2017 JOINT SERVICE POWER EXPO

The 21st Century Battery Revolution

Why the United States Cannot Afford to Lose the Battery Race

James J. Greenberger
May 2, 2017

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- Founded in 2008
- Not-for-Profit Trade Association
- Mission: To accelerate the development and commercialization of advanced battery technology across industry sectors

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Batteries Have a History of Failure

- Baghdad Battery (Parthian Battery) @ 0 A.D.
- Alessandro Volta demonstrates the Voltaic Pile in 1798
- Gaston Plante invents the lead acid battery in 1859 – most common battery used today

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Battery Technology Has Had Its Skeptics

"The storage battery is, in my opinion, a catchpenny, a sensation, a mechanism for swindling the public by stock companies. The storage battery is one of those peculiar things which appeals to the imagination, and no more perfect thing could be desired by stock swindlers than that very selfsame thing. ... *Just as soon as a man gets working on the secondary battery it brings out his latent capacity for lying*."

-- Thomas Edison, *The Electrician* (London) Feb. 17, 1883

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The Battery Revolution of the 1980's

- Dr. Masahiko Oshitani of GS Yuasa Company develops improved NiMH battery, roughly doubling the energy-density of lead acid batteries. First consumer grade cell sold in 1989
- Rechargeable Li-ion battery developed by Dr. Stan Whittingham at Exxon in early 1980s
- Dr. John Goodenough of Texas developed the lithium cobalt chemistry and later the lithium iron phosphate chemistry
- Sony sells the first commercial lithium-ion battery in 1991, roughly doubling the energy density of NiMH

Dr. Masahiko Oshitani

Dr. Stan Whittingham

Dr. John Goodenough

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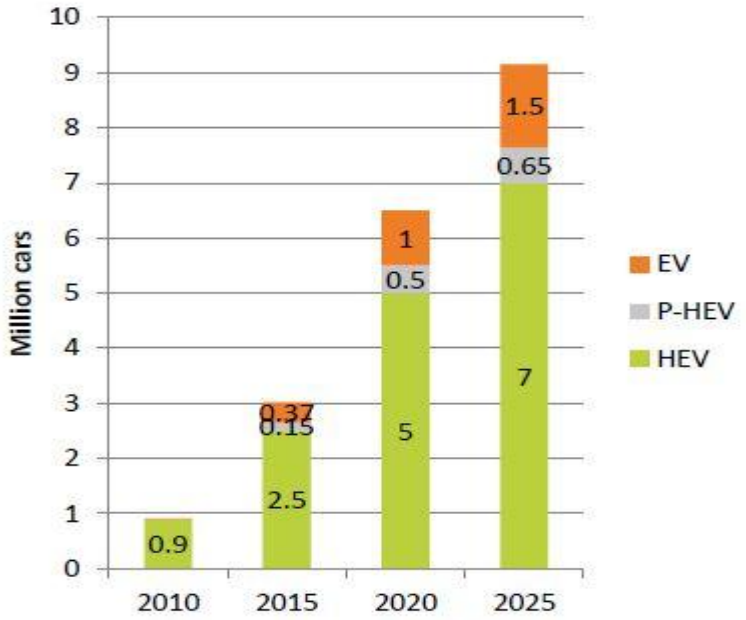
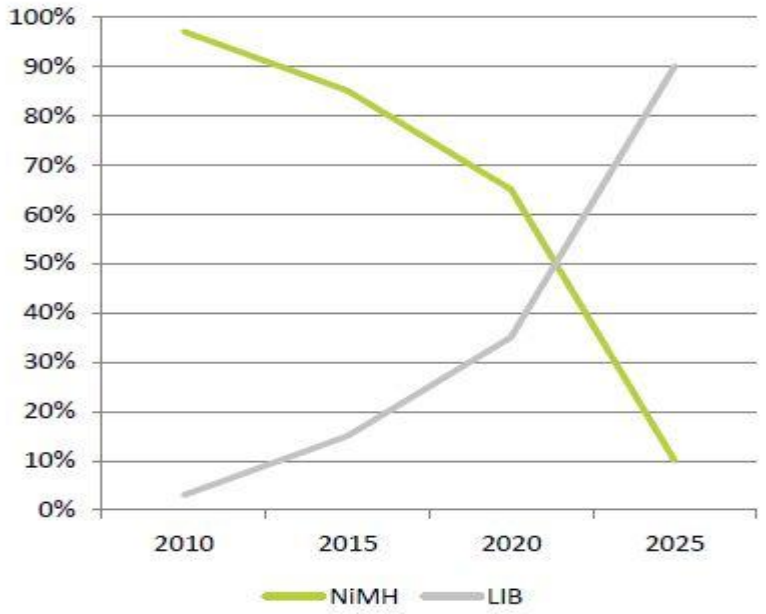
The Sad Fate of Dr. Oshitani

HEV, P-HEV & EV market forecasts up to 2025



LIB penetration in HEV 2010-2025



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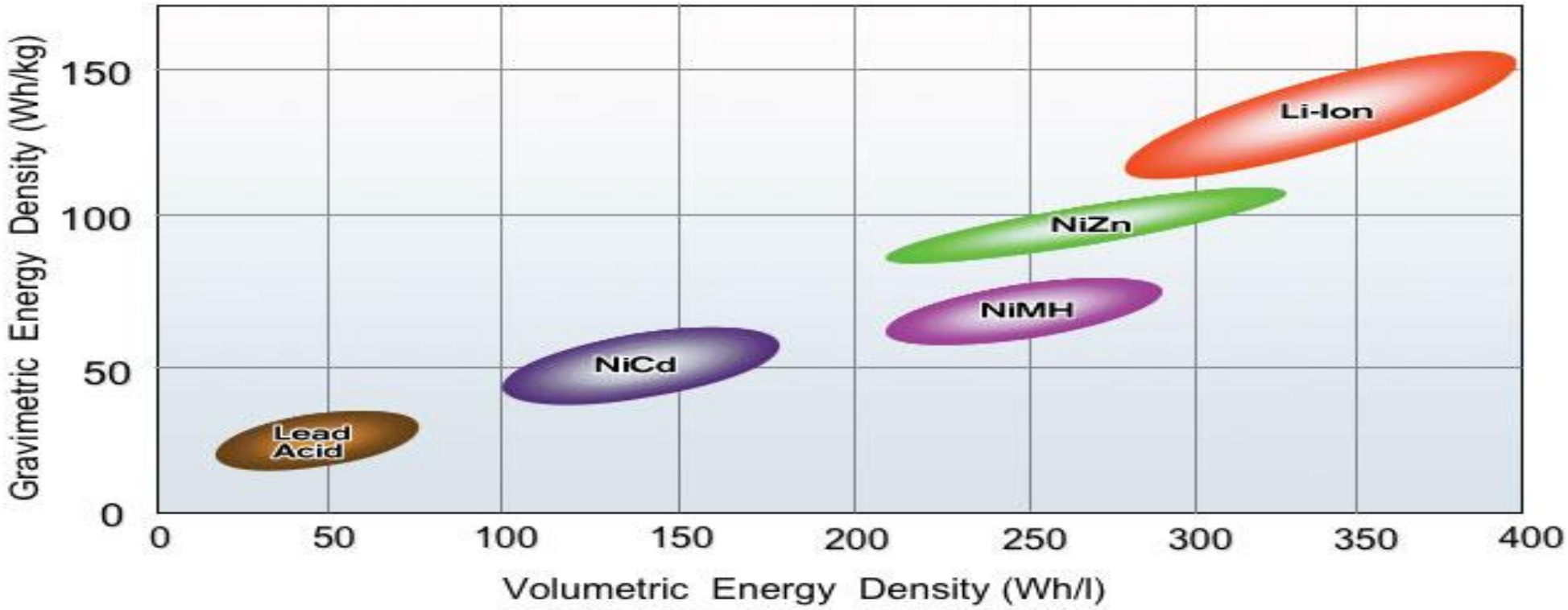
A Lot of Progress in 25 Years



