Lattice Energy LLC

LENR technology could help justify US$ 2 trillion valuation for Saudi Aramco in planned 2018 IPO

Some outsiders and company insiders believe valuations of US$ 400 billion up to max of 1.5 trillion are more realistic

Announcing major new R&D program in LENR technology by Aramco could boost valuation by increasing perceived future growth prospects and potentially enabling future production and sale of new types of revolutionary oil-derived CO_2-free fuels for transportation and power generation that would have over 5,000x the energy density of gasoline

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August 24, 2017

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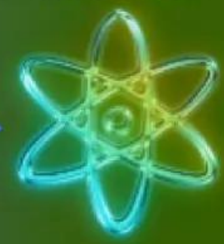
Strategy, valuation logic, and conclusions are summarized on Slides #41 - 45

Revolutionary ultralow energy neutron reactions (LENRs)

Radiation-free LENRs transmute stable elements to other stable elements

Fission and fusion

Evolution of nuclear technology



Safe green LENRs

Laura 13

No deadly MeV-energy gamma radiation

No dangerous energetic neutron radiation

Insignificant production of radioactive waste

Vastly higher energies vs. chemical processes

Revolutionary, no CO_2 , and environmentally green

Is fully explained by physics of Widom-Larsen theory

Image credit: co-author Domenico Pacifici
From: "Nanoscale plasmonic interferometers for multispectral, high-throughput biochemical sensing"
J. Feng et al., *Nano Letters* pp. 602 - 609 (2012)

LENRs are green: no energetic radiation or radwastes

Lack of hard radiation obviates need for shielding and containment

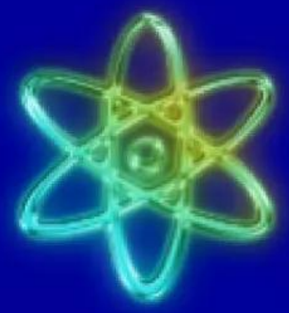
Major opportunity to develop broad range of competitive LENR power sources

Fission and fusion processes both emit deadly MeV-energy neutron and gamma radiation

Fission reactors need 1 foot of steel and 3 feet of concrete to protect human beings from dangerous hard radiation and wastes emitted by reactor; systems intrinsically large and heavy

Revolution in green nuclear technology

LENRs could enable future development of small, portable battery-like power sources that are very safe and disposable



Much larger LENR systems based on dusty plasma embodiments could potentially scale-up to megawatts

Fossil fuels could be converted into green LENR fuels

New breakthroughs in physics and nanotechnology make this possible

Crude oil, bitumen, and coal may be much more valuable as CO_2-free LENR fuels

In 2009, Lattice discovered that aromatic molecules could be processed and converted into 'green' LENR fuels from which there would be no hard radiation emissions, no production of any long-lived radioactive wastes, or emission of gaseous CO_2 into the atmosphere. These new, revolutionary types of LENR fuels could instead release > 5,000 times more thermal energy versus combustion of same Carbon-based molecules with Oxygen

Hydrocarbons contain aromatic and short-chain Carbon molecules that could be converted

Crude oil

Canadian bitumen

Anthracite coal

Comparison of LENRs to fission and fusion

Fission, fusion, and LENRs all involve controlled release of nuclear binding energy (heat) for power generation: no CO_2 emissions; scale of energy release is MeVs (nuclear regime) > 1,000,000x energy density of chemical energy power sources

Heavy element fission: involves shattering heavy nuclei to release stored nuclear binding energy; requires massive shielding and containment structures to handle radiation; major radioactive waste clean-up issues and costs; limited sources of fuel: today, almost entirely Uranium; Thorium-based fuel cycles now under development; heavy element U-235 (fissile isotope fuel) + neutrons → complex array of lower-mass fission products (some are very long-lived radioisotopes) + energetic gamma radiation + energetic neutron radiation + heat

Fusion of light nuclei: involves smashing light nuclei together to release stored nuclear binding energy; present multi-billion $ development efforts (e.g., ITER, NIF, other Tokamaks) focusing mainly on D+T fusion reaction; requires massive shielding/containment structures to handle 14 MeV neutron radiation; minor radioactive waste clean-up $ costs vs. fission

Two key sources of fuel: Deuterium and Tritium (both are heavy isotopes of Hydrogen)

Most likely to be developed commercial fusion reaction involves the following:

D + T → He-4 (helium) + neutron + heat (total energy yield 17.6 MeV; ~14.1 MeV in neutron)

Ultralow energy neutron reactions (LENRs): distinguishing feature is neutron production via electroweak reaction; neutron capture on fuel + gamma conversion to IR + decays [β^-, α] releases nuclear binding energy; early-stage technology; no emission of energetic neutron or gamma radiation and no long-lived radioactive waste products; LENR systems would not require massive, expensive radiation shielding or containment structures → much lower $$$ cost; many possible fuels --- any element/isotope that can capture LENR neutrons; involves neutron-catalyzed transmutation of fuels into heavier stable elements; process creates heat

Nuclear energy density surpasses any chemical technology

LENR-based power generation could have vast competitive advantage

Future possibility of converting Carbon aromatics to CO_2-free LENR fuels

LENRs Versus Chemical Energy Sources: Batteries, Fuel Cells, and Microgenerators	
Source of Energy	**Approximate Energy Density (Watt*hours/kg)**
Alkaline Battery	**164**
Lithium Battery	**329**
Zinc-Air Battery	**460**
Direct Methanol Fuel Cell (35% efficient)	**1,680**
Gas Burning Microgenerator (20% efficient)	**2,300**
100% Efficient Combustion of Pure Methanol	**5,930**
100% Efficient Combustion of Pure Gasoline	**11,500**
LENRs (based on an assumption of an average of 0.5 MeV per nuclear reaction in an LENR system)	**57,500,000** (maximum theoretical energy density – only a fraction would be achievable in practice)

~2,000 Wh/kg might someday be practical with Lithium-air batteries

~11,680 Wh/kg is theoretical maximum with Lithium-air

Chemical

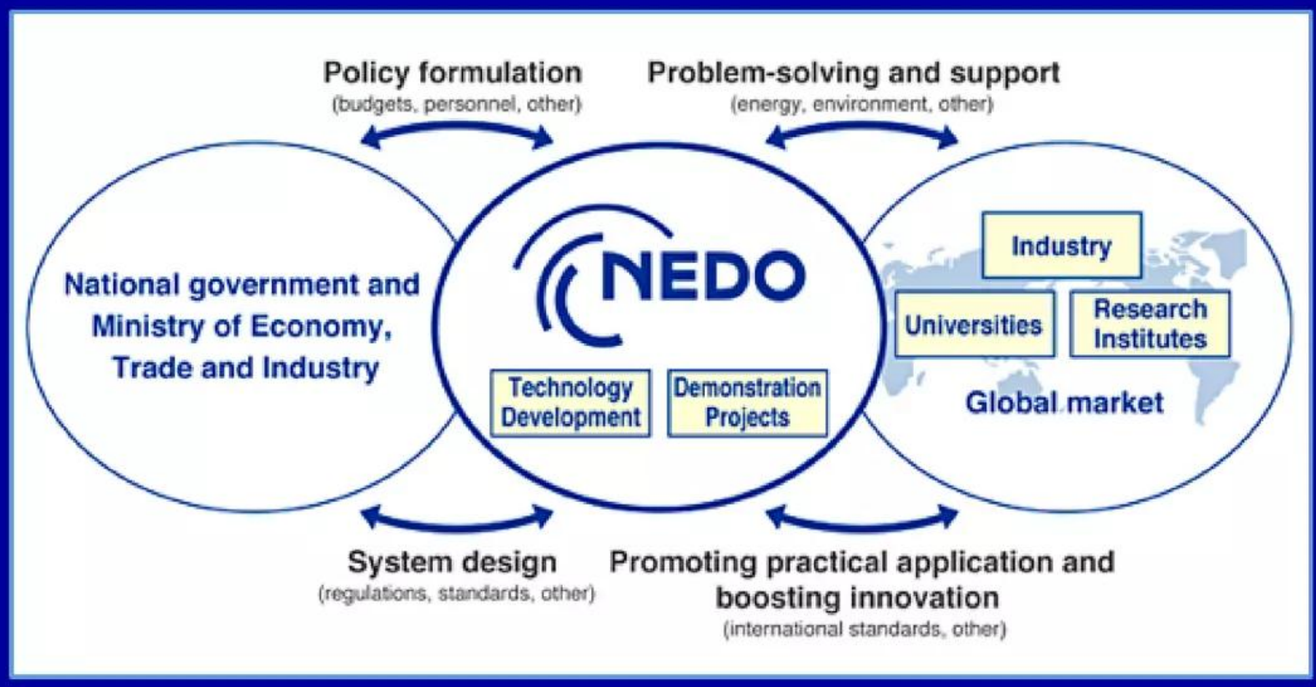
LENRs

Future of deep decarbonization for the transportation sector

LENRs are only energy technology on foreseeable horizon that could potentially enable elimination of gaseous CO_2 emissions for both the transportation and electric power generation sectors at reasonable societal economic $ cost

Mitsubishi Heavy Industries, Toyota, and Nissan Motors already conducting R&D programs aimed at commercializing LENRs to someday replace the internal combustion engine

経済産業省
Ministry of Economy, Trade and Industry



MITSUBISHI

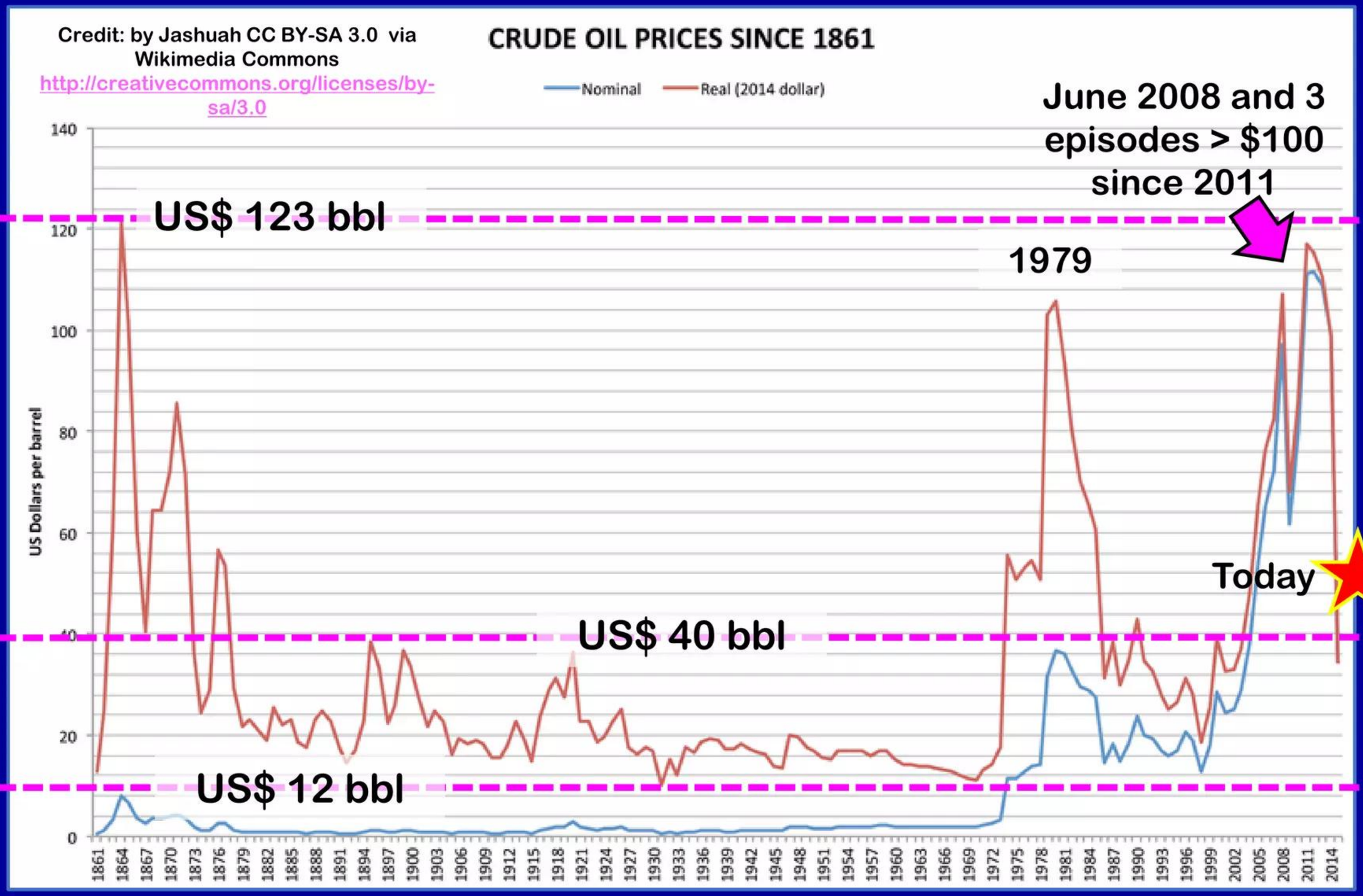
TOYOTA

NISSAN

Nominal and real (2014 Dollars) crude oil prices since 1861

Brent crude oil (ICE) closing price US$52.58 / barrel on August 21, 2017

Recent real price spikes >US$100 barrel suggest beginning of resource depletion



THE WALL STREET JOURNAL

For Aramco Insiders, Prince's $2 Trillion IPO Valuation Doesn't Add Up

Valuation discrepancy raises new challenges for a deal already fraught with complexity

THE WALL STREET JOURNAL

By Summer Said, Bradley Hope and Justin Scheck - April 25, 2017

https://www.wsj.com/articles/for-aramco-insiders-princes-2-trillion-ipo-valuation-doesnt-add-up-1493064170

"About two dozen employees have been working since last year to try and figure how to take Aramco public, and have been working with Western consultants to explore ways to restructure Aramco to maximize its value, say people familiar with the process."

