

The Slow Pace of *Fast* Change

# The Future of Energy Systems



**Garry Golden**

Forward Elements Inc  
March 4, 2019

**C H A N G E**

The word "CHANGE" is rendered in a 3D, blocky font. Each letter is a light gray cube with a black shadow underneath. The letters are arranged in a row. The letter 'G' is tilted upwards and to the right, with its top edge pointing towards the top right. The letters 'C', 'H', 'A', 'N', and 'E' are upright. The overall style is clean and modern.

# Foresight 101: Four Futures Thinking



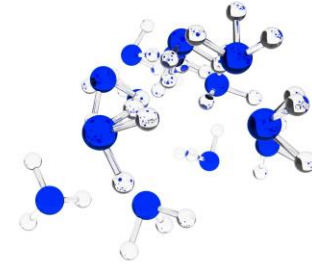
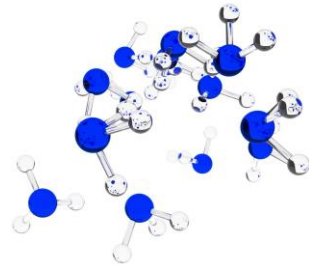
**Continued  
Growth**

**Disciplined  
Constrained**

**Transformed**

**Decline  
Collapse**

# Imagining the Four Futures of...



**Continued  
Growth**

**Disciplined  
Constrained**

**Transformed**

**Decline  
Collapse**

# The *Slow Pace* of Fast Change in Energy Systems



**20<sup>th</sup> Century Dynamics**

Alternative Futures

Baseline Future

Sector Integration (Gas + Grid; Mobility)  
Cyber Security  
Transactive Grid  
Distributed Energy Resources  
Design for Behavior Change

Maintenance,  
Preservation  
& Renewal

**21<sup>st</sup> Century Dynamics**

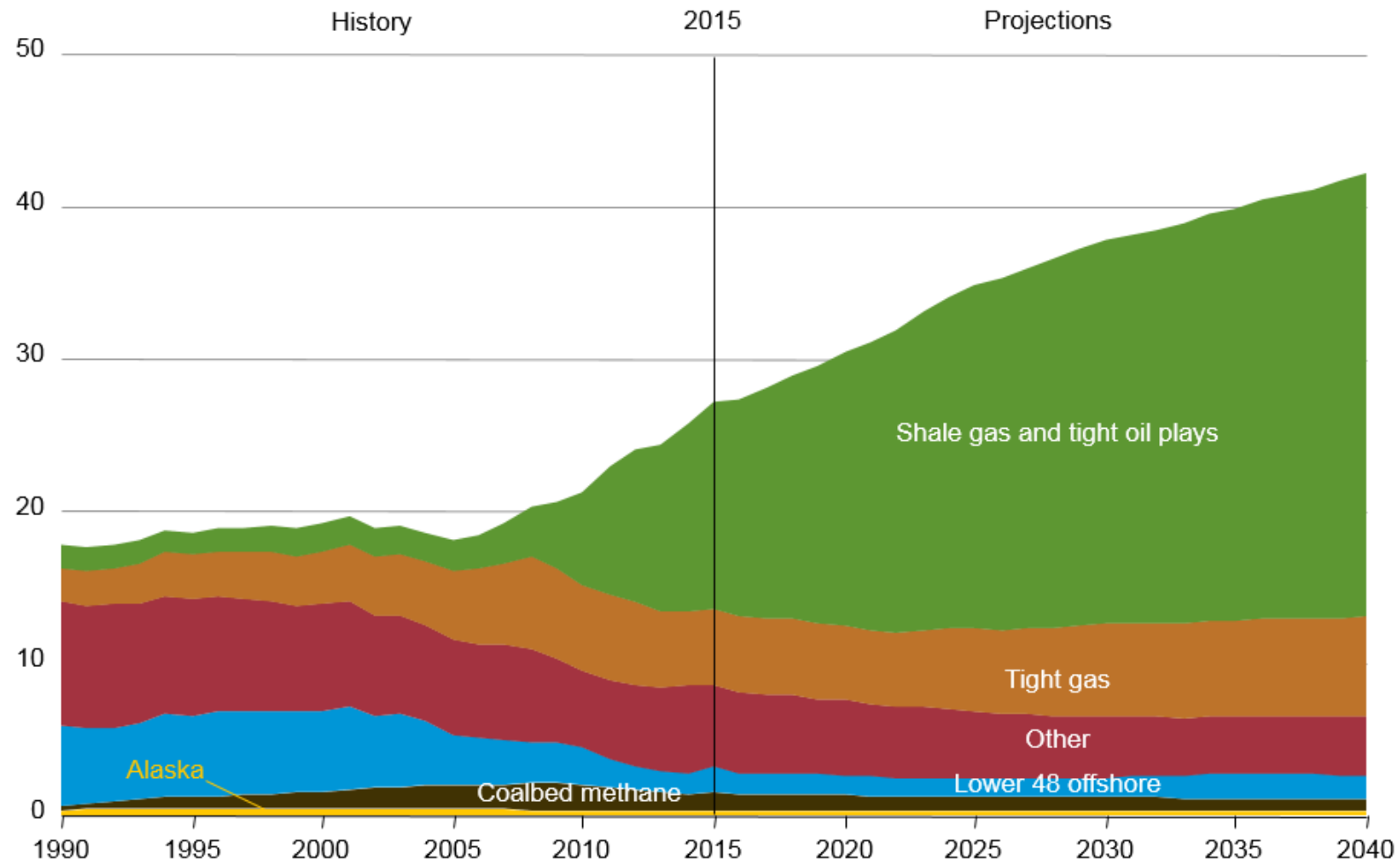
Digitalization Decentralization Decarbonization