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Advanced Batteries Enable the Technologies of the 21st Century

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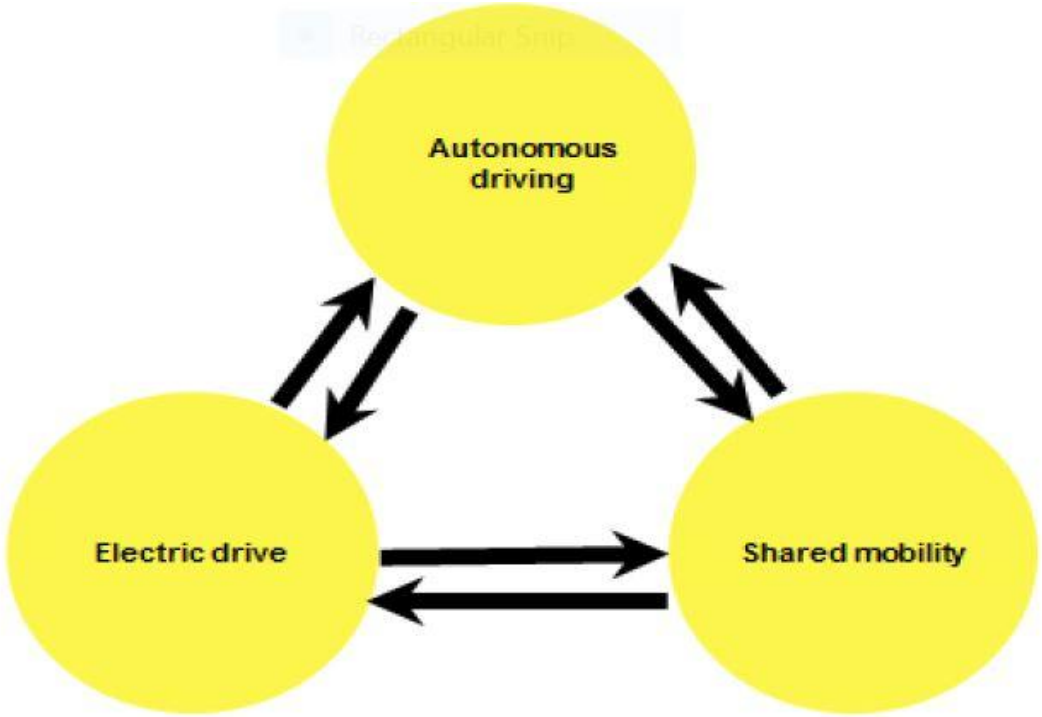
Mobility Revolution



Source: Morgan Stanley Research.

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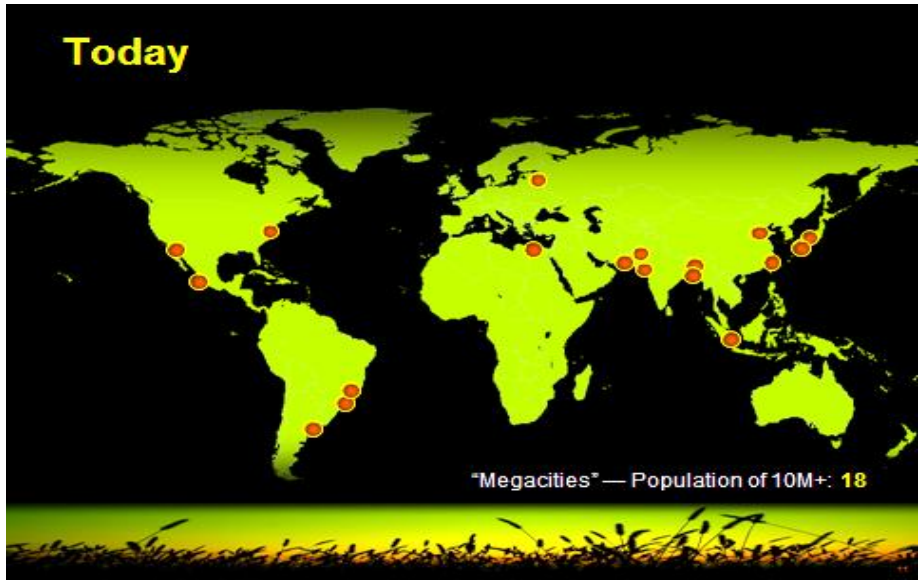
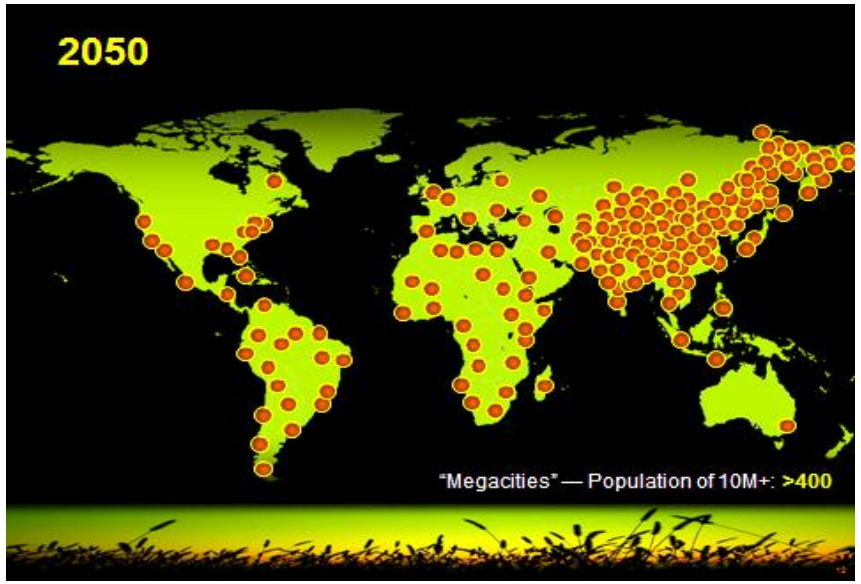
Urbanization Underlies Mobility Revolution