"According to internal documents reviewed by *The Wall Street Journal*, the team has determined several variables - or what some call 'levers' - likely to affect the price investors will pay for shares of the world's largest oil producer."

"But no matter how they pull those levers, which include the price of oil and Saudi tax policy, Aramco's projected value tops out at about $1.5 trillion, these people say."

"The Saudi government last month said it is reducing Aramco's tax rate to 50% from 85%, bringing its tax rate closer to the level of the world's biggest oil companies such as Exxon Mobil and Royal Dutch Shell."

"That move would result in higher dividends for potential shareholders, and it brought Aramco's internal value estimates to $1.3 trillion to $1.5 trillion from about half a trillion dollars, say people involved in the process."

Continuing quoted excerpts from April 25, 2017 WSJ article

"Bankers have offered company executives advice on how they might position the offering to investors to garner the highest valuation and how Aramco would compare with other oil and gas companies, this person said. "Yet even absent the specific financial information, this person said that it appeared highly unlikely that Aramco could achieve a valuation anywhere near $2 trillion unless it paid no taxes or royalties."

"Since deputy crown prince Mohammed bin Salman announced the stock-offering plan and his $2 trillion estimate early last year, insiders and outsiders have questioned how he arrived at that number. One Aramco official called the figure 'unrealistic and mind blowing'."

"A lower valuation means the IPO would fetch less money for the kingdom to invest under the Vision 2030 plan championed by the deputy crown prince."

"Aramco produces nearly 10 million barrels of oil a day, more than twice the output of Exxon Mobil, which is valued at $337 billion. Aramco has among the world's lowest production costs - Saudi oil tends to be cheap to pump - and says its reserves total about 260 billion barrels."

"Questions about Aramco's valuation surfaced earlier this year when a report for potential investors prepared by oil-industry consultant Wood Mackenzie Ltd. put Aramco's value at around $400 billion, according to a client who attended a private Wood Mackenzie briefing. The estimate, based on the 85% tax rate, surfaced in other media. That number was also close to an internal estimate Aramco's IPO team came up with before the tax rate was reduced, say people familiar with the matter."

OVERHEATED EXPECTATIONS

Valuing Saudi Aramco's IPO in light of climate change

By Greg Muttitt and Hannah McKinnon - August 2017

http://priceofoil.org/content/uploads/2017/08/Overheating-Expectations.pdf

"There has been a gap in commentary, on how moves to decarbonise the energy system will affect the IPO's valuation. This briefing aims to fill that gap, examining the climate dimensions of the proposed IPO through three lenses: how oil price will affect Aramco's valuation (section 3), how Aramco's oil production will compete with that of international oil companies (IOCs) in light of constrained demand (section 4), and how Aramco's reserves relate to carbon budgets (section 5)."

"We estimate Aramco's value using a discounted cashflow method. We find that the most important factor affecting valuation is the expectation of future oil price. As a result, investors in the IPO face significant risk due to efforts to limit climate change."

"Compared to a base-case estimate of around $1.5 trillion, the value of Aramco could be between 25% to 40% lower in the IEA's safer-climate scenarios (which correspond to the absolute minimum ambition within the range of the Paris goals)."

"If oil prices stay at $50 in real terms, Aramco's value could be reduced to less than $700 billion, 55% below the base case. Considering statements by Shell around their recent Q2 results, such a scenario may now seem much less unlikely than some years ago."

Continuing quotes from August 2017 Oil Change article

Aramco's oil reserves depleted in 59 years at present rates of extraction

"Aramco has a monopoly right to extract Saudi Arabia's vast reserves, and it does so slowly: at current rates, it would take 59 years to extract the reserves, compared to an average of 34 years for the five majors (on a like-for-like basis)."

"Assuming governments ultimately act to keep warming below 2 degrees, a large proportion of Aramco's reserves may be left unburned. However, this scenario would also entail rapid emissions cuts later, forcing down prices within investment timescales of 15 - 25 years, and causing significant destruction of oil company assets. As such, it creates the greatest financial risk to all."

"We conclude: If the IPO realises a value at the higher end of the likely range (say, above $1 trillion), its investors could face significant risk from climate policy. If it comes out lower, this may raise questions of whether IOCs are overvalued. While Aramco's value is likely to be discounted due to investors' perceptions of political risk, we find this is less important to assessments of value than the oil price."

"If fully extracted and burned, Saudi reserves would have a profound impact on the climate. Emissions from Saudi reserves would amount to 112 Gt of carbon dioxide, one seventh of total global emissions in a 2°C carbon budget, or one third of total global emissions in a 1.5°C carbon budget. The problem is not so much Aramco on its own, but Aramco in combination with IOCs, which constantly explore for and open up new reserves, to replace what they have extracted."

Continuing quotes from August 2017 Oil Change article

"Transportation accounts for 65% of world oil demand"

"Aramco has a monopoly right to extract Saudi Arabia's vast reserves, and it does so slowly: at current rates, it would take 59 years to extract the reserves, compared to an average of 34 years for the five majors (on a like-for-like basis)."

"Increasingly, financial leaders are confirming that the need for a transition to low carbon must be a consideration for relevant investment decisions. An example of the growing concern is the work of the Task Force on Climate-related Financial Disclosures (TCFD), which has been supported by many of the world's largest financial institutions. Investments in fossil fuel companies have a high-risk exposure, not only from their core product ultimately becoming obsolete, but also from declining prices of oil, gas, and coal during the transition, potentially within the next decade."

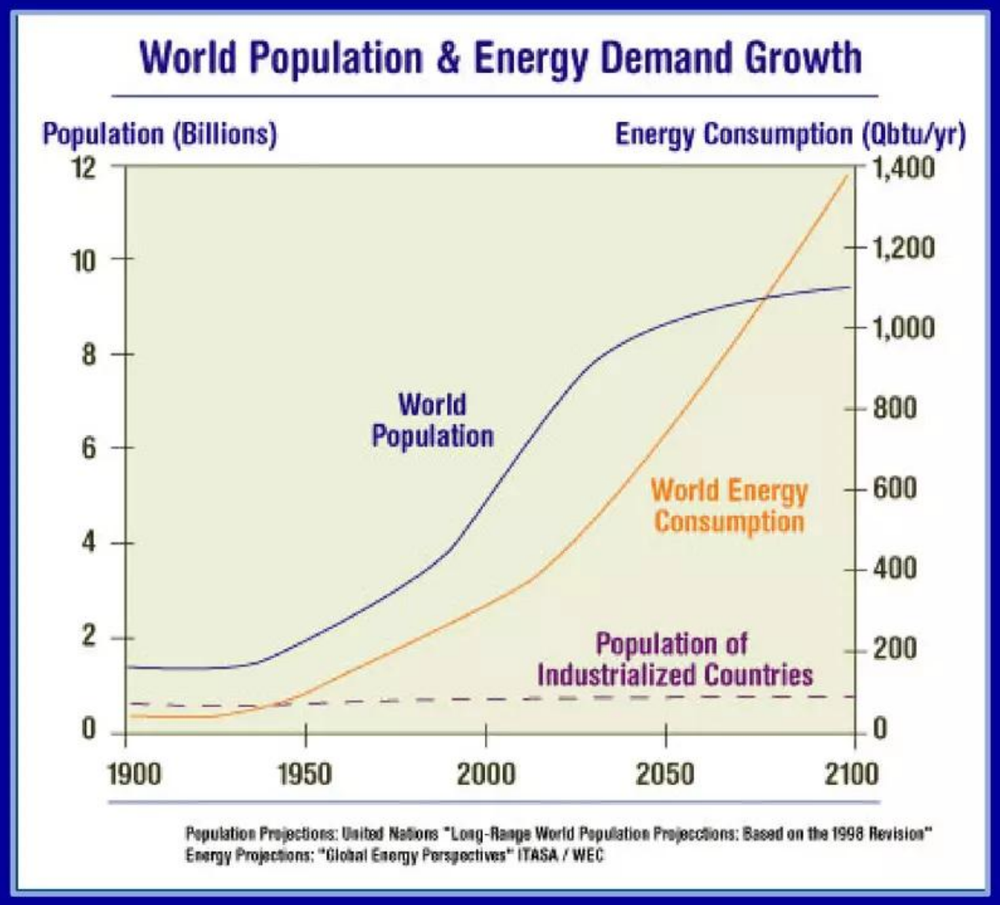
"The most visible disruptive change is the penetration of electric vehicles, which is now being embraced by the world's largest auto manufacturers. UBS predicts that by the early 2020s, the purchase price of an EV will be only very slightly higher than a petroleum-fueled car, with only small a fraction of the fuel and maintenance costs. Regulation is also a major driver. Both France and the United Kingdom have announced plans to ban petrol- and diesel-fueled cars from 2040, and several other European governments have also considered bans, some as early as 2025. Cities are restricting the use of diesel vehicles, due to air pollution concerns. The Indian government aims to achieve 100 percent electric cars sales by 2030, through incentives and innovative financing."

Saudi Aramco could be facing turbulent times in near future

Strategic issue: oil reserves will likely run-out in 59 years --- what then?

Besides reserve depletion: governments could mandate drop in fossil fuel usage

Global energy demand should remain very strong in future



Population projections: United Nations
Energy consumption projections: IIASA / WEC

- **Oil reserve depletion:** in-ground oil supplies exhausted in ~ 59 years; **what happens to Saudi Aramco's revenue stream after that?**
- **Climate change:** emerging scientific consensus posits global warming is being caused by increasing CO_2 emissions from human activities; **need huge cuts in CO_2 ?**
- **Fear of global warming:** has lead to calls for radical decreases in vehicle CO_2 emissions to mitigate further rise in global temperature; **will governments restrict use of fossil fuels?**
- **All these issues create concerns about "Carbon bubbles": they render remaining in-ground fossil fuels "stranded" and worthless**

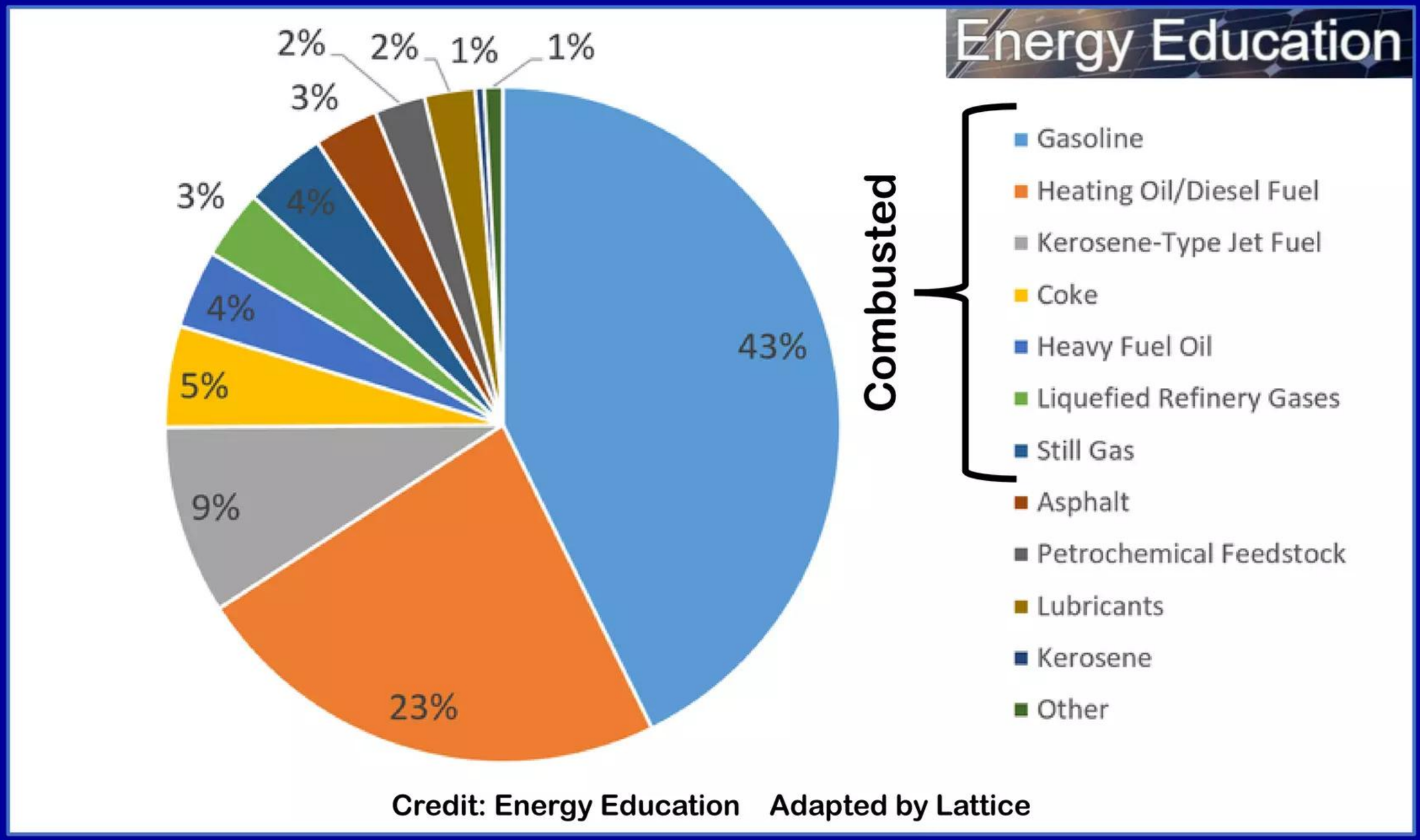
Global energy demand has been increasing exponentially; will likely continue to do so