# 10 Years: Uncertainties in Fuel Dynamics

Figure MT-46. U.S. dry natural gas production by source in the Reference case, 1990–2040

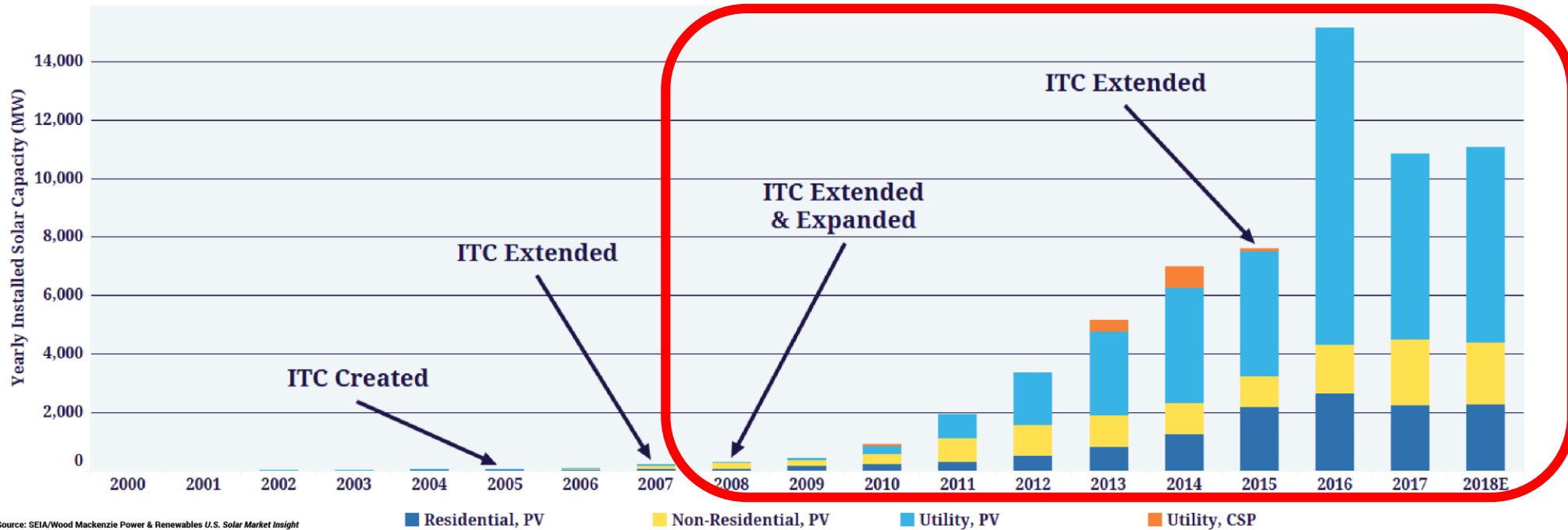
trillion cubic feet



# 10 Years: Uncertainties in Policy (2020 – 2030)



## Annual U.S. Solar Installations



Source: SEIA/Wood Mackenzie Power & Renewables U.S. Solar Market Insight



# 10 Years: Uncertainties in Players & Business Models



TESLA

SIEMENS

Alphabet

amazon

**Oil Giant Shell Wants to Sell You Electricity**

**Big Oil pivots to electricity,  
Total leads the way**

**Microsoft Is Getting Hungry  
for Fuel Cells**

By Anna Hirtenstein  