Source: Kleiner Perkins Caufield & Byers

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Vehicles Require More Electric "Stuff"

- Electrical power supply systems…
  - Enable electrical features
  - Enable fuel economy functions
  - Are highly critical for customer satisfaction and safety

1905:
- Light
- Starter

1985:
- *Light*
- *Starter*
- ABS
- Power windows
- …

2015:
- *Light*
- *Starter*
- *ABS/ESP*
- *Power windows*
- Engine ECU
- Customer ports
- EPS
- Driver assist
- Heated/cooled features
- Start/Stop operation
- …

2020+:
- *Light*
- *Starter*
- *ABS/ESP*
- *Power windows*
- *Engine ECU*
- *Customer ports*
- *EPS*
- *Driver assist*
- *Heated/cooled features*
- *Start/Stop operation*
- e-Booster
- Fully autonomous vehicle
- Active chassis systems
- …

Picture source: Auto Motor und Sport

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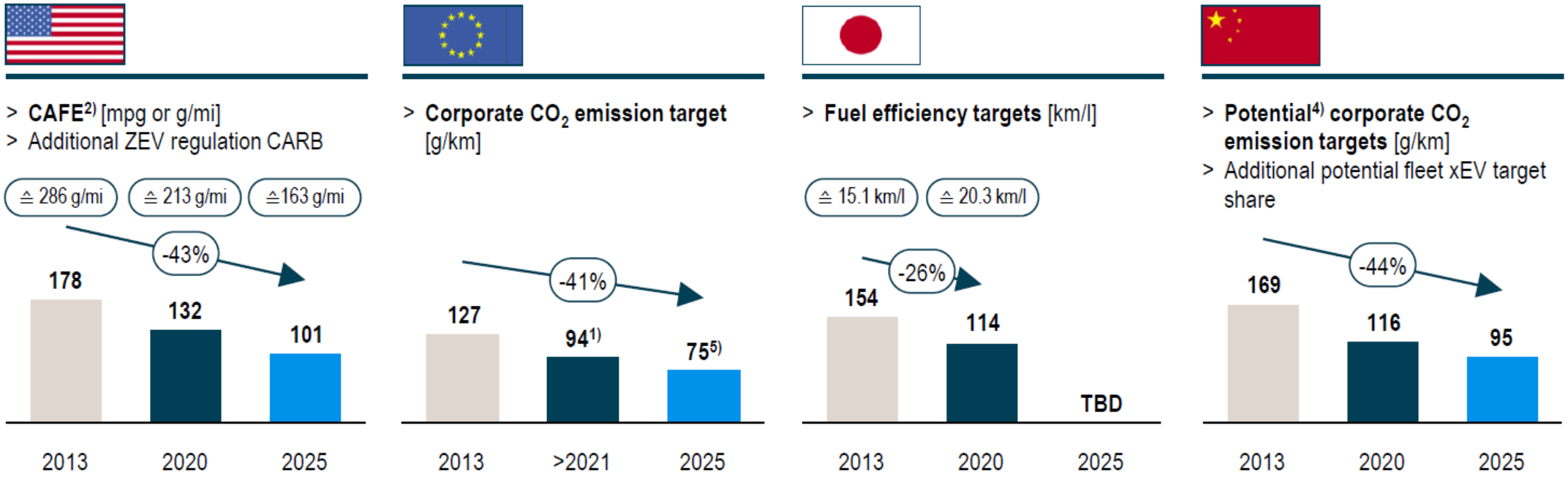
Decarbonization Policy is Real



Source: Roland Berger 2015

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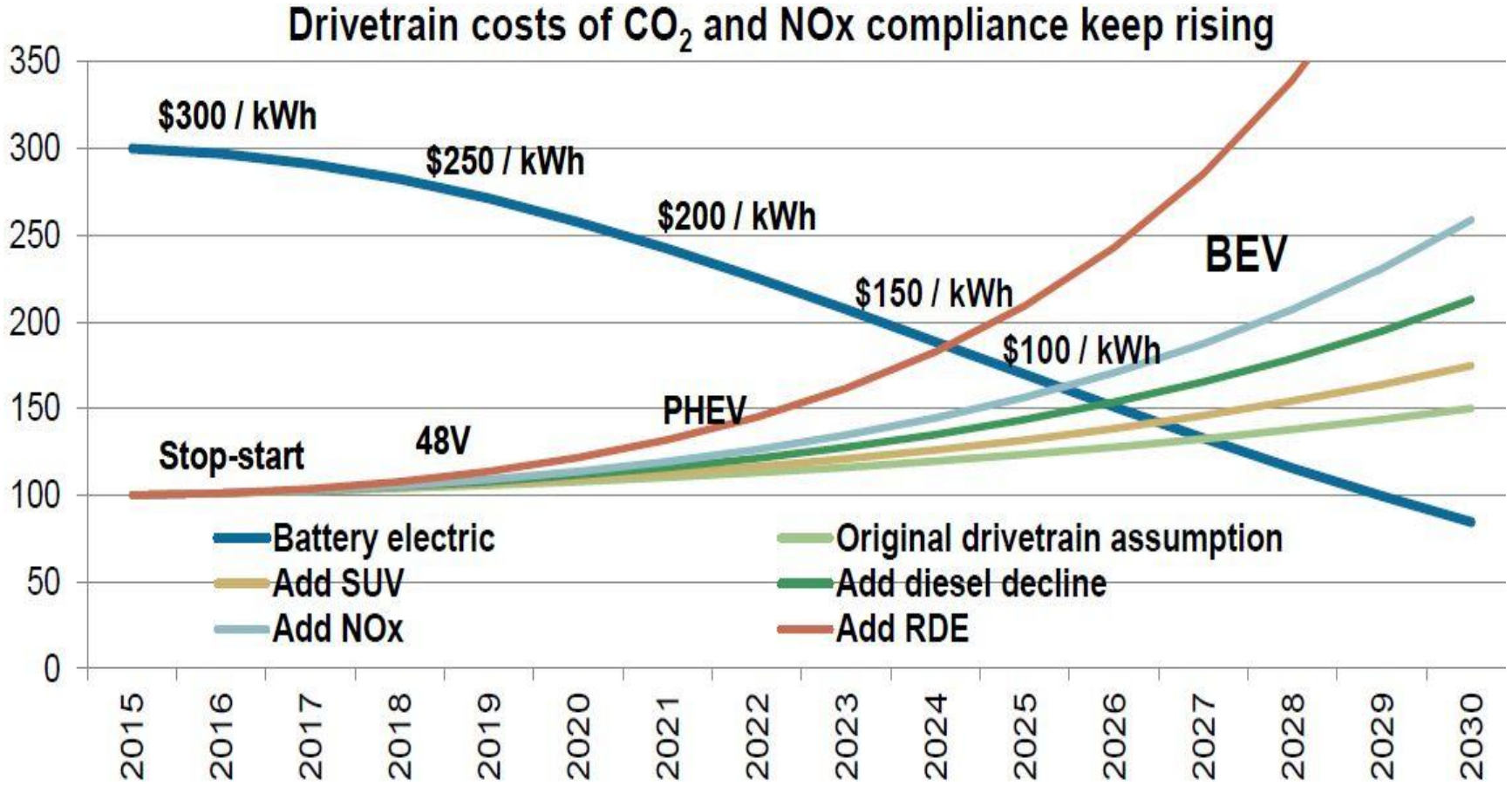
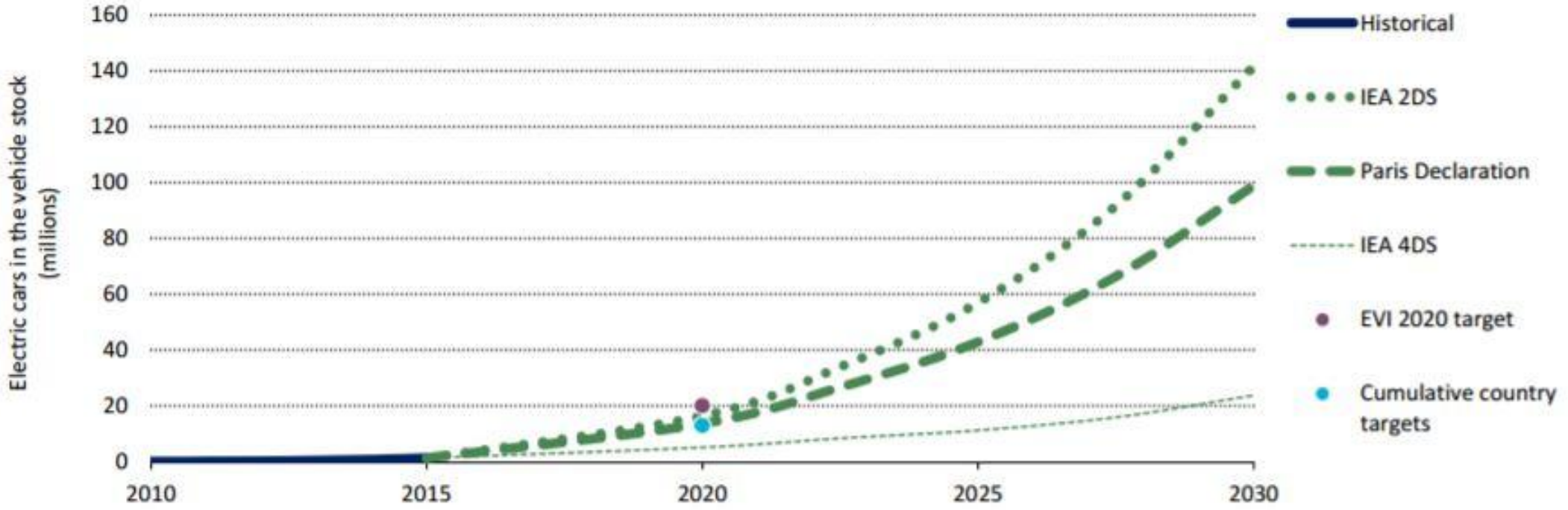
Rising Cost of ICE vs. Falling Battery Costs



