Compressed Air Vehicles: A Drive Cycle Analysis of Vehicle Performance, Environmental Impacts, & Economic Costs

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Introduction

Compressed Air Vehicles (CAVs, or "air cars") are proposed as a gasoline vehicle alternative with superior environmental characteristics and adequate performance for city driving.

However, this analysis reveals that CAVs perform worse than existing gasoline and electric vehicles in nearly all metrics. Further, the utility of an air car is significantly limited by its short driving range of 29 miles.

Methodology

Analysis of CAVs relies on three steps:

- Drive Cycle Simulation of CAV fuel economy and range. Relies on second-by-second calculation of vehicle performance and energy use.
- Energetic Calculation of compressed air as a transportation fuel. The energy density (by mass and volume) is compared to other fuels and battery types.
- Well-To-Wheels Analysis of the CAV's operational greenhouse gas emissions. Relies on upstream carbon intensity of electricity generation, including fuel extraction/processing, generation, and distribution. A sensitivity analysis accounts for the difference between clean, average, and dirty electricity generation.

Comparison to Other Vehicle Types

CAVs compared to gasoline and electric vehicles across five categories:

- Driving Range
- Fuel Economy
- Carbon Footprint (using clean, average, dirty power)
- Operation costs (fuel)

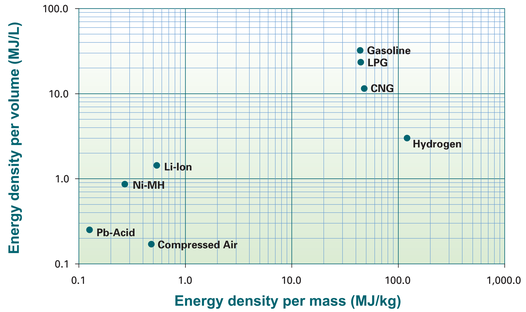
Gasoline and electric vehicle performance based on published specifications of existing models (Volkswagen Fox, Think! City EV)

For a valid comparison, all vehicles measured on the same drive cycle—European Urban Drive Cycle (EUDC)

Finding 1: Compressed air stores less energy than any other fuel or battery type.

Energy is stored in compressed air in the form of higher pressure, and is released as the air expands to ambient pressure. Energy density per mass and volume are a function of temperature and pressure. Compressed air holds 1% of the energy in gasoline and 12% of lithium-ion batteries (per volume).

Energy Density of Transportation Fuels



Finding 2: Compression and expansion losses limit CAV pump-to-wheels efficiency to 14.7%.

Efficiency of compression and expansion is bounded by thermodynamic limits, reducing the pump-to-wheels efficiency of the CAV. Total PTW efficiency is 14.7%. Principal components of PTW efficiency:

- Compression: deliver compressed air @ 30MPa. Calculated based on published specs for high-pressure compressors. N(comp) = 53%
- Expansion from air tank to pneumatic motor. Calculated assuming adiabatic expansion in two expansion steps. N(exp) = 71%
- Motor efficiency of converting air power to mechanical power. Calculated based on published specs for high-power pneumatic motors. 40% across the simulated drive cycle.

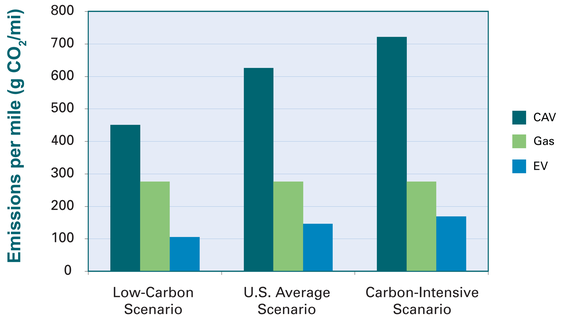
Finding 3: The CAV's carbon footprint is higher than gasoline and electric vehicles.

