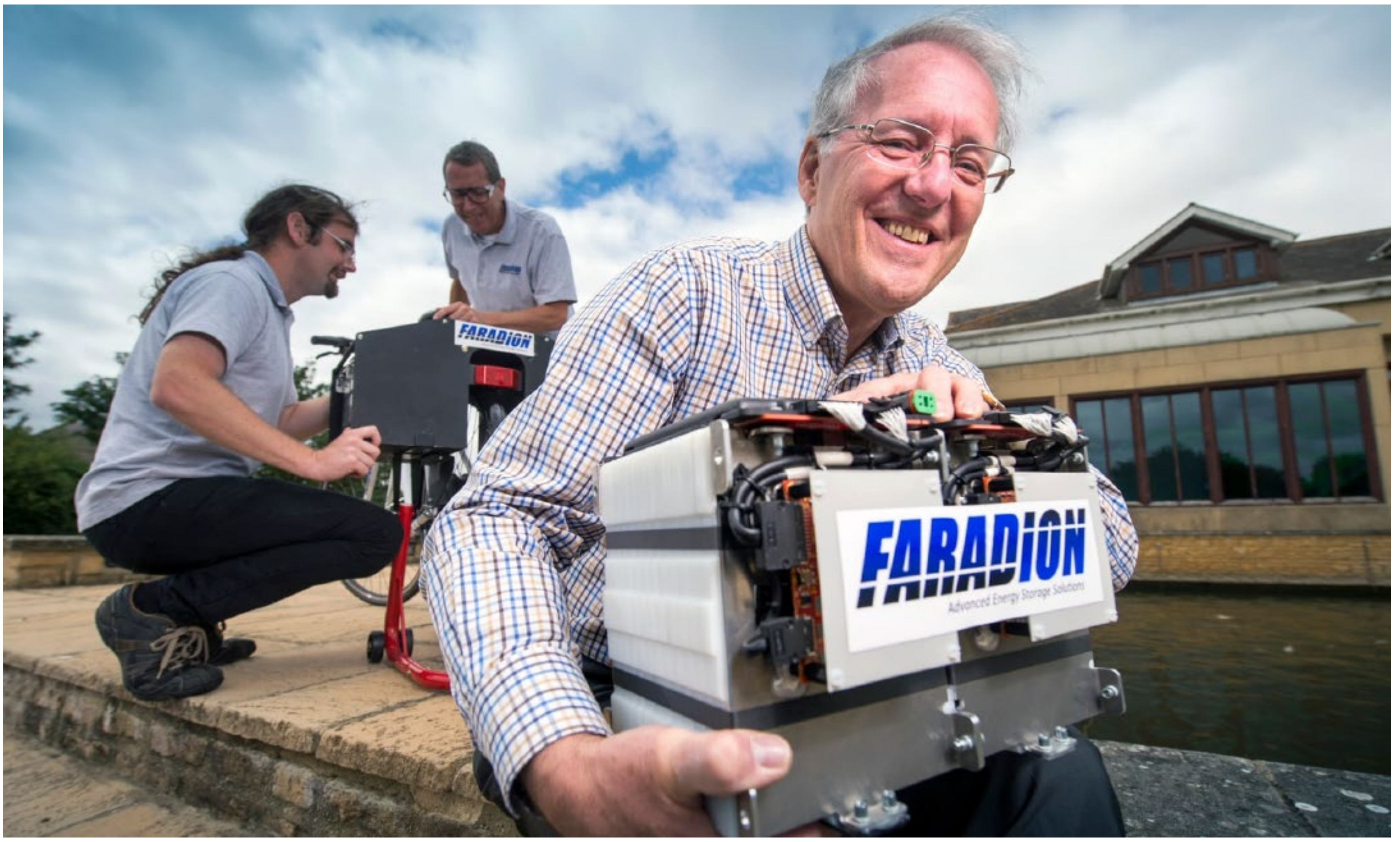
The Future of Clean Transportation: Sodium-ion Batteries

Dr. Ashish Rudola

Bridge India: The 'India Story' abroad is often presented through a narrow lens, be it focusing only on business and the economy, society or policy landscape. Given its diversity, everything about India, and its polar opposite, is true in unison. Bridge India seeks to highlight and celebrate this nuance, to help NRIs and India-watchers understand India better.



Chris Wright, the chairman of Faradion, with the sodium-ion electric car battery developed by the company. Photograph Adrian Sherratt.