Source: Morgan Stanley Research

xEV Market Projections are Robust



Source: International Energy Agency 2016

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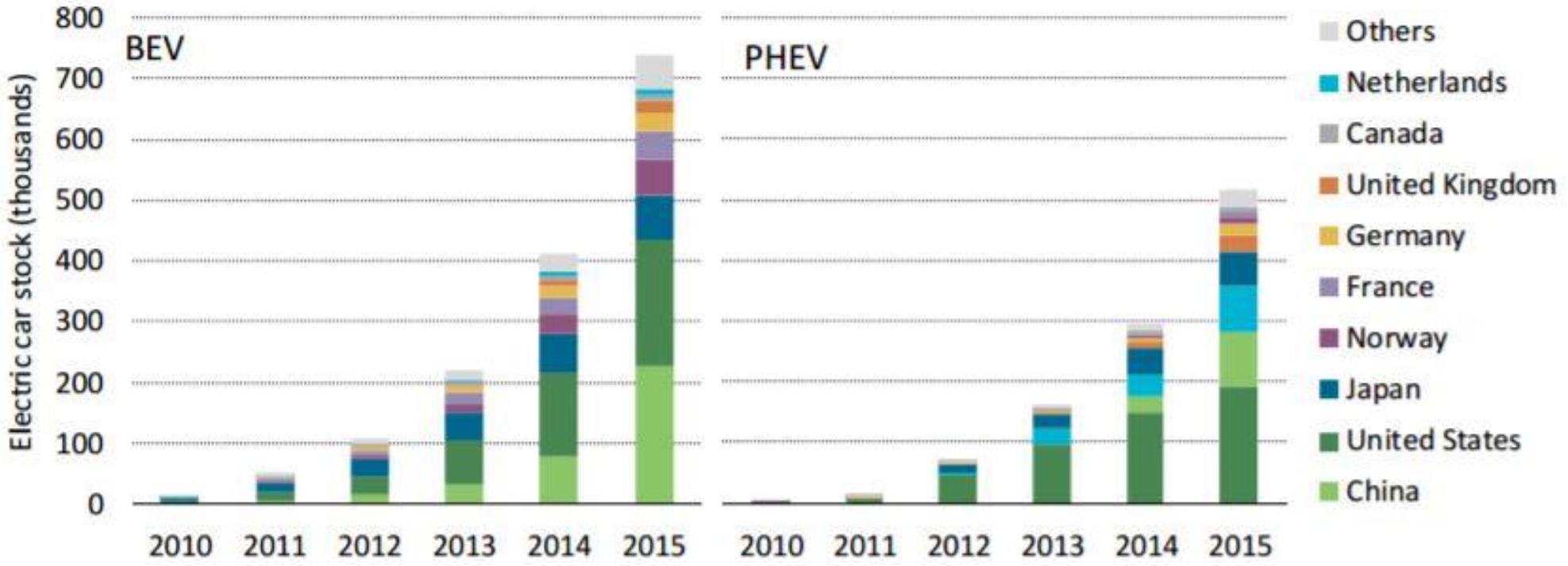
Experience May Support Optimism