October 31, 2017, 1:00 AM EDT

**Walmart takes a page from  
Amazon, invests in Plug Power**

**Amazon wants to help make it easier to lower your power bill**

# 10 Years: Uncertainties in Technology Deployment

Coal comeback? Cleaner Natgas?

Transforming Generation Asset Utilization & Longevity?

<b>Coal plant – no CO<sub>2</sub> capture</b>	<b>500 MW</b>	<b>.06 (\$/kWh)</b>
90% amine capture	400 MW	.11 (\$/kWh)
<b>90% CO<sub>2</sub> capture w/ fuel cell</b>	<b>900 MW</b>	<b>.08 (\$/kWh)</b>
5% CO <sub>2</sub> capture with fuel cell	522 MW	.06 (\$/kWh)

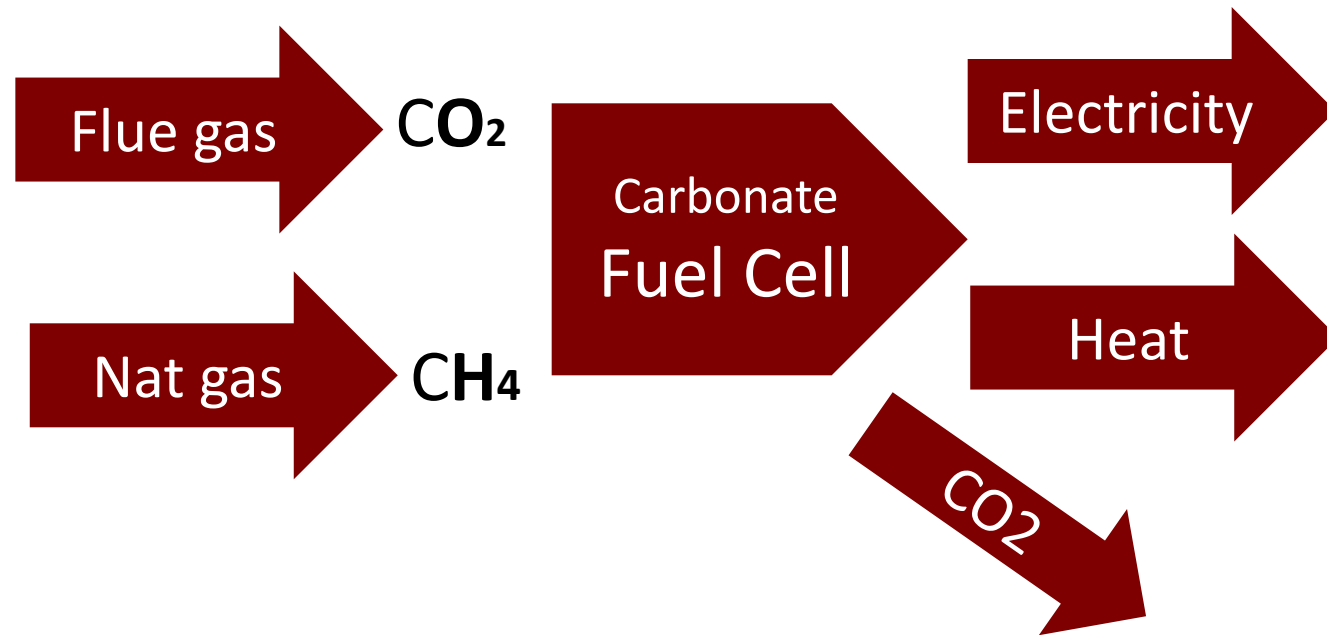
(Source: Fuelcell Energy & ExxonMobil)