The lithium-ion battery is the highest energy density battery technology currently in existence commercially (energy density is a measure of how much energy can be stored in a given volume or weight). It is hence no surprise that for electric vehicle (eV) applications, it is the go-to battery if one requires a long driving range per charge (an eV's range per charge is proportional to its battery's energy density).

However, the high energy density offered by lithium-ion batteries comes at a high price. The lead-acid battery, on the other hand, is much cheaper than lithium-ion battery (about 3-6 times cheaper), however, its energy density is significantly lesser (about 4-6 times lower).

This means that basing eVs on lead-acid batteries might decrease costs for the customer but it would significantly shorten the mileage of the vehicle per charge. But what is so special about lithium-ion batteries that results in such high energy densities?

Lithium-ion batteries currently dominate the market

At its core, the current lithium-ion batteries have a lithium containing material such as lithium nickel-cobalt-manganese oxide ('NMC') as the positive electrode (cathode), graphite as the negative electrode (anode) with flammable organic compounds-based liquid electrolytes. When the battery is charged, lithium ions (Li+) are extracted from the cathode and inserted into the anode. When this battery is actually being used to drive the eV, the Li+ shuttle back from the anode into the cathode.

The reason why such batteries cost a lot is because of two key reasons: high cost of lithium resources and also high cost of cobalt that is used in the NMC cathode. Lithium is a scarce element in the earth's crust (world terrestrial lithium resources estimated at 62 million tonnes from the US Geological Survey 2019).

The dominant forms of lithium production can be from brine (led by South American countries such as Chile) or mined from minerals where Australia is the leading producer. Such scarcity means that supply of lithium will always be an issue, especially if demand increases (this is inevitable with the expected greater future demand for lithium-ion batteries not only for eV applications, but also in mobile phones, laptops, grid-storage etc).

Cobalt is similarly rare in the earth's crust (estimated global terrestrial cobalt resources at only 25 million tonnes) and is quite unique in that most of the cobalt production (~94 % of global production) occurs as a by-product of other minerals' production. This means that the supply and hence price of cobalt will be highly dependent on the demand for the other elements of the principal minerals – this uncertain global cobalt supply-chains is unfavourable for price security.

On the other hand, the primary cobalt reserves are located in the geo-politically sensitive Democratic Republic of Congo where unscrupulous mining practices such as child labour can be often used to extract cobalt from the mines. Therefore the high cost of commercial lithium-ion batteries arises because of the materials they use.

Alternatives to lithium-ion batteries

Can a battery then be made with the benefits of the lithium-ion battery, but uses more earth-abundant materials?

The answer to this question could lie in sodium-ion batteries. The sodium-ion battery works exactly in the same manner as the lithium-ion battery, just with the lithium compounds swapped with sodium compounds. Sodium is the sixth most abundant element in the earth's crust with vast global reserves of sodium minerals: for example, the terrestrial reserves of just soda ash (also known as sodium carbonate) are estimated at potentially 47 billion tonnes. Even more appealingly, sodium is present in appreciable quantities in seawater indicating that sodium reserves are effectively infinite on earth. The upshot of this is that there will never be any supply issues for sodium resources, irrespective of demand, for most countries especially those which have a coastline such as India.

Research interest in sodium-ion batteries really took off from 2011 onwards when the scientific community realised limited lithium resources was a fatal flaw inherent to lithium-ion batteries. Until 2010, there were only 115 scientific papers ever published on such batteries by 2010. In the subsequent nine years, this number grew 50-fold in just nine years, to 5,804.

Of course, as noted in the case of NMC for lithium-ion batteries, the type of cathode, anode and electrolyte used in sodium-ion batteries will ultimately also determine the cost, performance and safety of such batteries. By 2011, since the scientific community was already aware of using earth-abundant elements in batteries, conscious efforts were expended to avoid using costly cobalt in the sodium-ion cathodes.

As a gauge on what viable sodium-ion cathode materials are based on, Faradion (the first commercial sodium-ion battery company, established in 2011 in the UK) has filed multiple patents on sodium nickel and manganese-based oxide cathodes which do not contain any cobalt. Manganese is a very earth-abundant element and nickel is also present in appreciable quantities in the earth's crust, with estimated 89 million tonnes of terrestrial reserves. The energy density of these sodium-ion cathodes has been shown to be almost similar (~80%) to that of NMC lithium-ion cathodes.