The carbon footprint of the CAV, powered by an electric compressor, is up to 1.6-2.5x greater than that of a gasoline vehicle and 4x greater than an electric vehicle. GHG emissions are calculated on a full well-to-wheel basis including emissions from fuel extraction, processing (or electricity generation), distribution, and vehicle consumption.

Emissions associated with gasoline vehicles were calculated from the GREET model. Unlike a gasoline vehicle, which has just one fuel pathway, The CAV and EV GHG emissions depend on the upstream fuel mix of electricity generation. Emissions from electricity generation were calculated under three scenarios representing clean, U.S. average, and dirty power generation.

The three scenarios utilize the following emission factors: a U.S. average generation WTW emission factor of 694 g CO2/kw-hr; a low-carbon natural-gas generation WTW emission factor of 500 g CO2/kw-hr; and a carbon-intensive coal generation WTW emission factor of 950 g CO2/kw-hr.

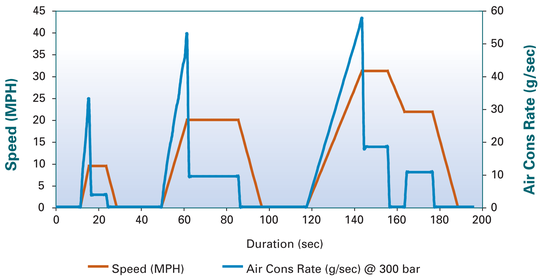
Carbon Footprint of Selected Vehicle Types



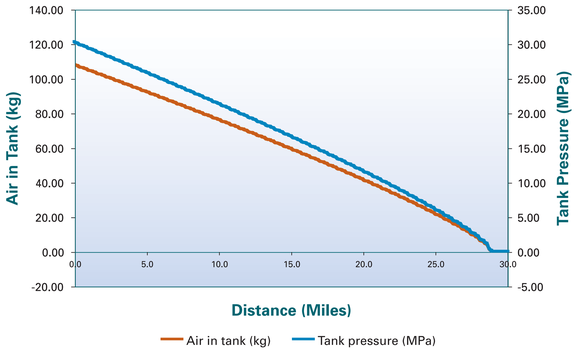
Finding 4: The CAV achieves just 29 mile range on a city drive cycle.

- Drive cycle simulation of air car, second-by-second calculation of energy used.
- Vehicle parameters (size, weight, power) based on published air car specifications.
- Simulation based on European Urban Drive Cycle (EUDC), representing typical city driving—slow speeds and frequent stops.

Drivecycle Speed & Air Consumption



Driving Range and Tank Contents



Summary of Results

	Compressed Air Vehicle	Urban Gasoline Vehicle	Urban Electric Vehicle
Fuel Type	Compressed Air	Gasoline	Battery
Fuel Economy	38 MPG-e	32 MPG	163 MPG-e
Urban Range	29 mi	408 mi	127 mi
CO_2 Emissions (low-carbon)	361 g CO_2/mi	243 g CO_2/mi	184 g CO_2/mi
CO_2 Emissions (U.S. average)	626 g CO_2/mi	276 g CO_2/mi	147 g CO_2/mi
CO_2 Emissions (carbon-intensive)	721 g CO_2/mi	276 g CO_2/mi	169 g CO_2/mi
Fuel cost	$0.21/mi	$0.09/mi	$0.05/mi

Conclusions

Across all environmental, performance, and economic metrics, compressed air vehicles are inferior to similarly-sized gasoline and electric vehicles. The carbon footprint and fuel costs of CAVs are 1.6-2.5x greater than that of a gasoline vehicle and 4x greater than an electric vehicle, depending on the carbon intensity of electricity generation.

As a fuel, compressed air stores just 1% of energy in gasoline, per volume. This, combined with the inefficiencies of compression and expansion, limit the CAV's range to just 29 miles on a tank of air. As a result, the viability of CAVs as a transportation option is severely constrained.

These results indicate that while CAVs are an unconventional idea for current transportation challenges, they are inferior to other transportation options.