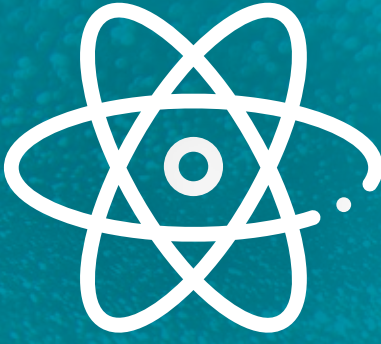


NOTABLE LI-ION ALTERNATIVES

An at-a-glance look at up and coming zero-emission technologies



HYDROGEN FUEL CELLS



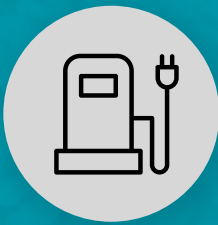
DEVELOPMENT STAGE

For sale today in CA as test market; still being refined for broader distribution



ENVIRONMENTAL IMPACT

Excellent provided mass scale production can be solved



INFRASTRUCTURE NEEDS

High – requires new fuel distribution and delivery mechanisms



RECHARGING SPEED

High – five minutes adds 400-mile (650 km) range



PASSENGER SAFETY

Safe or safer than ICE. Unlike gasoline, hydrogen quickly dissipates if tank is punctured



COST

Low if hydrogen can be obtained from sea water

PROGNOSIS

5-10 years before widespread adoption. Limited to urban and high traffic corridors



SOLAR PANELS



DEVELOPMENT STAGE

First mass-produced solar-powered vehicle rolling off assembly line this year: the Aptera



ENVIRONMENTAL IMPACT

3-25 times less impact than when generating same amount of energy from fossil fuels. Still requires a battery



INFRASTRUCTURE NEEDS

Low, although will soon require more recycling plants and/or better overall recycling for panels



RECHARGING SPEED

Requires ideal weather conditions but battery or supercapacitor can even out periods of varying sunlight



PASSENGER SAFETY

Too early to tell. Vehicles with low drag and low weight may not be as crashworthy



COST

Coming down, starting with \$25,900 for the Aptera

PROGNOSIS

Great potential especially if Musk turns his interest in solar panels from buildings to solar-powered cars



GRAPHENE SUPERCAPACITORS



DEVELOPMENT STAGE

Some commercial applications exist but not yet capable to primarily power a vehicle



ENVIRONMENTAL IMPACT

Poor given current manufacturing techniques; however, material is a carbon-sink with excellent environmental potential



INFRASTRUCTURE NEEDS

High – requires completely new charging infrastructure



RECHARGING SPEED

Very high – able to fully charge within seconds



PASSENGER SAFETY

Excellent – material is non-toxic and non-reactive



COST

Low – carbon is cheap and readily available, but manufacturing techniques need to catch up

PROGNOSIS

Limited to a battery companion technology for foreseeable future since supercapacitors have difficulty maintaining charge



MICROBIAL BATTERIES



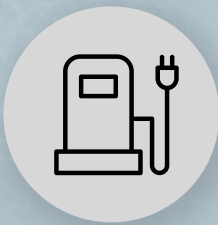
DEVELOPMENT STAGE

Very early. Proof of concept has been completed but not in commercial use



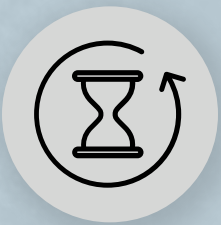
ENVIRONMENTAL IMPACT

Excellent – bacteria are organic, create acetate (which is biodegradable), and are self-renewing



INFRASTRUCTURE NEEDS

Low, assuming batteries are paired with solar panels – their most likely use case



RECHARGING SPEED

Slow – batteries currently require 16 hours to charge for 8 hours of use



PASSENGER SAFETY

Organic components are much safer than Li-ion batteries

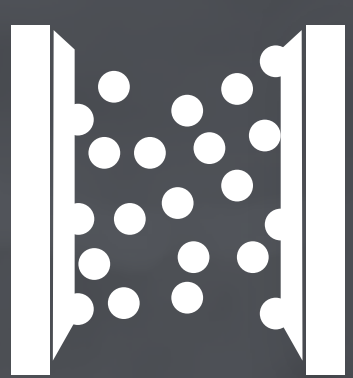


COST

Low since the primary component – bacteria – are self-replicating

PROGNOSIS

10 years plus. Although work continues, hurdles in efficiency and cycles need to be overcome



COBALT-FREE LITHIUM BATTERIES



DEVELOPMENT STAGE

Cathodes using other metals are in various stages of R&D. Expect to see some in production by 2023



ENVIRONMENTAL IMPACT

Replacement chemistries don't have all the concerns of cobalt, but many don't eliminate mining problems either



INFRASTRUCTURE NEEDS

Pricing equivalent to that of current EV infrastructure



RECHARGING SPEED

With careful formulation, charging rate can be same as existing cobalt-based Li-ion batteries



PASSENGER SAFETY

Issues with thermal regulation and fires need to be solved as cobalt does better job of shedding heat



COST

Much better than standard Li-ion – for example manganese is 18 times cheaper than cobalt

PROGNOSIS

Has promise given Musk's ambitions plans to ditch cobalt and given several other OEMs are pursuing cobalt-free battery designs



SOLID-STATE BATTERIES



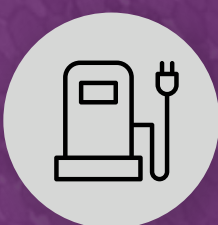
DEVELOPMENT STAGE

In production for small devices like RFID tags, pacemakers, and smart watches; R&D stage for cars



ENVIRONMENTAL IMPACT

Many electrolyte materials are under investigation. Chemistry of "winner" will determine final impact



INFRASTRUCTURE NEEDS

With longer ranges possible, fewer mid-trip EV charging stations are required



RECHARGING SPEED

Potential to charge much faster than Li-ion



PASSENGER SAFETY

Excellent – non-toxic solvents have low flammability, are non-volatile, and have thermal stability



COST

Expensive now but expected to be lower. Only materials less expensive than Li-ion will survive market pressures

PROGNOSIS

Initial commercialization expected by 2024 but not likely widespread until 2030

Visit the [Third Law ZEV blog](#) for more detailed information on each of these technologies.