Furthermore, the anode used in sodium-ion batteries is also carbon-based, being an allotrope of graphite. This material, called 'hard carbon', can be conveniently made from high temperature pyrolysis of biomass, or indeed, any oxygen-rich organic material, indicating again infinite resources in-principle. The sodium-ion electrolyte uses less flammable organic solvents – this is made possible because hard carbon anode is chemically compatible with propylene carbonate, an organic solvent with a high flash point (propylene carbonate is not compatible with graphite anode used for lithium-ion batteries, precluding its use in lithium-ion systems).

The use of thermally stable solvents means sodium-ion batteries are inherently safe and very unlikely to catch fire, as occurs routinely for lithium-ion batteries using flammable solvents. With reference to safety, sodium-ion batteries can also be discharged to 0 V (zero energy) without any issues; in contrast, lithium-ion batteries can never be discharged to such low voltages as the copper current collector used on the lithium-ion anode side adversely reacts at such low voltage values.

Hence, lithium-ion batteries always need to be stored or transported at a partially or fully charged state, where a battery is at its most unstable state. This is why there are global regulations which tightly dictate how lithium-ion batteries can be transported (this is the reason why airlines disallow lithium-ion batteries to be checked-in, for example).

For sodium-ion batteries, 0 V storage and/or transportation is not a problem due to the use of aluminium current collectors on the cathode as well as the anode. The use of aluminium not only enhances safety of sodium-ion batteries, but also increases energy density and reduces cost of such batteries as aluminium is significantly lighter and cheaper than copper.

Utilising these above technical breakthroughs, Faradion has shown energy densities of sodium-ion batteries to be almost comparable (around three-fourths) with that of NMC-based lithium-ion batteries. Of course, the energy density of such sodium-ion batteries are about four times higher than that of lead acid-batteries at crucially, similar cost levels, with significantly longer cycling stability and much higher efficiency.

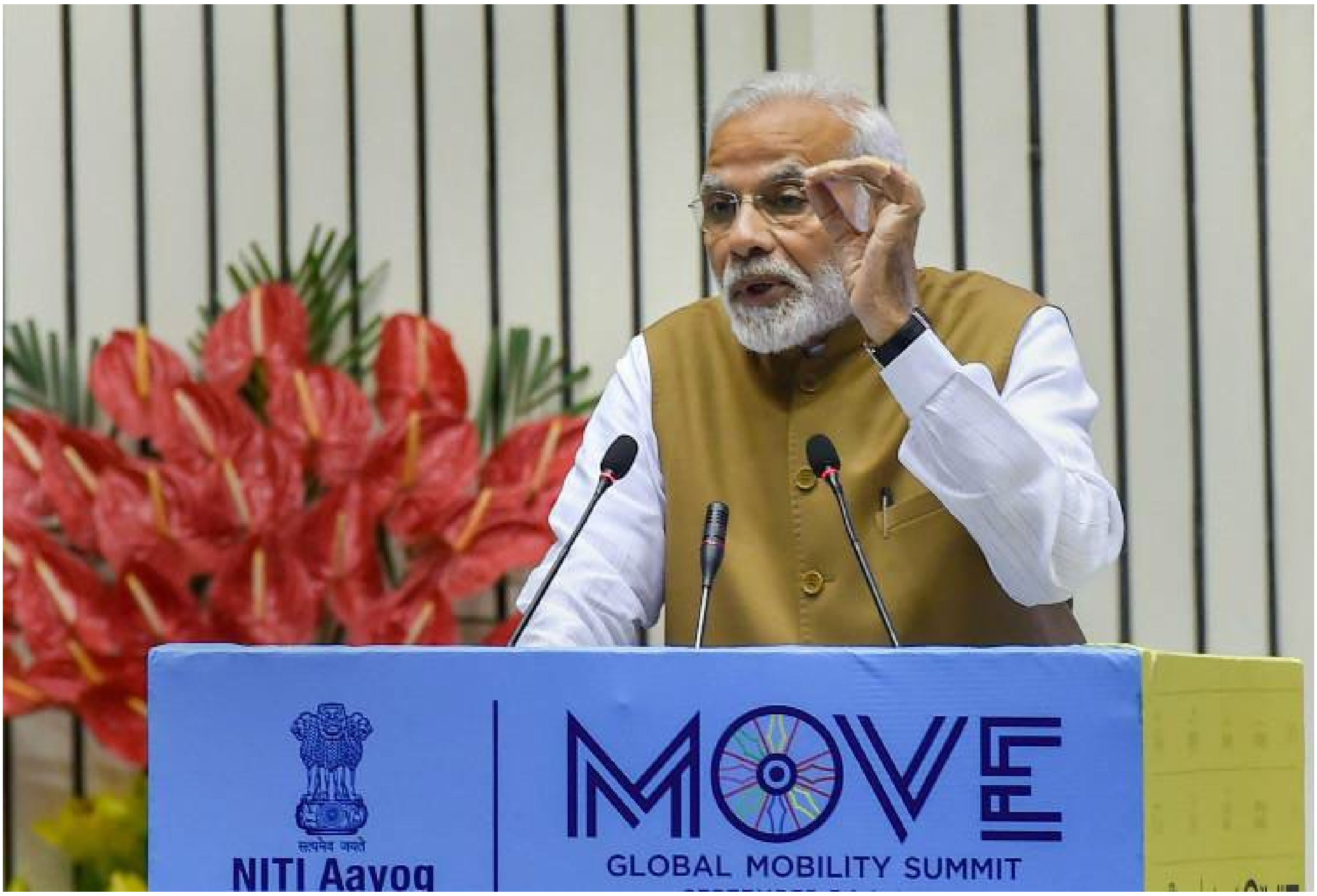
The future of clean transportation in India