Source: International Energy Agency, 2016

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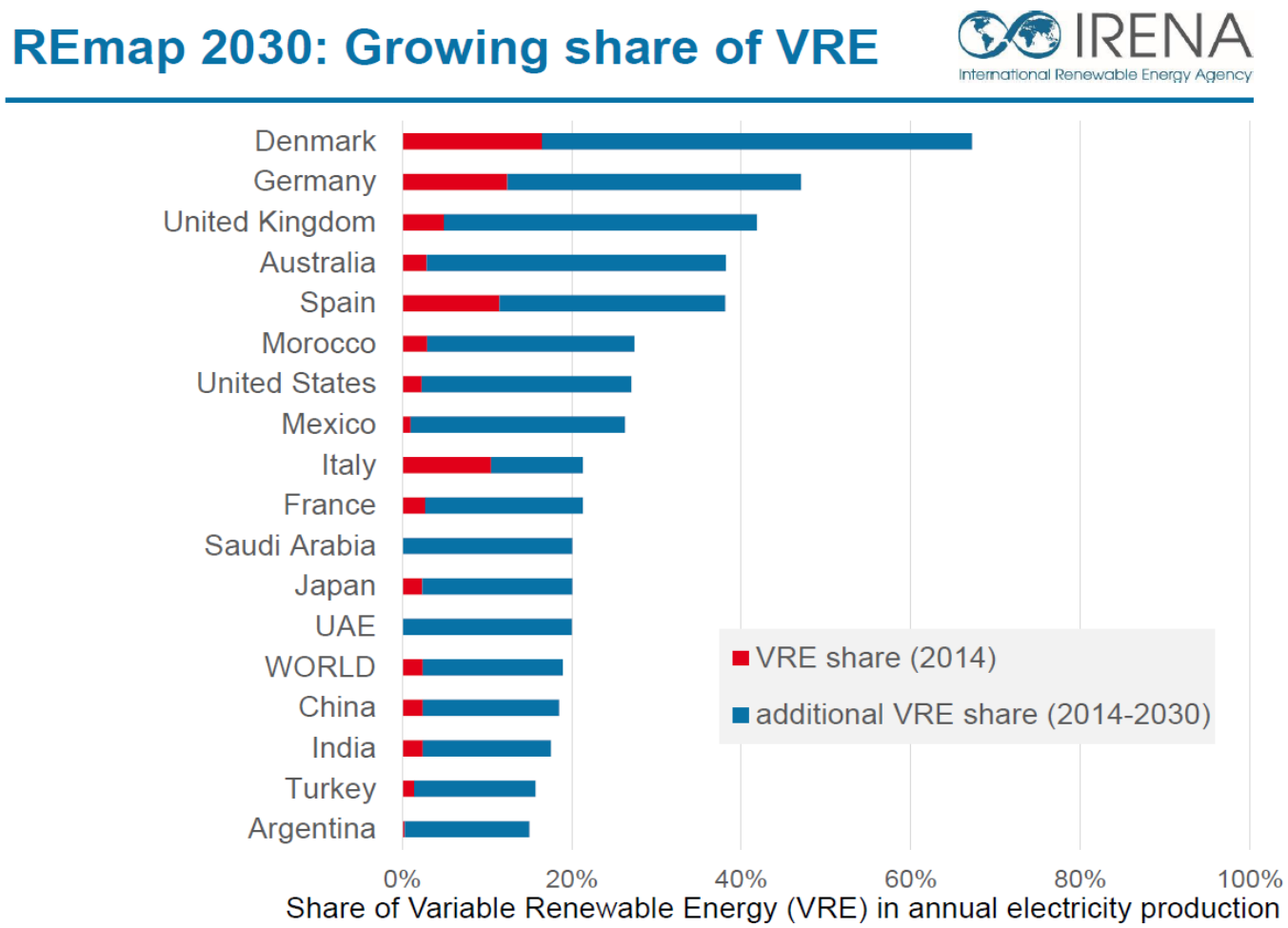
Electricity Grid Revolution



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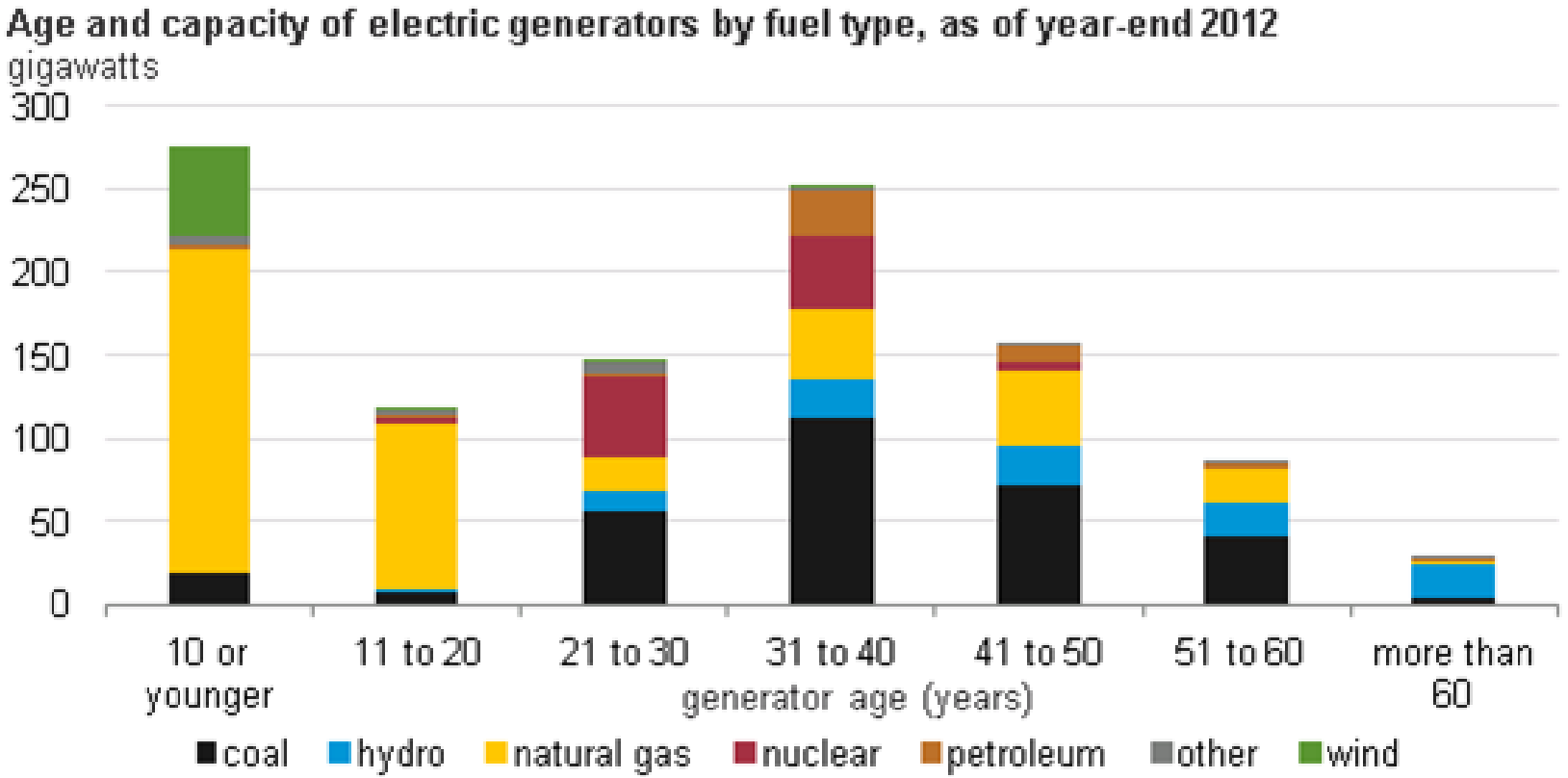
The Electricity Grid is Aging