Percentages of products produced from a barrel of crude oil

91% of crude oil products combusted with Oxygen: produce heat & CO_2

High energy density of oil-derived fuels has enabled domination of transportation

Overwhelming % of cars, trucks, trains, aircraft & ships still powered by combustion



Credit: Energy Education Adapted by Lattice

Energy density is why fossil fuels dominate transportation

Solar PV and wind have insufficient density to 100% replace fossil fuels

World will still require dense energy sources for transportation & portable power

Comparison of intrinsic energy densities

Table 1 Energy density

Source	Joules per cubic meter
Solar	0.0000015
Geothermal	0.05
Wind at 10 mph (5m/s)	7
Tidal water	0.5–50
Human	1,000
Oil	45,000,000,000
Gasoline	10,000,000,000
Automobile occupied (5800 lbs)	40,000,000
Automobile unoccupied (5000 lbs)	40,000,000
Natural gas	40,000,000
Fat (food)	30,000,000

Gasoline way more energy-dense

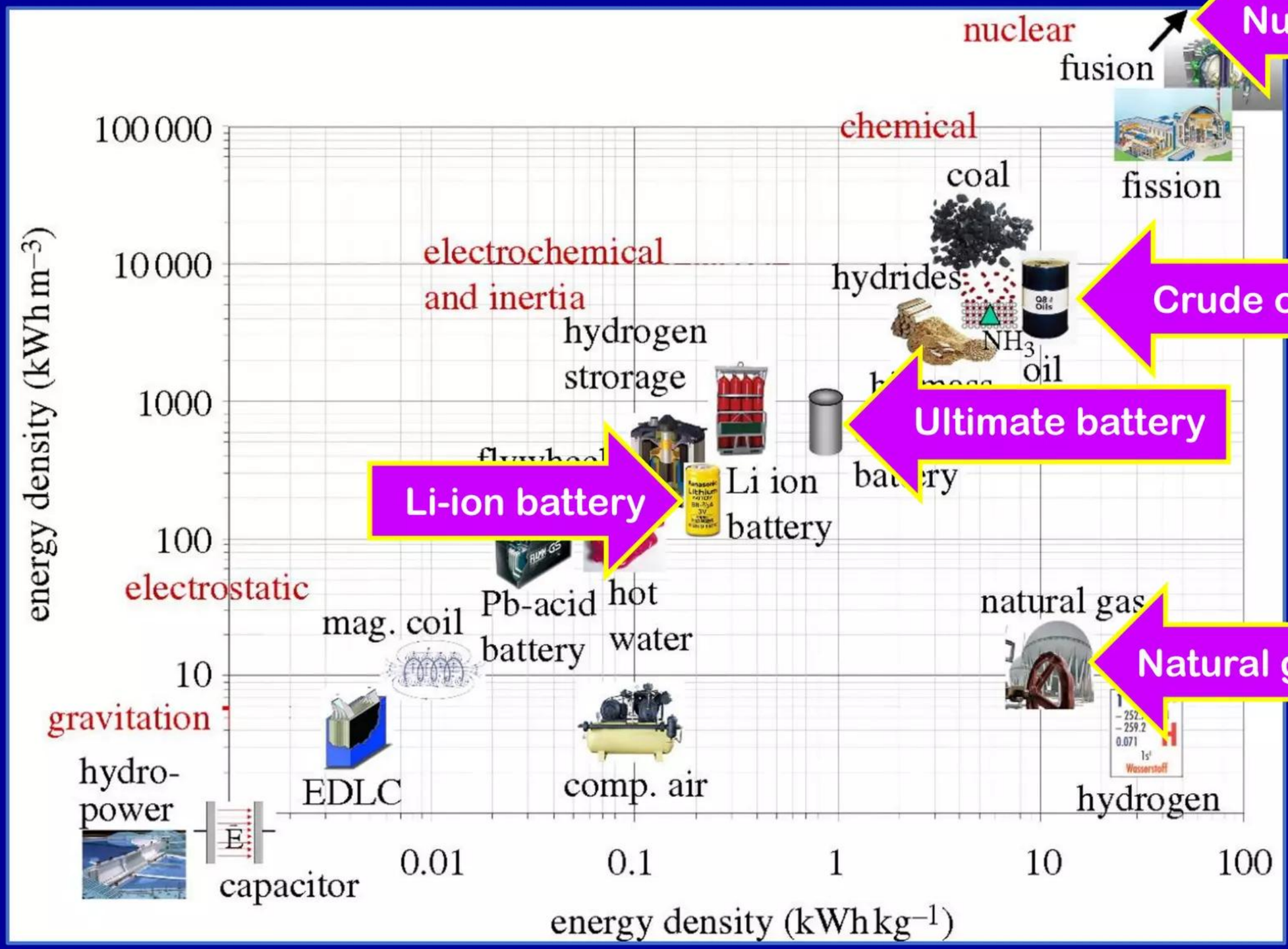
Petroleum energy density:
"A single gallon of gasoline contains approximately forty (40) megajoules of chemical energy. Dividing energy by volume yields an energy density of ten billion joules per cubic meter. **Gasoline is ten quadrillion times more energy-dense than solar radiation and one billion times more energy-dense than wind and water power.**"

Reference: B.E. Layton, *International Journal of Green Energy* 5 pp. 438 - 455 (2008)

Source: http://www.drexel.edu/~/media/Files/greatworks/pdf_sum10/WK8_Layton_EnergyDensities.ash

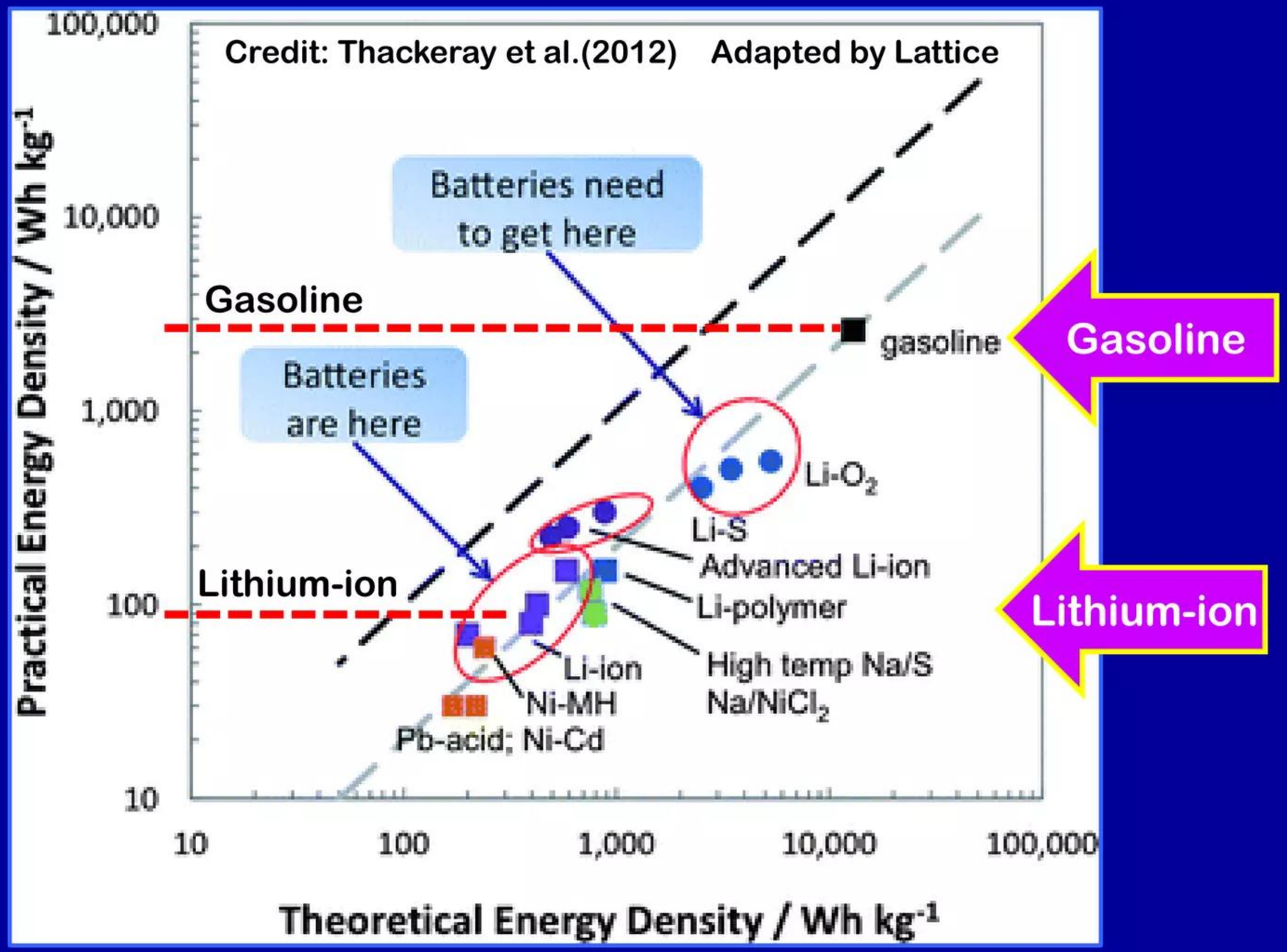
Energy density of technologies from hydropower to fusion

Fig. 7 in "Hydrogen: the future energy carrier" A. Zuttel *et al.*
***Phil. Trans. R. Soc. A* 368 pp. 3329 - 3342 (2010)**



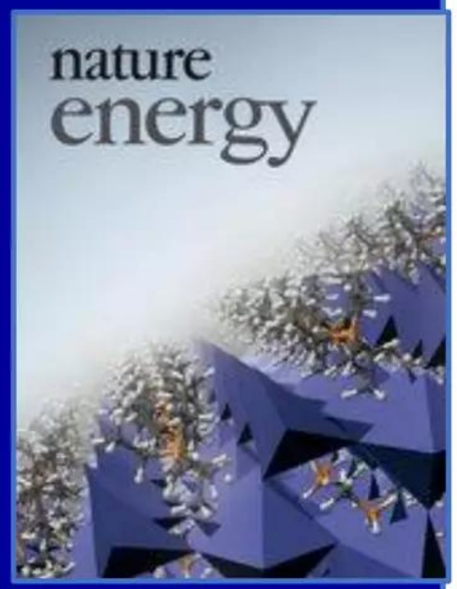
Battery technology far away from energy density of gasoline

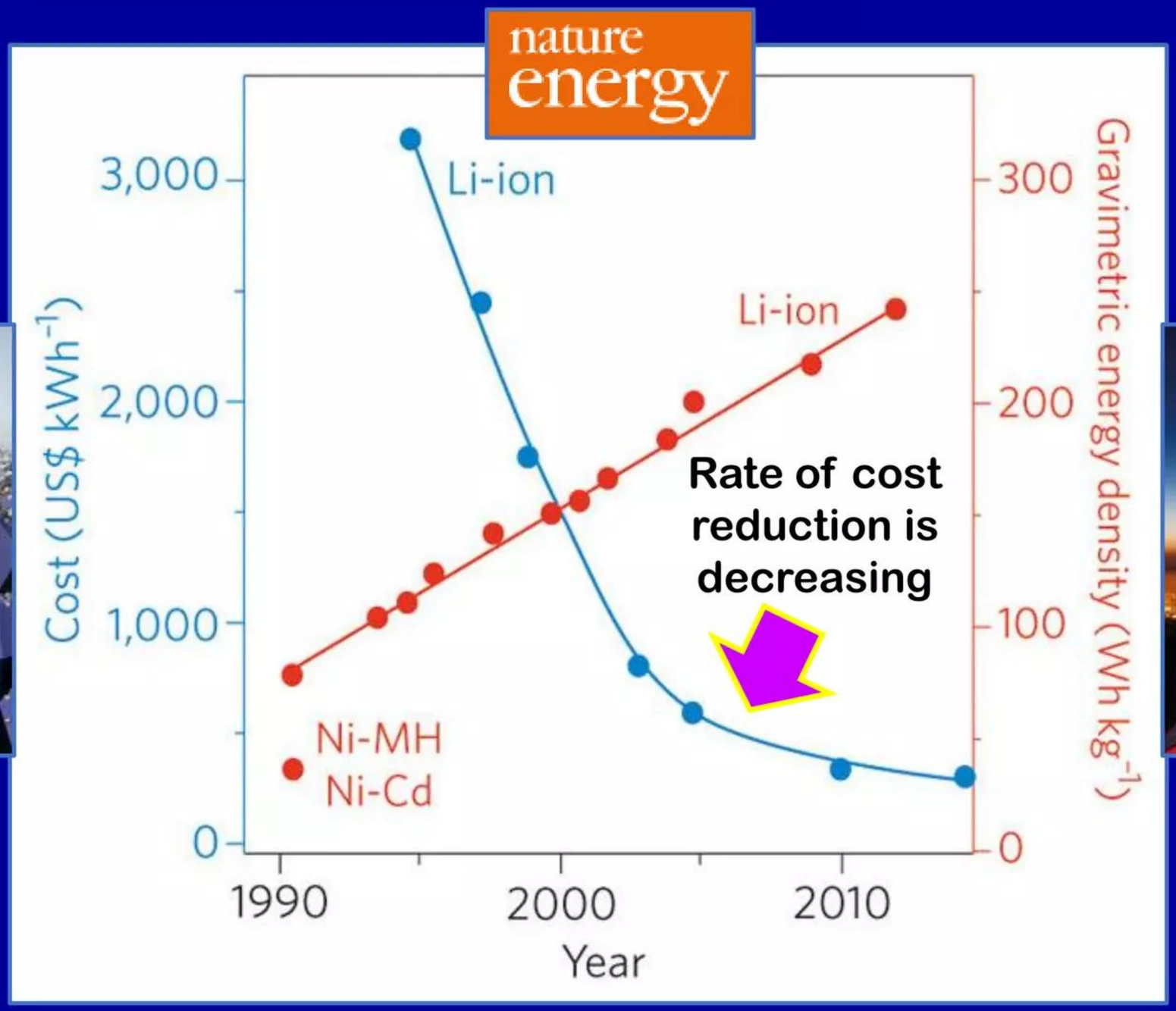
"Electrical energy storage for transportation - approaching the limits of, and going beyond, Lithium-ion batteries"
M. Thackeray et al. *Energy & Environmental Science* 5 pp. 7854 - 7863 (2012)