Table 1 below provides a bird's eye view of the differences in the chief metrics between the three types of battery technologies. It can be seen that the sodium-ion battery technology would be very well placed for those eVs demanding up to moderate energy densities such as smaller eVs (e-rickshaws and e-scooters) or e-buses: in these applications, the sodium-ion battery's cost would be similar to that of the lead acid battery, but provide 3-4 times the driving range. In keeping with India's FAME II initiative to aggressively expand the number of such eVs on Indian roads, sodium-ion batteries would be the ideal battery technology to enable this vision to fruition.

Table 1: Differences in chief metrics between lead-acid, lithium-ion and sodium-ion batteries

	Lead-acid battery	Lithium-ion battery	Sodium-ion battery
Cost	Low	High	Low
Energy Density	Low	High	Moderate/High
Safety	Moderate	Low	High
Materials	Toxic	Scarce	Earth-abundant
Cycling Stability	Moderate (high self-discharge)	High (negligible self-discharge)	High (negligible self-discharge)
Efficiency	Low (< 75%)	High (> 90%)	High (> 90%)
Temperature Range	-40° C to 60° C	-25° C to 40° C	-40° C to 60° C
Remarks	Mature technology; fast charging not possible	Transportation restrictions at discharged state	Less mature technology; easy transporation

Source: Wikipedia



Prime Minister Narendra Modi has launched an ambitious e-mobility policy in India.

India could establish manufacturing dominance in sodium-ion batteries

From an energy security viewpoint, it is highly relevant to note that no country has yet established manufacturing dominance in sodium-ion batteries as occurs for lithium-ion batteries (China controls worldwide lithium-ion manufacturing capabilities). In the same vein, China also controls the refinement of lithium-ion cathode minerals along with being the leading suppliers of the graphite anode and the electrolyte implying that even if lithium-ion cell manufacturing might occur elsewhere, the raw materials required to produce these cells would most probably still have to be imported from China.

But as an exciting opportunity, since the manufacturing process of sodium and lithium-ion batteries is identical including all equipment, the next hot-bed of sodium-ion battery manufacturing could be any country with attractive governmental policies. The window is currently open for a country or region to create sodium-ion supply-chain clusters to take the lead in sodium-ion battery manufacturing as was done by Japan initially in the 1990s followed by South Korea and China for lithium-ion cell manufacturing.

This level of technological maturity for sodium-ion batteries has been achieved in just eight years – with a few more years of similarly rapid development, the signs are indicating that the energy densities of commercial sodium-ion batteries would be comparable to those of NMC-based lithium-ion batteries. In the near future, it is realistic to expect that sodium-ion batteries would break through into the long-range eV market.

Sodium-ion battery manufacturing would align well with India’s ‘Make in India’ policy, enabling it to take global ownership of an industry where it may otherwise compete with, or depend on, China.

Dr. Ashish Rudola

Dr Ashish Rudola is a battery scientist at Faradion, based in Sheffield, UK. He was earlier a Research Fellow at the National University of Singapore, where he completed his PhD in sodium-ion batteries. He invented a new Fe-based cathode and developed a non-flammable liquid non-aqueous electrolyte.

BRIDGE India

Bridge India is a progressive non-profit think tank
dedicated to discourse on public policy.
Registered with England & Wales Charity Commission, number 1183696.

Email: contact@bridgeindia.org.uk | Phone: +44 (0) 20 7993 6851
Website: www.bridgeindia.org.uk

@BridgeIndiaOrg
@BridgeIndia
@BridgeIndiaOrg
@BridgeIndia