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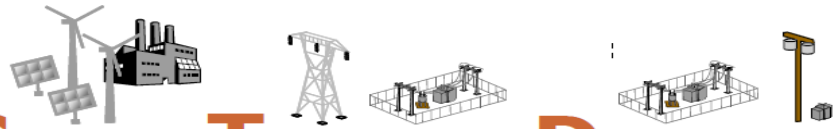
…and Inefficient



	Generation	Transmission	Distribution
# in U.S.	17,350 plants	164,000 miles	3 million miles
Utilization	47%	43%	34%
Projected spend 2010-2030	$505B	$298B	$582B
Projected underutilization	~$1.4 TRILLION of future US infrastructure will be underutilized without storage		

Energy storage unlocks value in existing assets by increasing low rates of utilization

Sources: "Electric Power System Asset Optimization." NETL, March 2011; "The Power of Five Percent." The Brattle Group, May 2007

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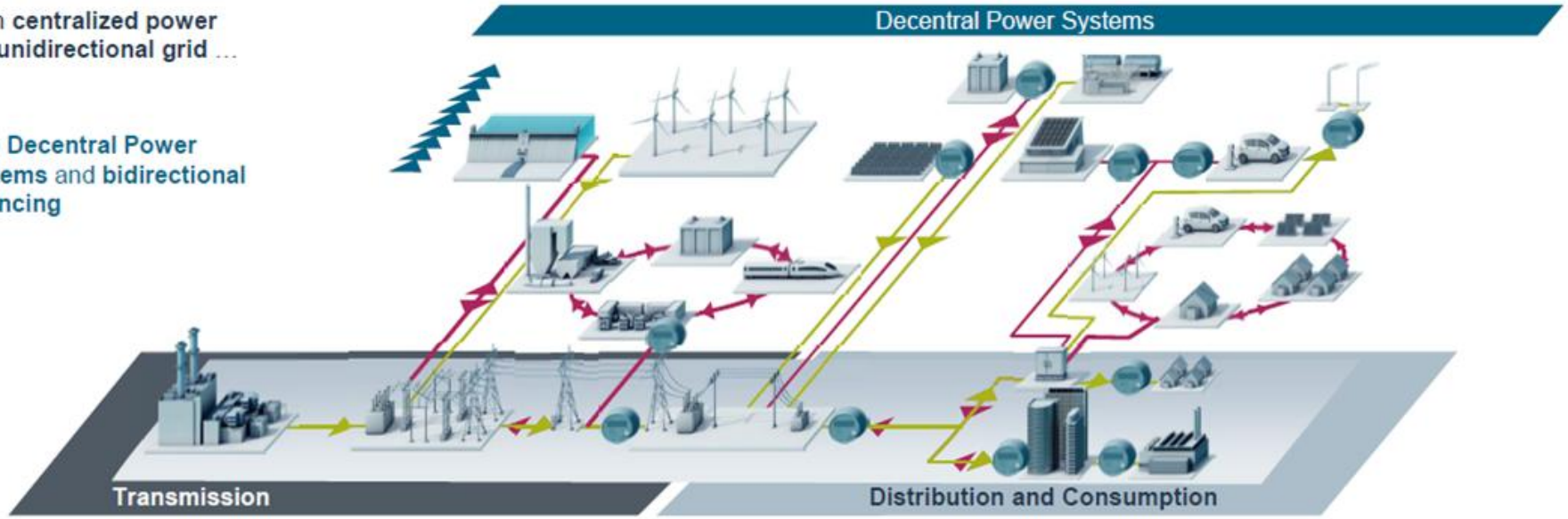
The New, Decentralized, Bidirectional Grid

From **centralized power** and **unidirectional grid** ...

... to **Decentral Power Systems** and **bidirectional balancing**



1. **Changing generation mix** — higher volatility drives invest in stability / availability
2. **Generation capacity additions** — generation capacity increase requires new connections
3. **Distance from source to load** — natural resources and demand centers to be linked
4. **Decentralization (public / private)** — small / decentral units drive invest in distr. automation / IT
5. **Refurbishment / upgrades** — installed base is enhanced to cope with new challenges

Source: Siemens

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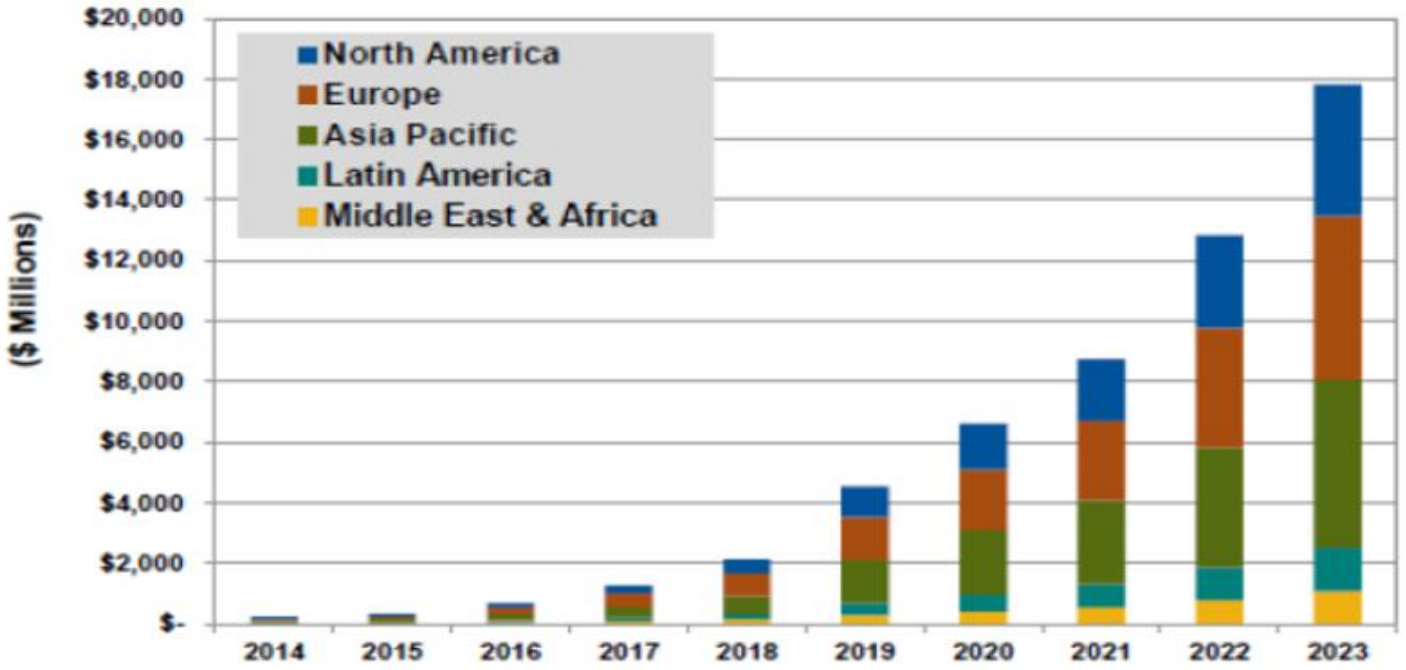
Electricity Storage is Key to the New Grid Design