**ExxonMobil**

**fuelcellenergy**



Carbonate Fuel Cells



# 10 Years: Uncertainties in Regulatory Landscape

Allam Cycle Natural-gas plant in La Porte, Texas



50-megawatt thermal (25MWe)  
world's only industrial-scale  
supercritical carbon dioxide-based  
power plant and CO<sub>2</sub> cycle test facility.



# Surfacing Uncertainties that might Impact the Natural Refrigerant Industry...





# The Big Picture Distributed Resources & Sector Coupling



Gas + Grid



Transportation + ??

# Policy Scenarios: *Electrify Everything* vs Deep Decarbonization

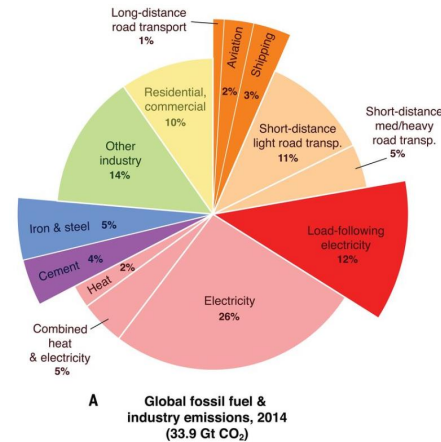
## Electrification Pathway



### Renewables

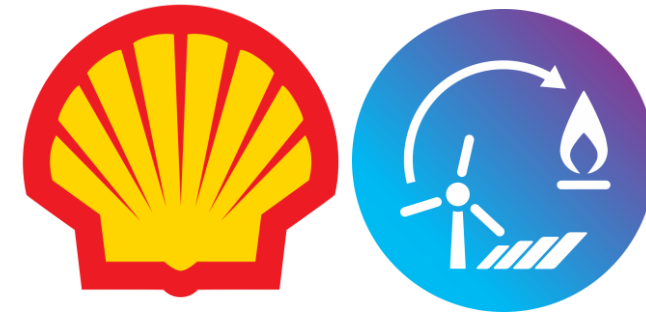
Battery Storage  
& V2G Integration