Battery cost reduction tied to increases in energy density

If energy density increases slow down then cost reductions will stagnate





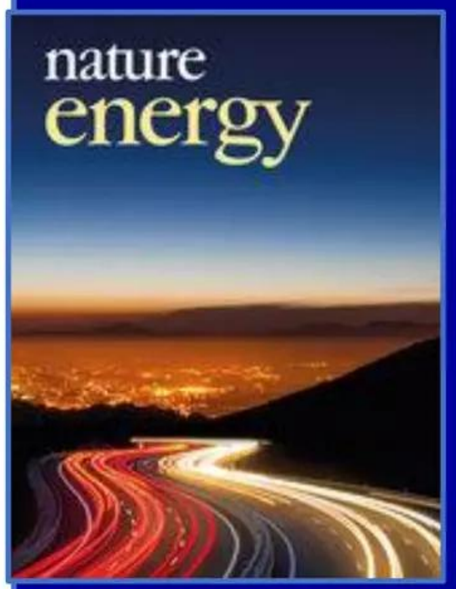


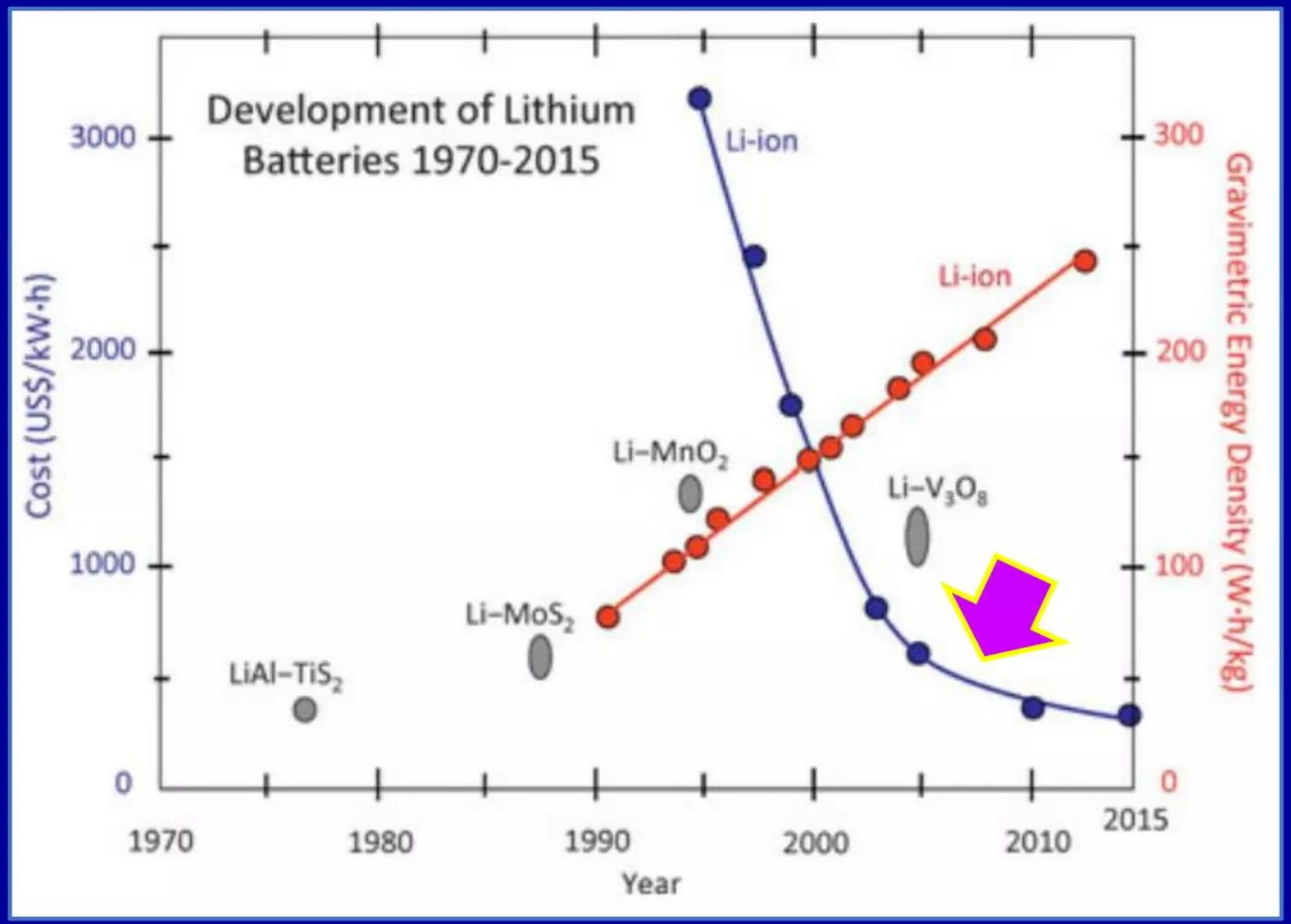
Fig. 3 in "The frontiers of energy" R. Armstrong *et al. Nature Energy* 1 Article # 15020 (2016)

http://www.nature.com/articles/nenergy201520

Crabtree et al. note same slowdown in battery cost reductions

1990 - 2015: only linear increase in energy density of single battery cells

"The energy-storage frontier: Lithium-ion batteries and beyond"
G. Crabtree et al. *MRS Bulletin* 40 pp. 1067 - 1076 (2015) Figure 1.
https://tinyurl.com/ybsostda

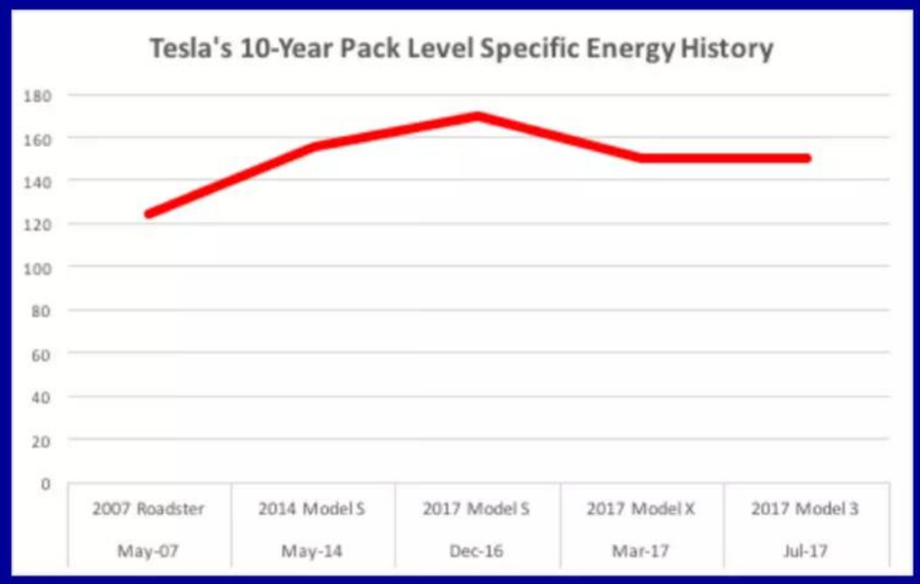


Tesla's 10-year battery pack energy density is now flattening

Pack-level energy density substantially lower than single battery cells

E-vehicle battery packs may contain tens to thousands of individual cells

"Tesla's first decade of battery pack progress - much ado about nothing"
John Petersen published this data in *Seeking Alpha* on August 25, 2017 Graph from article
https://seekingalpha.com/article/4101993-teslas-first-decade-battery-pack-progress-much-ado-nothing



Tesla's battery pack energy density could be flattening because Tesla is acutely aware of and has had experience with dangers of bad thermal runaways in large EV battery packs. Consequently, they may be doing more safety engineering with packs because Tesla's choices of stable battery chemistries with adequate energy density for good range are limited. While Tesla doesn't disclose proprietary technical details about pack engineering, it is known that boosting safety could entail steps like: increasing volume of fluid circulating in cooling channels; increasing volumes of intumescent materials; increasing spacing between batteries; etc. Altogether, such design changes will decrease effective energy density for battery packs, as shown in Petersen's graph

Tesla's Model S is presently U.S. leader in full-size sedan EVs

Range and acceleration are good but price is still high vs. IC competitors

EVs like Model S still many years away from substantially displacing IC vehicles

2015 Tesla Model S P90D --- MSRP as configured was roughly US$121, 950

TESLA

Model: 2015 Tesla Model S
MSRP: From $105,000
Horsepower: 691 hp
Range: 253 mi battery-only
Engine: Electric
MPGe: 89 city / 98 highway
Battery: 90 kWh lithium-ion
Curb weight: 4,830 lbs

101/102 MPGe	5.1 sec	691hp	140 mph
EPA	0-60	HP	Top Speed

Only modest improvements in battery energy density & cost

Assumption that future electric vehicle costs will drop sharply is mistaken

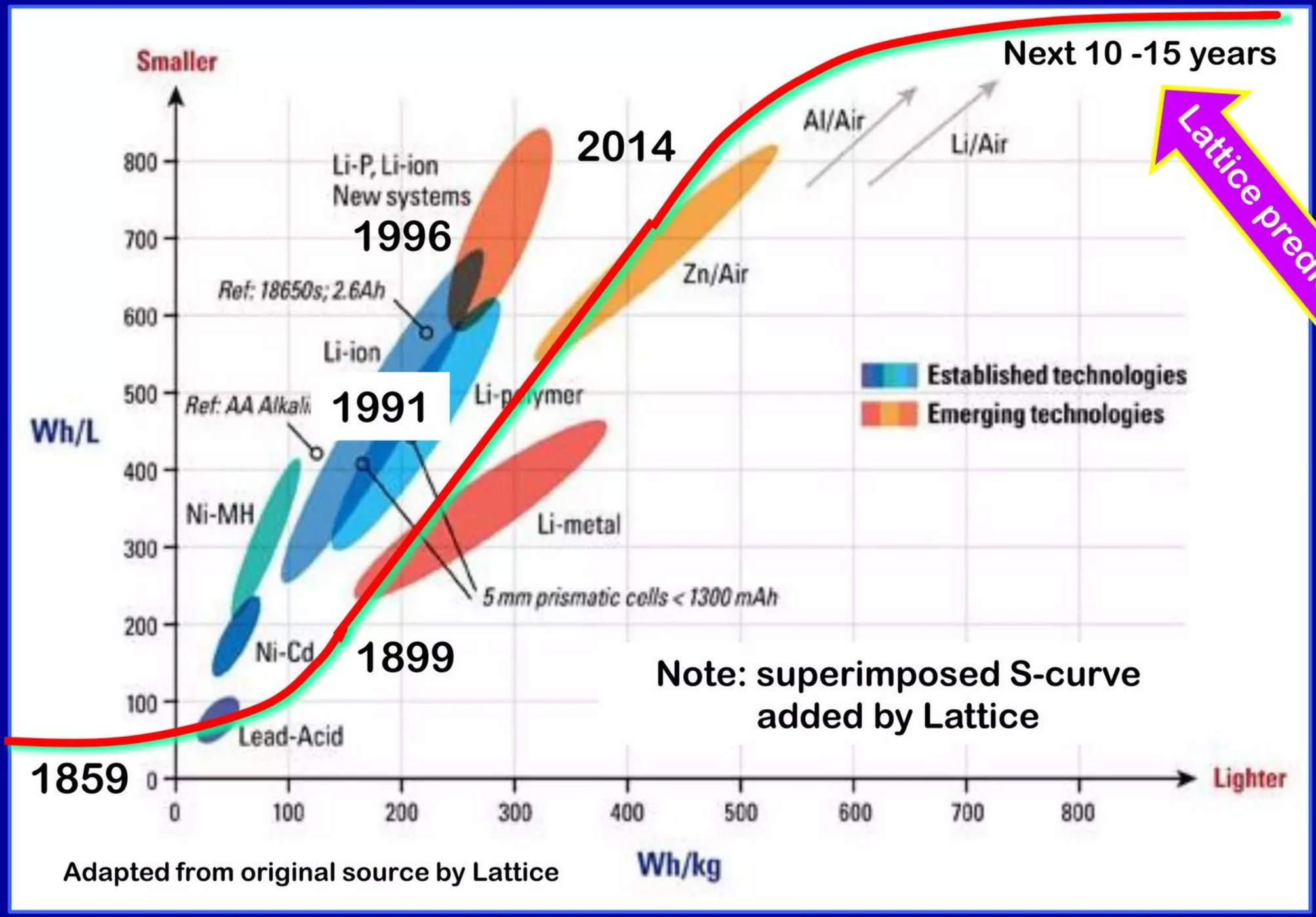
- Hardly a week goes by without another glowing PR announcement from some researcher or organization to the effect that they have achieved a new technical breakthrough that will either substantially increase battery energy density or drastically reduce if not eliminate the risk of thermal runaway fires or explosions. However, near the end of the press release there is usually a caveat that it will require more funding and years of additional effort before the 'advance' can be commercialized
- Some call this the "battery hype cycle." Extensive promotion of now languishing Lithium-air batteries is recent example of this phenomenon
- While modest increases in battery energy densities and decreases in costs are very likely, quantum-leap improvements in these two crucial competitive parameters are becoming increasingly less probable and more difficult to achieve. This is occurring because chemical battery technology is finally maturing and, as Lattice predicts, will likely begin to approach its fundamental energetic limits within the next 10 - 15 years