Energy Storage For Renewables Integration New Installations, World Markets: 2014-2023



(Source: Navigant Research)

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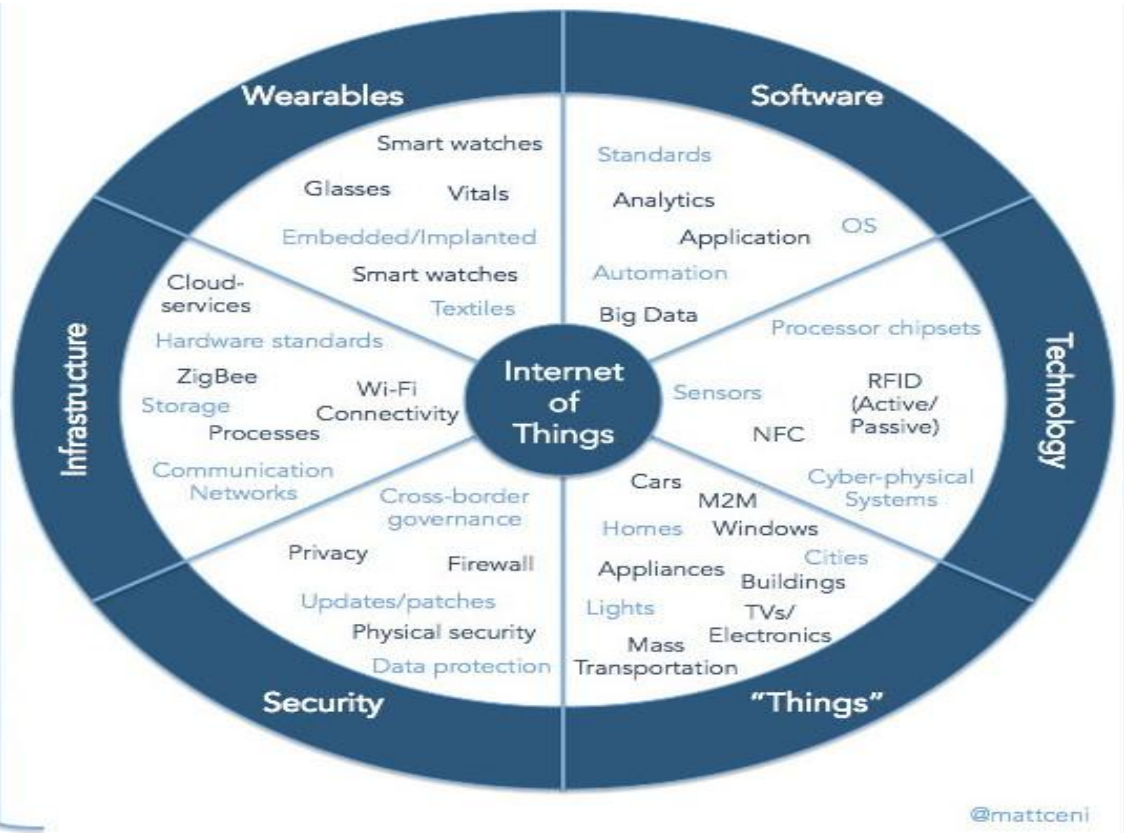
The Data Revolution (Internet of Things)

The IoT market by 2020

- The Internet of Things estimated market value: $8.89 trillion
- Wearables estimated market value: $8.3 billion
- If "Wearables" were removed from the estimated IoT value, the IoT overall value would STILL be $8.89 trillion

The sizeable IoT market opportunity is in software, security and infrastructure



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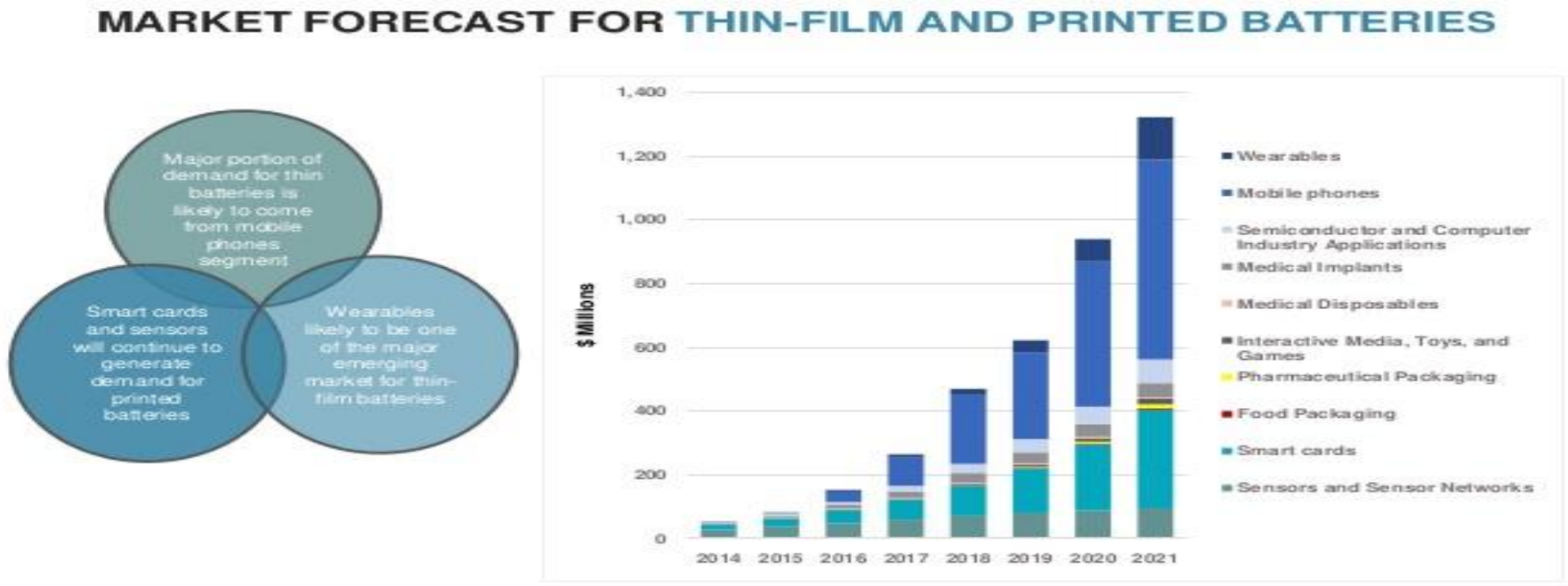
Powering the Internet of Things



