- ✓ Existing buildings , this is the most difficult sector to decarbonize
 - Huge installed base of furnaces are costly to replace (\$20K to \$40K per home)
 - Some homeowners will refuse to have the modification
 - Solution – Biofuels
 - Carbon-Neutral solution
 - Replace the fuel not the equipment
 - Can use existing gas & oil delivery infrastructure of pipelines and tankers.

Maritime

✗ Ammonia

- Tissue irritant, strong smell

✗ Hydrogen

- Bulky, tanks expensive

✓ Biofuel

- Methanol or other
- High energy density
- Easy to store, tanks the least expensive
- Use existing engines (with modifications)
- Carbon neutral or carbon negative if some of the biofuel is sequestered

Complete Clean Energy Ecosystem