For detailed support of these assertions see following Lattice PowerPoint:

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-battery-energy-density-product-safety-thermal-runaways-and-ultralow-energy-neutron-reactions-april-14-2016

Batteries are maturing and approaching technological limits

Predict single cell energy density increases and cost reductions will slow



http://www.estquality.com/technology

"Electric cars - The death of the internal combustion engine"

The Economist **Article published Aug. 17, 2017** The Economist

https://www.economist.com/news/leaders/21726071-it-had-good-run-end-sight-machine-changed-world-death

"But its days are numbered. Rapid gains in battery technology favour electric motors instead (see Briefing). In Paris in 1894 not a single electric car made it to the starting line, partly because they needed battery-replacement stations every 30 km or so. Today's electric cars, powered by lithium-ion batteries, can do much better. The Chevy Bolt has a range of 383 km; Tesla fans recently drove a Model S more than 1,000 km on a single charge. UBS, a bank, reckons the 'total cost of ownership' of an electric car will reach parity with a petrol one next year --- albeit at a loss to its manufacturer. It optimistically predicts electric vehicles will make up 14% of global car sales by 2025, up from 1% today. Others have more modest forecasts, but are hurriedly revising them upwards as batteries get cheaper and better --- the cost per kilowatt-hour has fallen from $1,000 in 2010 to $130 - 200 today. Regulations are tightening, too. Last month Britain joined a lengthening list of electric-only countries, saying that all new cars must be zero-emission by 2050."

"The shift from fuel and pistons to batteries and electric motors is unlikely to take that long. The first death rattles of the internal combustion engine are already reverberating around the world --- and many of the consequences will be welcome."

Possible future Chinese ban on new vehicles with IC engines

Sept. 9, 2017: government official announced studying date for mandate

"New-energy vehicles and batteries are key parts of Beijing's plans" for future

South China Morning Post INTERNATIONAL EDITION

"Why Beijing's plan to stop producing petrol and diesel cars could be a game-changer for the industry?"

By Wendy Wu September 9, 2017

http://www.scmp.com/news/china/policies-politics/article/2110485/china-mulls-blue-sky-vision-phase-out-fossil-fuel-cars

"China is working on a timetable to stop production and sales of fossil-fuel vehicles as it races to develop new-energy vehicles and clear the country's polluted skies, a senior Chinese industry official said on Saturday."

"Addressing a car forum in Tianjin, Xin Guobin, Vice-Minister of Industry and Information Technology, said China was considering following in the footsteps of some European countries to phase out fossil-fuel cars."

"New-energy vehicles and batteries are key parts of Beijing's plans to turn China into a hi-tech powerhouse in the next few decades. The National Development and Reform Commission, the country's top planning agency, has also said it will not approve any new fossil-fuel car projects.

"China is … world's biggest car market, with nearly 200 million registered vehicles … Only 1.09 million of those cars are new-energy vehicles …"

Reports of internal combustion engine's death are premature

Market penetration of electrics remains only tiny % of vehicle population

Market's verdict is: EVs still not competitive with IC vehicles on price/performance

- 250 - 260 million operable cars and trucks are present in the U.S. today; as of November 2016, total population of 540,000 electric vehicles were on roads in U.S.; electrics thus represent just 0.22% of all cars and trucks
- In 2016, 17.5 million new cars and trucks were sold in U.S. Only 159,139 of all these vehicles were electric (all-electric EVs + hybrid gas-electric HEVs); electrics only accounted for 0.9% of 2016 vehicle sales. ~50% of 2016 U.S. electric vehicle sales occurred in California, where minimum percentages of zero-emission vehicles sold are mandated by state law
- 29,158 market leading Tesla Model S EV 4-door sedans were sold in 2016
- HEVs much more competitive than EVs in some commercial market niches: over past 5 - 7 years, HEVs have displaced 90% of IC-powered passenger cabs in Chicago's non-Uber fleets due to lower annual operating costs
- Oil price staying at ~US$ 50/bbl is not helping competitiveness of electrics
- Continued minuscule worldwide market penetration by electrics is now frustrating many governments worried about CO_2 emissions and climate change; some are planning future bans on new vehicles with IC engines

New wild card risk: governments interfere with oil demand

Some governments plan to ban future sales of vehicles with IC engines

Aramco could mitigate this risk by developing new CO_2-free transportation fuels

- Per British Petroleum's 2017 Statistical Review estimates, global proved oil reserves will be depleted within ~51 years at 2016 rates of extraction. Under normal economic circumstances, at some time during the depletion process real price of oil should increase to levels far above todays ~$US 50/bbl that will ration total demand and encourage development of technological substitutes
- Unfortunately, new wild card risk factor has arisen that could distort pricing processes that normally occur during resource depletion. Governments now attempting to mitigate effects of climate change and global warming by boldly mandating drastic reductions in societal CO_2 emissions. Since transportation sector overwhelmingly uses CO_2-producing gasoline and diesel fuels to power vehicles, it is being targeted by government regulators to slash CO_2 emissions
- Consequently, a number of countries are presently planning to institute future bans on sales of vehicles equipped with internal combustion engines. This would have the economic effect of artificially reducing demand for oil in such countries which could in turn have rather negative impact on future price of oil
- Saudi Aramco could mitigate this risk and increase its valuation by developing new types of transportation fuels created from crude oil that do not utilize combustion and can release process heat for power without emitting any CO_2

What if hydrocarbons could be converted into CO_2-free fuels?

What if these new green fuels had 5,000x energy density of gasoline?

If Aramco developed such fuels it could cut risks restraining IPO valuation

- We believe Lattice is the world-leader in proprietary knowledge about LENR device engineering required to develop high-performance, long lived, scalable power sources. Our published peer-reviewed theoretical papers rigorously explain breakthrough physics of LENR processes, including the unique absence of dangerous energetic neutron or gamma radiation and insignificant production of long-lived radioactive wastes
- Since 2010, Lattice has extended proprietary aspects of LENR theory to aromatic Carbon molecules. This advance has created a technological opportunity to utilize LENR transmutation rather than age-old chemical combustion of Carbon for CO_2-free power generation in future vehicles
- With such a technology, aromatic molecules could either be extracted directly from crude oil, created via conversion of lower alkanes, or even produced via catalytic conversion of natural gas. Proprietary nanotech processes would then be used to convert aromatic molecules into very versatile nanoparticulate LENR fuels that have 5,000 times the energy density of gasoline. Existing petroleum refineries could be upgraded to produce and sell LENR fuels in parallel with traditional industry products

Many moieties contain or are convertible into aromatics

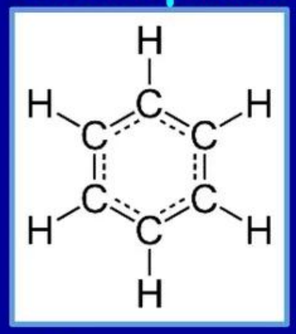
LENR fuels can be created from many different types of Carbon sources

Base feedstock → Aromatic molecules → Nanoparticulate fuels

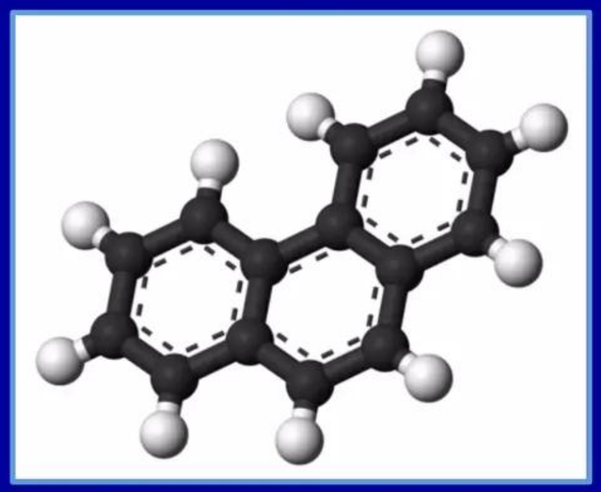
- Lower alkanes — Convert
- Heavy oils and natural bitumen — Extract
- Coal — Extract
- Lignin from renewable biomass — Digest
- CH_4 natural gas — Mo catalyst → LNG
- CO_2 → C nanofibers — Processing

Variety of simple and complex aromatic molecules

Examples:



Benzene



Phenanthrene

Enormous gain in energy density makes processing conversions $$$ economic

Chemical processing — Process into — plus nanotech

Green CO_2-free LENR fuels

5,000x greater energy density

Bottom line: just about any Carbon-based moiety can be converted into aromatic ring-structure molecules using chemical processes

Widom-Larsen ultralow energy neutron reactions (LENRs)

Can transmute Carbon with neutrons rather than combusting it with O_2

Many-body collective LENRs are very different from few-body fusion and fission

Many-body collective neutron production reaction is: $e_n + p_n \rightarrow n_{ule} + v_e$

LENRs involve production of safe ultralow energy neutrons and benign neutrinos from protons and electrons via hard radiation-free electroweak nuclear reaction. This is followed by local neutron captures on target fuels such as Lithium or aromatic Carbon. These captures release nuclear binding energy from LENR fuels which creates high-quality process heat for integrated energy conversion systems that can generate electrical or motive power

Fossil Carbon can be transmuted rather than combusted

Crude oil could be chemically processed to create CO_2-free LENR fuels

Carbon atoms on aromatic rings can serve as fuel for radiation-free transmutation

Hard radiation-free LENR transmutation of fuels

Neutrons + target fuel atoms → heavier elements + decay products + heat

Process does not emit deadly neutron or gamma radiation or produce radioactive wastes

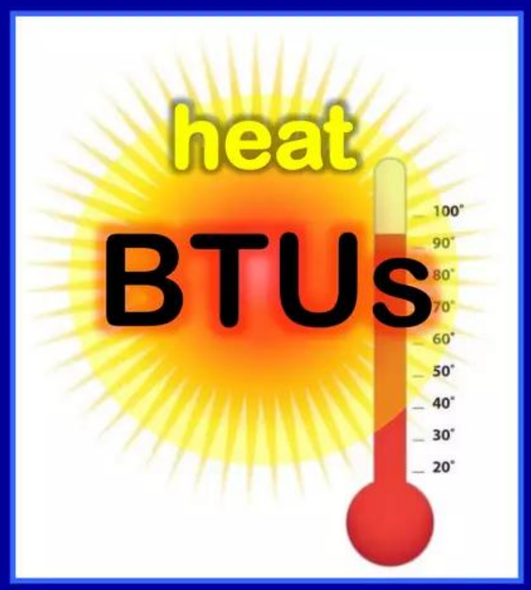
Catalytic neutron 'match'

Neutrons are readily absorbed by LENR target fuels such as inexpensive Nickel, Titanium, Lithium, or aromatic Carbon