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The Military Battery Revolution

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Compression of Military and Civilian Technology

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Potential Breakthroughs in Battery Technology 2017-2050

- Lithium Ion with Silicon based anode
- High Voltage Li-Ion (4.4-4.7V)
- Li-Ion Solid Electrolyte (Li-ion, Li-metal)
- Lithium Sulfur
- Lithium Air

Source: Shmuel De-Leon Energy Ltd., 2017

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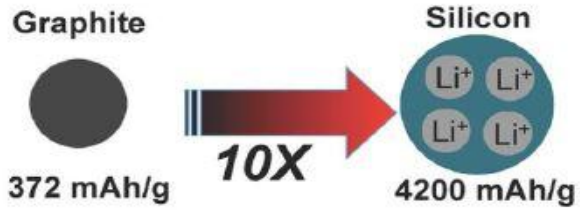
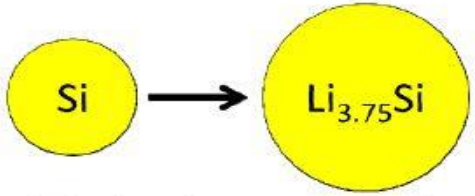
Silicon Anodes / High Voltage

- **Anodes are carbon based – Si stores 10X more energy than Li carbon (250-300 Wh/Kg).**





- **18650 3.5-4Ah cells projected by American Lithium Energy, Panasonic, LG, Samsung and Sony (2015-2018).**

Panasonic NCR18650GA

Sony US18650VC7

Source: Shmuel De-Leon Energy Ltd., 2017

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Solid Electrolyte Pouch Cells

Developers:
Toyota
Apple
Samsung
Imprint
Prologium
And 20 more…

- **Higher energy density than Li-Ion (When use Li-Metal anode)**
- **Safety – no flammable electrolyte, No leaks (Ceramic, Dry Polymer)**
- **less Lithium dendrite formation**
- **Can fit any casing shape (soft packaging)**
- **Cells can be made as thin as 0.1 mm or about one-tenth the thickness of the thinnest prismatic liquid Li-ion cells**
- **Low potentially manufacturing cost**
- **Excellent cycling stability**
- **Excellent shelf life**

Source: Shmuel De-Leon Energy Ltd., 2017

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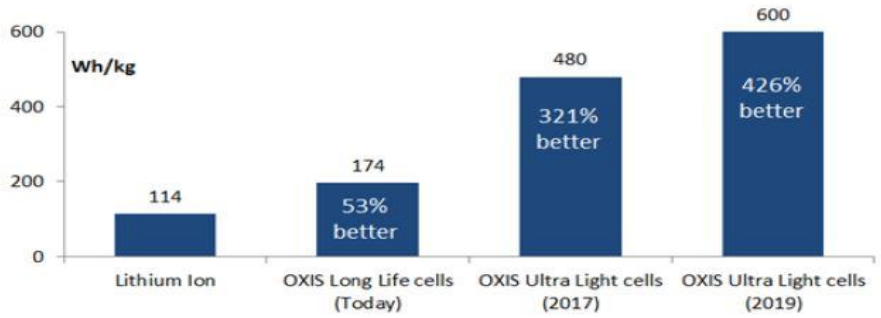
Lithium Sulfur

- **High theoretical capacity, energy and power density – Expected for practical 300 to 600 Wh/kg**
- **Sulfur cost is cheap and environmentally safe**
- **Li-S can provide the break through we are waiting for – but farther development needed**
- **Developers: Sion power (U.S.A.), Eagle-Picher (USA), PulyPlus (U.S.A.), Oxis Energy (U.K.) - Oxis is leading with a 310 Wh/kg pre-production**



	Li-S	Li-Ion
Wh/Kg	2500	580
Wh/L	2660	1810

Source: Shmuel De-Leon Energy Ltd., 2017

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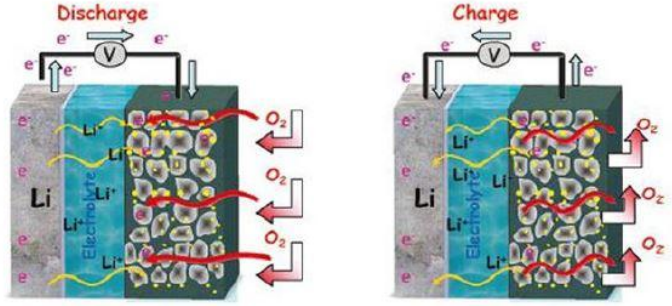
Metal Air batteries - Lithium Air

- **Metal Air batteries provide higher energy densities**
  - **Aluminum Air**
  - **Zinc Air**
  - **Silicon Air**
  - **Lithium Air**
- **But these metal air batteries up till now have been primary batteries (non rechargeable or only mechanically rechargeable)**
- **Academics and Industry alike are working on making the lithium air battery rechargeable.**



Source: Shmuel De-Leon Energy Ltd., 2017

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Asian Companies Dominate Li-Ion Mfg.

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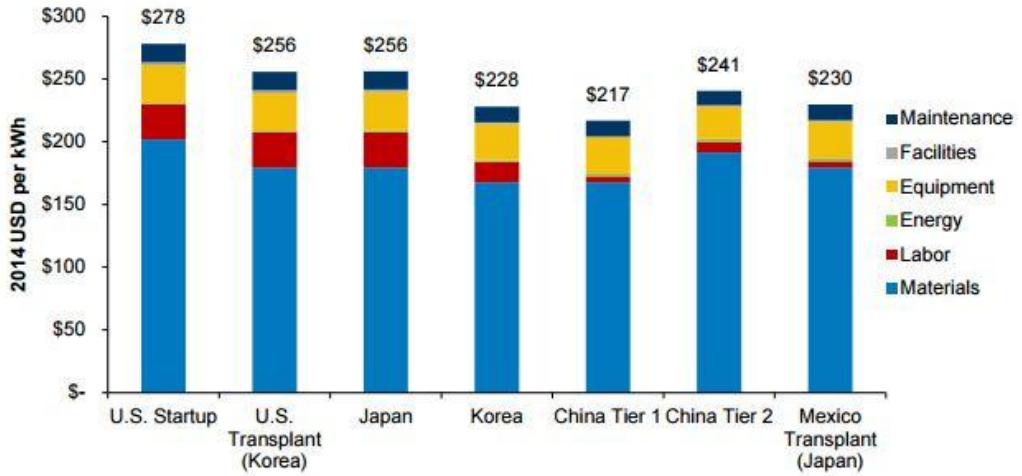
Why Does Asia Dominate?

- Lower costs
- Incumbency
- Government subsidy
- U.S. indifference

Modeled Li-Ion Cell Mfg. Costs per Region



Source: Clean Energy Analysis Manufacturing Center (CEMAC) 2016

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Play to Your Strength

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Thank You

James J. Greenberger
Executive Director
NAATBatt International
(312) 588-0477
jgreenberger@naatbatt.org

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