Direct conversion of neutron capture and decay-related gammas to IR and beta/alpha particles create heat

capture +

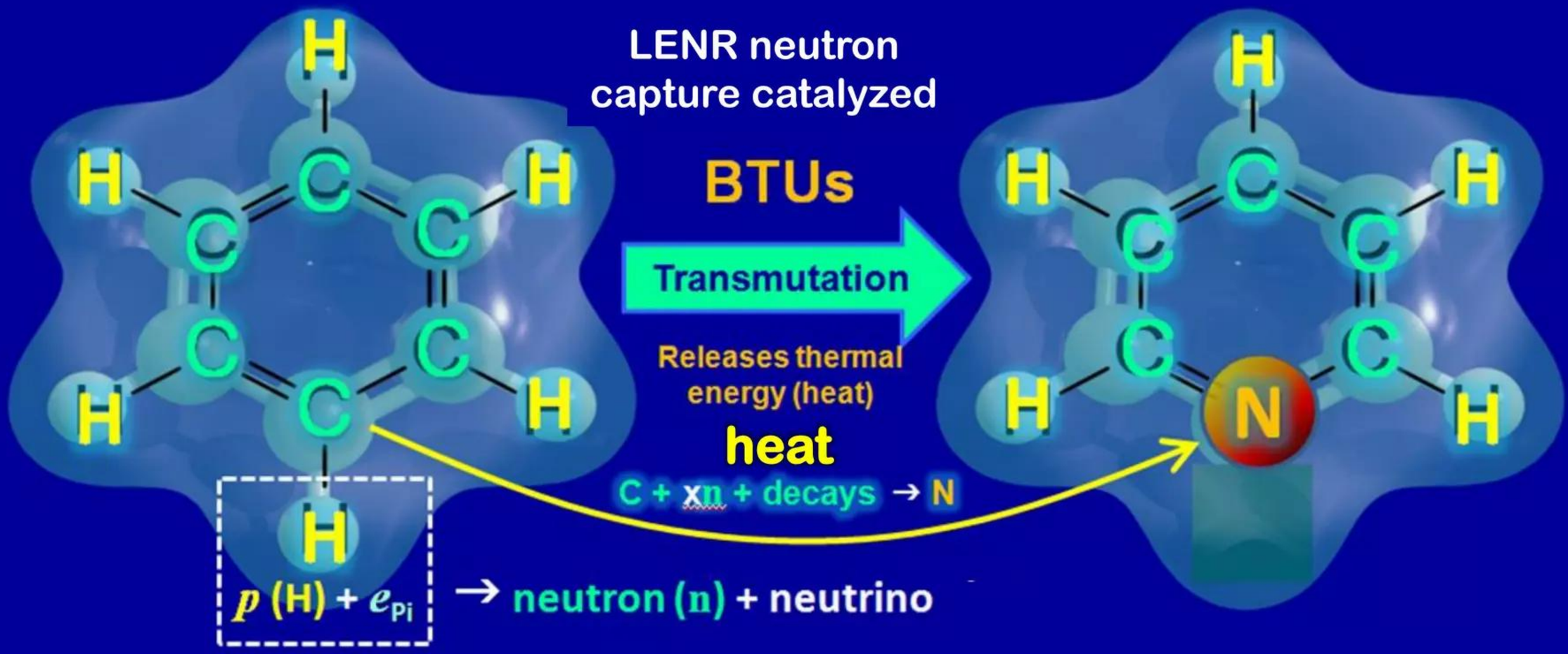
produces →



Convert ring Hydrogen atoms (protons) into ULE neutrons

Neutrons are captured by ring Carbon atoms that are then transmuted

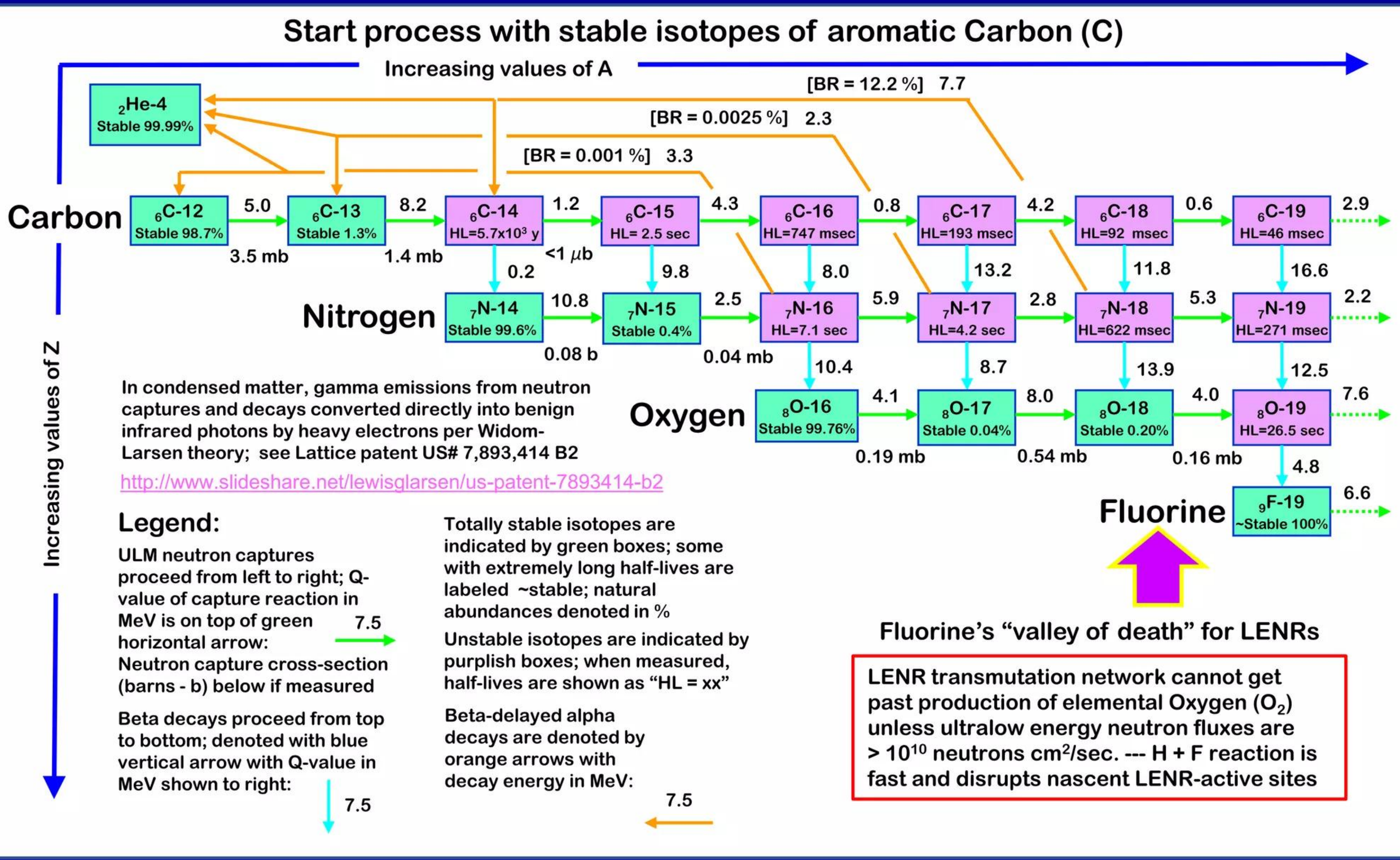
Below an aromatic Carbon atom is transmuted into Nitrogen with LENR process



Process does not emit any deadly radiation or produce troublesome radwastes

LENR C → N → O neutron-catalyzed transmutation network

Carbon is 1st transmuted to Nitrogen; typically self-terminates at Oxygen



In condensed matter, gamma emissions from neutron captures and decays converted directly into benign infrared photons by heavy electrons per Widom-Larsen theory; see Lattice patent US# 7,893,414 B2

http://www.slideshare.net/lewisglarsen/us-patent-7893414-b2

Legend:

ULM neutron captures proceed from left to right; Q-value of capture reaction in MeV is on top of green horizontal arrow: 7.5 Neutron capture cross-section (barns - b) below if measured

Beta decays proceed from top to bottom; denoted with blue vertical arrow with Q-value in MeV shown to right: 7.5

Totally stable isotopes are indicated by green boxes; some with extremely long half-lives are labeled ~stable; natural abundances denoted in %

Unstable isotopes are indicated by purplish boxes; when measured, half-lives are shown as "HL = xx"

Beta-delayed alpha decays are denoted by orange arrows with decay energy in MeV: 7.5

Fluorine's "valley of death" for LENRs

LENR transmutation network cannot get past production of elemental Oxygen (O_2) unless ultralow energy neutron fluxes are > 10^{10} neutrons cm^2/sec. --- H + F reaction is fast and disrupts nascent LENR-active sites

Japanese automakers see opportunity with LENR technology

Mitsubishi Heavy Industries, Toyota, and Nissan all have R&D programs

One can only conclude that their goal is to replace internal combustion engine

- In March 2017, Japanese government's New Energy and Industrial Technology Development Organization (NEDO) officially confirmed that Nissan Group had become involved with Toyota, Mitsubishi Heavy Industries, and 4 well-respected Japanese universities in multi-year government-sponsored research program aimed at developing LENRs for "realization of commercial energy devices"

- Unlike Mitsubishi Heavy Industries (MHI) and Toyota, Nissan is a newcomer to LENRs; first indications of Nissan's R&D involvement surfaced in 2015. For many years, Mitsubishi publicly maintained its R&D program in LENRs was only aimed at nuclear fission waste remediation. That is, to be able to transmute dangerous long-lived radioactive isotopes like Strontium-90 and Cesium-137 (produced in fission reactors) into environmentally benign, stable isotopes of other elements found in the Periodic Table. MHI demonstrated experimental proof-of-concept for transmutation of radioactive isotopes by using LENRs to convert stable Strontium (Sr) into stable Molybdenum (Mo) and stable isotopes of Cesium (Cs) into stable Praseodymium (Pr); MHI's results were reported at conferences and published in journals. In 2013, Toyota confirmed MHI's 2002 results for transmuting Cs into Pr

For further details see 2-page public Lattice document:

https://www.slideshare.net/lewisglarsen/lattice-energy-llc-japanese-nedo-confirms-nissan-involved-in-government-funded-lenr-research-march-15-2017

Japanese companies & government pursuing R&D in LENRs

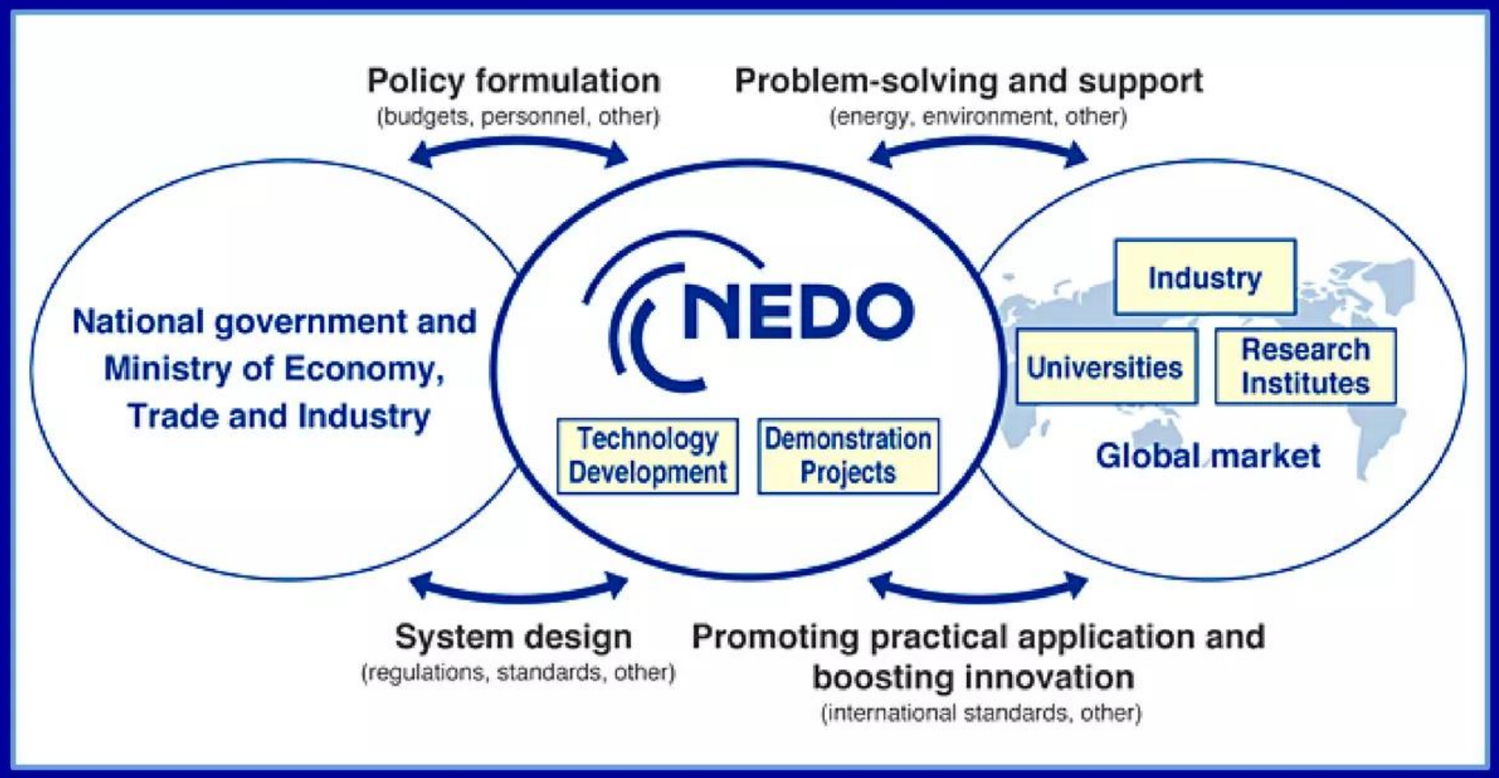
NEDO orchestrates relationships between private industry and academia

NEDO New Energy and Industrial Technology Development Organization

Combining the efforts of industry, government and academia and leveraging established international research networks, NEDO is committed to contributing to the resolution of energy and global environmental problems and further enhancing Japan's industrial competitiveness

http://www.nedo.go.jp/english/

NEDO's mode of operation - graphic is copied from home page of NEDO website



経済産業省 Ministry of Economy, Trade and Industry

MITSUBISHI

TOYOTA

NISSAN

Lattice explored economic impact of new LENR Carbon fuels

"Stranded asset" scenario showed value of reserves could increase 500x

- Japanese corporate and government programs validate Lattice's assertion that LENRs are a strategic technology opportunity to develop CO_2-free green energy
- Development of LENR Carbon transmutation technology would enable Saudi Aramco to convert potentially stranded crude oil reserves into revolutionary, vastly more energy-dense types of green, CO_2-free LENR fuels suitable for broad range of applications in transportation as well as power generation. Would mitigate Aramco's "stranded asset" financial risk issues for oil reserves
- Successful commercialization and sale of LENR Carbon fuels by Saudi Aramco and its strategic partners could potentially increase effective economic BTU $$$ value of its 260 billion barrel in-ground proven petroleum reserves by 500x. Large magnitude of value multiplier increases effective price per barrel of oil
- Carbon transmutation could substantially extend the effective usable economic lifetime of Aramco's in-ground crude oil reserves from estimated 59 years per *Oil Change* (2017) out to at least 25,000 years into the future. This factor would support higher valuation because of increased duration of its earnings stream

For details about stranded asset scenario and calculations see public Lattice document:

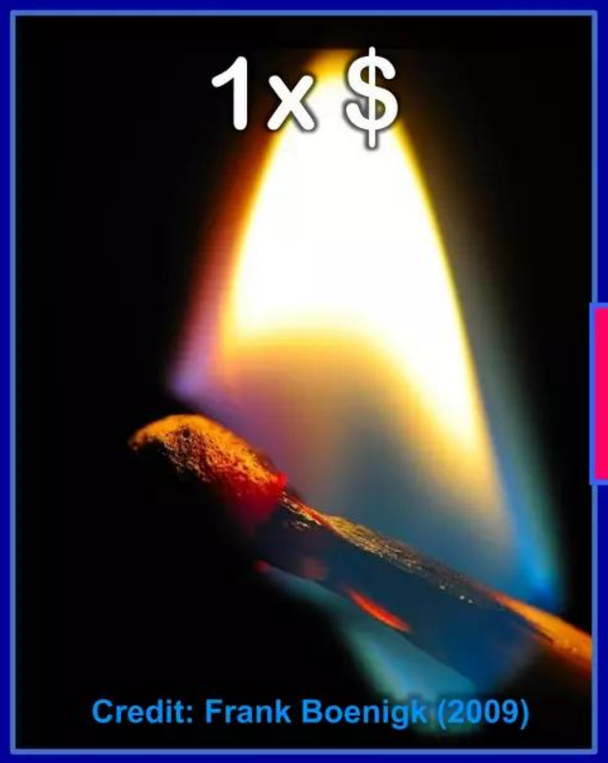
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-lenrs-dramatically-expand-financing-opportunities-for-oil-and-gas-industry-october-8-2015

Transition from Carbon combustion to Carbon transmutation

BTU values for LENR Carbon-based fuels could be about 5,000x gasoline

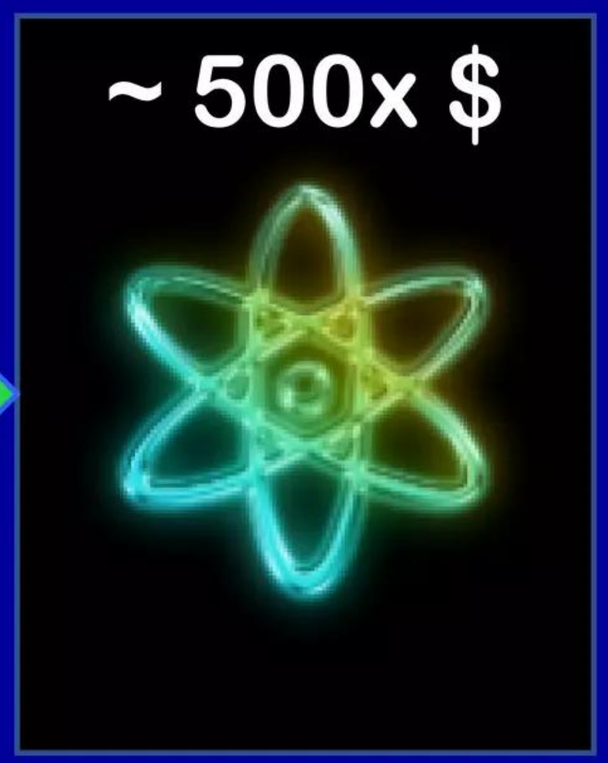
Realizable value of oil-derived LENR Carbon fuel products could increase by 500x

Combustion of Carbon



Adoption of LENR technology

Transmutation of Carbon



Today: barrel of crude oil where fuel products are combusted is priced at ~ US$ 50

Future: LENR fuels made from same barrel of oil could be worth US$ 25,000

Nanoparticulate LENR fuels could be used in many systems

Huge energy density advantages vs. fossil fuels & chemical batteries

Green LENR fuels energy densities could be 5,000x larger vs. gasoline

Consequences: an automobile powered by LENRs could travel around the entire world on a quantity of nanoparticulate fuel that fits into a medium-size FedEx box. **Unlike fission and fusion, LENRs scale downward. This enables future development of portable LENR power systems that could compete directly with batteries and fuel cells, thus vastly expanding range of markets**

LENR fuels would be inert and benign and could use existing package delivery systems for resupply; typical gasoline or diesel tanker truck carries ~5,000 - 12,000 US Gallons of liquid fuel; LENR fuels producing same # of BTUs could be shipped in 1 - 2 FedEx boxes

LENRs could dominate transportation and power generation

Power sources with 50 - 250 kw_e output could decarbonize transportation

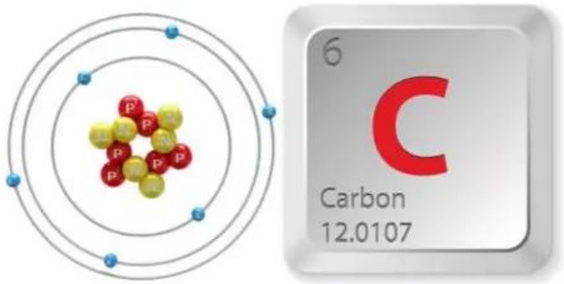
LENR fuels would be excellent for broad application in power generation

- At electrical power outputs of just 50 - 250 kwh, LENR-based systems could begin utilization in many types of motor vehicles and small subsonic aircraft, ending combustion's 120 year dominance of key transportation applications
- At system power outputs of just 5 - 10 kwh, modular LENR-based distributed power generation systems providing combined heat and electricity (CHP) could potentially satisfy the requirements of a majority of urban and rural households and smaller businesses worldwide, including rural powerless
- If widespread deployment of small-scale distributed generation could be achieved, nowhere near as many new, large fossil-fueled and/or fission power plants would have to be built to reliably supply low-cost electricity to regional grids that enjoy $99^{+}\%$ uptime availability. In the future, grid-based centralized power generation could gradually be displaced by vast numbers of smaller, distributed CO_2-free renewable and LENR-based power systems
- Although they could very likely be designed and built, megawatt LENR power plants are not mandatory to change the world of energy for the better

Certain Dinosauria escaped extinction by evolving into birds

Aramco could use LENRs to enter New World of Carbon transmutation

LENRs could extend revenues from Aramco oil reserves out to 1,000s of years



Carbon → Nitrogen → Oxygen

Combustion replaced by transmutation

Neutron catalyzed LENRs

Saudi Aramco faces three key near-term company challenges

Perception of future growth prospects can overwhelm 'fundamentals'

- Saudi Aramco faces near-term challenges: (1) Japanese automakers have thrown down the gauntlet on LENRs; (2) some governments plan to artificially restrict future demand for oil; and (3) goal of increasing Aramco's valuation for 2018 IPO
- Herein we have shown how developing LENR technology could potentially benefit Aramco by mitigating many long-term risk factors cited by those who are now arguing that valuation substantially below US$ 2 trillion is much more justifiable
- Justifications for an IPO valuation under 2 trillion are based on implicit, unstated perceptions that lead to widely-held presumption that Aramco is simply another large, modestly growing multinational oil company very much like ExxonMobil: its principal value-creating product, crude oil, is tied closely to global transportation sector which is presently coming under heavy fire from environmentalists and some governments bent on slashing CO_2 emissions to help avert climate change
- How can such perceptions about Aramco and its future outlook be changed prior to the upcoming IPO? While it is world-class oil company, how could it be sharply distinguished from other publicly traded international oil companies? Widely-held public perceptions about future prospects for growth are extremely important in determining price of a given stock and can overwhelm apparent 'fundamentals'. Good example of this phenomenon is Tesla: stock is presently trading at ~$350 though company has never been profitable and is facing increasing competition from larger automakers … yet it still enjoys a market cap larger than GM and Ford

LENR technology readiness level has advanced up to TRL-3

Timing of generously funded program for LENR R&D is now propitious

- LENR R&D modestly funded by energy business standards: total cumulative global R&D investment amounted to only US$ 250 - 300 million over 26 years. In spite of this, technology readiness level gradually advanced to TRL-3 by 2017
- Given that basic science of LENRs is now understood (15 years ago it wasn't); relevant device physics theory has been published in peer-reviewed journals; and body of published experimental data supporting correctness of theory is overwhelming; it not unreasonable to conclude that remaining technical hurdles in critical path to commercializing LENRs primarily involve engineering. In that case, timing is propitious for initiating a generously funded LENR R&D program
- Prior to IPO, Saudi Aramco could plan and announce initiation of a 5-year, US$ 10 billion program aimed at commercializing LENRs for green power generation. Following Japan's LENR technology development model, King Abdullah City for Atomic and Renewable Energy (K.A.Care), King Abdullah University for Science & Technology (KAUST), SABIC, and other KSA entities could participate
- US$ 10 billion in funding would likely dwarf Japanese investments in LENR technology and radically accelerate if not finish process of commercialization. Given Aramco's size and immense future financial benefits that could result from commercialization of LENRs for green CO_2-free power generation, it would be a reasonable bet-size. Such funding would also insure that the world's very best scientific and engineering talent could be recruited to work in the R&D program

Aramco stock could become a market growth play via LENRs

LENRs could increase margins; sell new CO_2-free fuels to its customers

New LENR fuels could be produced and sold in parallel with today's products

- Prior to IPO, it would be advantageous for Aramco to partner with several international automakers who are not already pursuing LENRs: GM and VW might be recruited to help develop 'engines' and standards for LENR fuels
- As of today, there is not a single oil major company involved in LENR R&D
- If Aramco successfully commercialized LENR technology and surrounded it with a massive patent portfolio, new LENR fuel products would not initially be commoditized and could provide much higher margins vs. selling raw crude oil; it would capture much larger % of economic value-added to its products
- Market value of annual global energy consumption now exceeds US$ 9 trillion (largest market on Earth), of which "oil and oil products" comprise ~ 38%; for past 3 years global energy consumption only grew at ~1%. LENR Carbon fuels would have huge energy density and cost advantages compared to all present chemical power sources and energy storage technologies. If Aramco could commercialize LENRs, it should then be able to disruptively displace many products that exist in today's global marketplace. By doing so, it could finally escape boundaries of present-day "oil and oil products" markets and would be able to grow future sales and profits at higher rates than overall energy market. Aramco stock could be growth play and become a 'Google' of energy

LENRs could enable vast growth in Aramco's future profits

New vision for future of energy may increase Aramco's valuation for IPO

$2 trillion valuation is possible if investors believe Saudi Aramco's exciting vision

- Internal utilization of CO_2-free LENR Carbon transmutation for process heat could 'green' Saudi Aramco's upstream and downstream operations and reduce costs for its present traditional products. Future sale of green LENR Carbon fuels to customers would help decarbonize transportation and power generation writ large. Aramco could become a darling of environmentalists
- Visionary technological shift to LENRs would also be highly synergistic with renewable energy sources like wind and solar because renewables could supply electricity that provides input energy for LENR systems that could effectively amplify input power by 5x - 10x. Think of LENR technology serving as an integrated power amplifier for wind or solar systems. Saudi Aramco and its IPO investors, solar and wind power industries, energy consumers, and Earth's environment would all win with the development of LENR technology
- Shifts in perceptions do not necessarily require long gestation; they can change in an instant. If Aramco can clearly communicate a new vision for the future of energy to investors prior to IPO date, there is reason to believe that a US$ 2 trillion valuation might be well-received. As an established global oil company with good profitability, huge asset base, and stable 37-year track record under Saudi government ownership, Saudi Aramco's vision of its own future should be just as believable and exciting as that of Tesla's Elon Musk

Commercializing LENRs: how does Saudi Aramco get there?

Nanotechnology must be applied to successfully commercialize LENRs

Large length scales

What was formerly thought impossible becomes possible by utilizing Widom-Larsen and applying nanotechnology

Nuclear-strength electric fields in μ-sized LENR active sites enable $e + p$ reaction

Enormous array of new technological possibilities and opportunities open-up at micron to nanometer length-scales

Widom-Larsen enables commercialization of LENRs

Applied nanotechnology and LENRs are mutually joined at the hip

Development risks can be reasonable thanks to Widom-Larsen and nanotech

Guided by physics of the Widom-Larsen theory, an opportunity to commercialize LENRs as truly green CO_2-free nuclear energy source has been enabled by a unique juxtaposition of very recent parallel advances in certain very vibrant areas of nanotechnology (esp. plasmonics), quantum entanglement, new innovations in nanoparticle fabrication techniques, as well as an array of new discoveries in advanced materials science.

Simulation of high local electric fields associated with surface plasmon electrons on substrate

Power densities of primitive experimental LENR devices

Device power densities of 4.28 x 10^3 W/m^2 same as thermal power plants

LENR system areas small: no shielding and fuel energy density > 5,000x gasoline

Present stage of LENR technology development is TRL-3

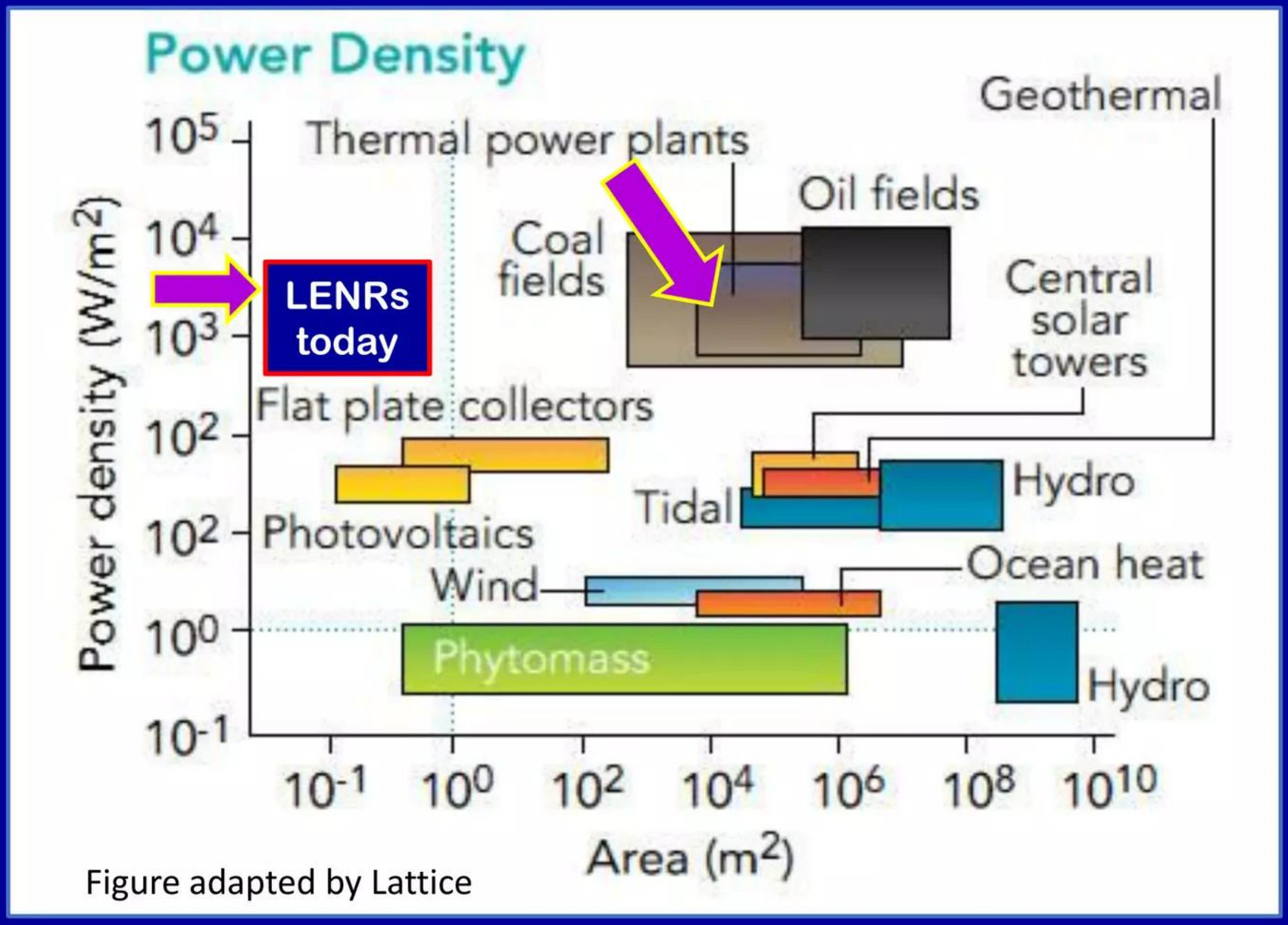


Figure adapted by Lattice

Source: "Do We Have the Energy for the Next Transition?" R. A. Kerr in *Science* 329, pp. 781 (2010)

Widom-Larsen theory enables commercialization of LENRs

Microscopic reproducibility of active sites is the key to commercialization

Stage of LENR technology is presently TRL-3; existing nanotech can be leveraged

- **In present-day's successfully fabricated primitive laboratory devices, LENRs routinely reach temperatures of 4,000 - 6,000° K in relatively small numbers of microscopic LENR active sites located on substrate surfaces.** Evidence for existence of such tiny, very hot localized sites is provided in post-experiment SEM images of working surfaces wherein distinctive crater-like structures are visible. Such features are produced by nuclear heating in μ-scale LENR active sites that create local flash-boiling of metals such as Palladium and Tungsten
- **Present stage of LENR technology is TRL-3:** trying to now fabricate cm-scale and larger devices that can reliably and controllably produce macroscopically large fluxes of excess heat - "boiling a cup of tea" - is putting the cart before the horse
- **Main goal should be to first get key LENR effects --- especially excess heat and transmutations --- working reliably on microscopic scales.** One must be able to reproducibly create rationally designed nanoparticulate structures with dimensions ranging from nm to microns that are fabricated using selected, off-the-shelf nanotechnology techniques and methods. Such nanostructures are then emplaced, along with suitable fuel nuclei (e.g., Lithium, Carbon, transition metals) in close proximity to what will be LENR active sites on substrate surfaces

LENR engineering program should have three key stages

(1) Reproducible fabrication of well-performing LENR active sites

(2) Scale-up heat output by increasing # of active sites per unit area/volume

(3) Select and integrate energy conversion subsystems suitable for specific applications

- **Once microscopic reproducibility of active sites is achieved, output of LENR heat sources could be readily scaled-up,** either by (1) fabricating larger area-densities of affixed nanostructures that facilitate formation of LENR active hot spot sites on device surfaces, or by (2) injecting larger quantities of specially designed target fuel host nanoparticles into volumetrically larger reaction chambers containing turbulent dusty plasmas, with or without spatially organized magnetic fields being present
- **Variety of existing off-the-shelf energy conversion subsystems could potentially be integrated with commercial versions of LENR-based heat sources.** These include: thermophotovoltaic; thermoelectric; steam engines; Rankine cycle steam turbines; Brayton cycle gas turbines, simple boilers, etc. **Other more speculative possibilities involve some entirely new types of radical direct energy conversion technologies that are still in early stages of commercial development**

Key conclusion of theoretical paper published in Pramana

Journal is peer-reviewed publication of Indian Academy of Sciences

"A primer for electro-weak induced low energy nuclear reactions"

"The analysis presented in this paper leads us to conclude that realistic possibilities exist for designing LENR devices capable of producing 'green energy', that is, production of excess heat at low cost without lethal nuclear waste, dangerous γ-rays or unwanted neutrons. The necessary tools and the essential theoretical know-how to manufacture such devices appear to be well within the reach of the technology available now. Vigorous efforts must now be made to develop such devices whose functionality requires all three interactions of the Standard Model acting in concert."

Publications about the Widom-Larsen theory of LENRs

Index provides comprehensive guide to available online information

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen (author's copy)
European Physical Journal C - Particles and Fields 46 pp. 107 - 112 (2006)
http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen (author's copy)
Pramana - Journal of Physics 75 pp. 617 - 637 (March 2010)
http://www.slideshare.net/lewisglarsen/srivastava-widom-and-larsenprimer-for-electroweak-induced-low-energy-nuclear-reactionspramana-oct-2010

"Theoretical Standard Model rates of proton to neutron conversions near metallic hydride surfaces"
A. Widom and L. Larsen
Cornell physics preprint arXiv:nucl-th/0608059v2 12 pages (2007)
http://arxiv.org/pdf/nucl-th/0608059v2.pdf

"Index to key concepts and documents" all hyperlinks in document are live
v. #21 updated and revised through Sept. 7, 2015
L. Larsen, Lattice Energy LLC, May 28, 2013 [133 slides] download is enabled
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-hyperlinked-index-to-documents-re-widomlarsen-theory-and-lenrs-september-7-2015

Popular science books re LENRs and Widom-Larsen theory

Three volumes in series titled "Explorations in Nuclear Research"

Provides overview of entire field at level of *Scientific American* article

"Hacking the Atom" (Volume 1)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, September 11, 2016 (484 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0996886451

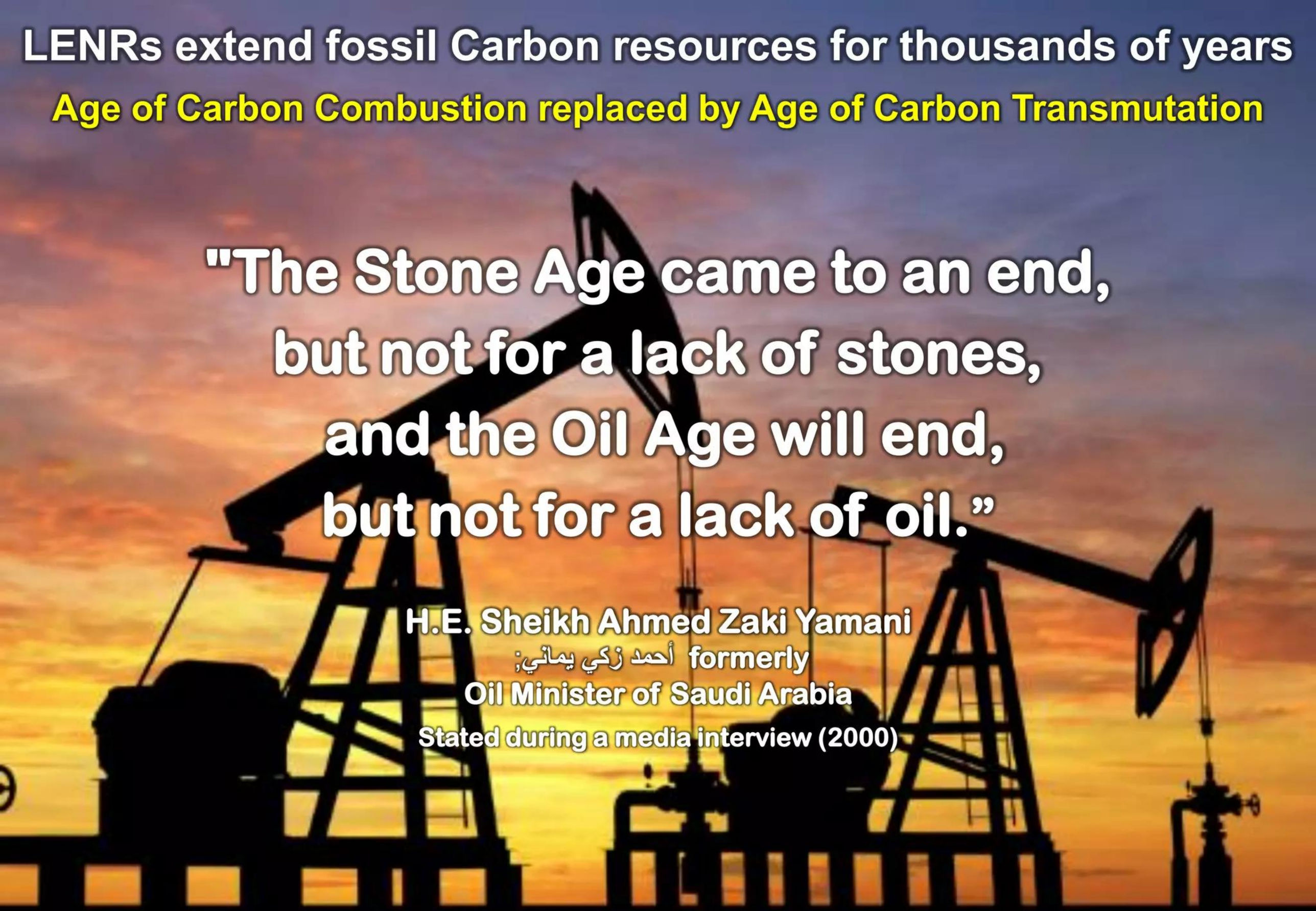
"Fusion Fiasco" (Volume 2)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (531 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0976054523

PowerPoint synopsis of book with additional commentary:
http://tinyurl.com/z6fsbn2

"Lost History" (Volume 3)
Steven B. Krivit
Pacific Oaks Press, San Rafael, CA, November 11, 2016 (380 pages)
Paperback US$16.00; hardcover US$48.00; Kindle US$3.99
https://www.amazon.com/dp/0996886419

LENRs extend fossil Carbon resources for thousands of years

Age of Carbon Combustion replaced by Age of Carbon Transmutation



"The Stone Age came to an end,
but not for a lack of stones,
and the Oil Age will end,
but not for a lack of oil."

H.E. Sheikh Ahmed Zaki Yamani
أحمد زكي يماني; formerly
Oil Minister of Saudi Arabia
Stated during a media interview (2000)