## Molecules-led Pathway



### Decarbonization

Scale & Versatility



### Incumbents

PtG Pathway  
for Oil & Gas



# Momentum: Renewables Plus Storage for Power Grid



**Renewables on the Rise**



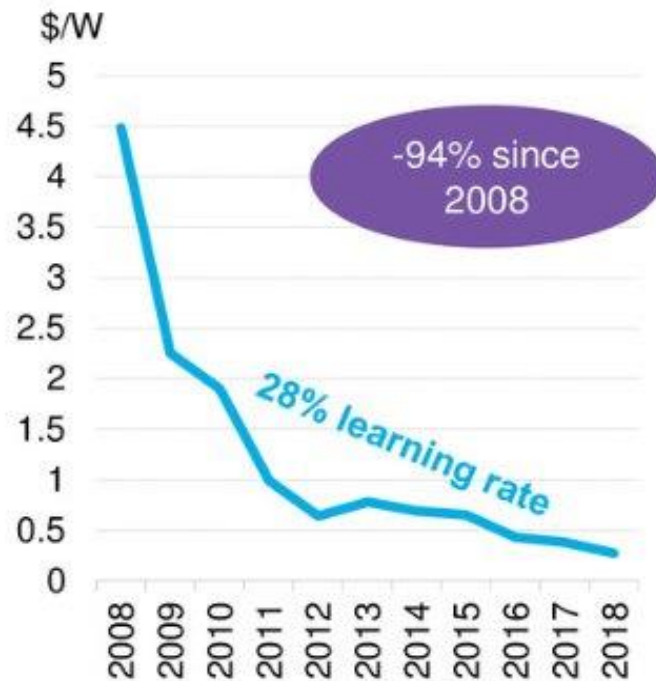
**Energy Storage  
Battery Revolution**



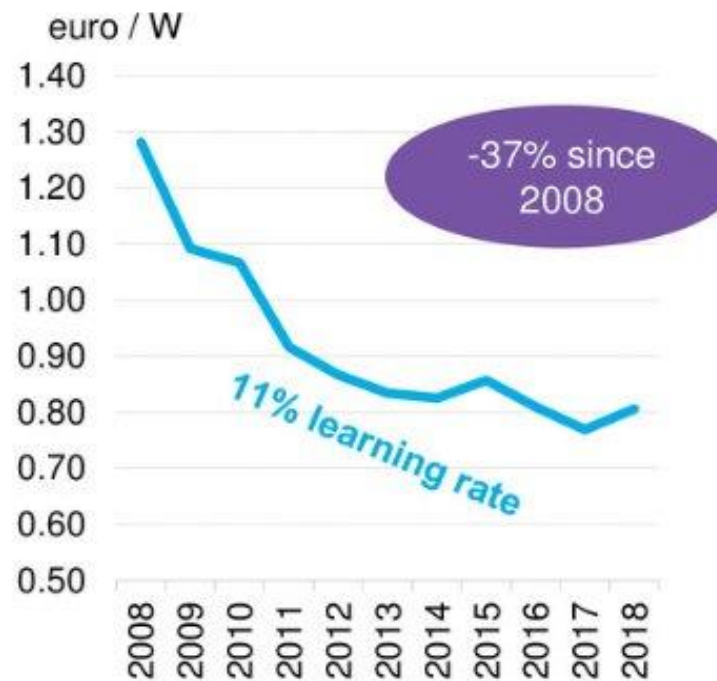
# Policy-led Technology 'Miracle'

## Transitions driven by technology

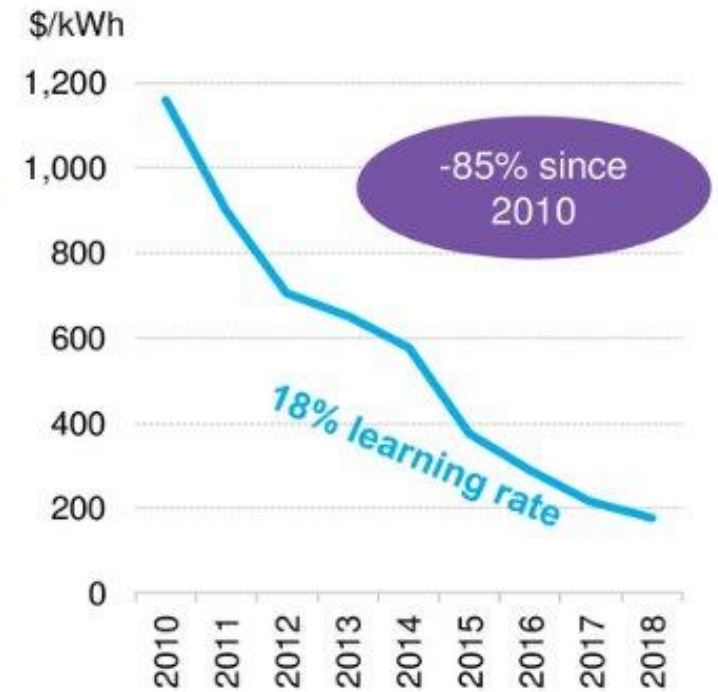
### Solar PV module prices



### Onshore wind turbine prices



### Lithium-ion battery prices



Source: BloombergNEF.

# Renewables with Storage & ‘Virtual Power Plant’

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## First US wind-solar-storage site unveiled

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14 February 2019 by David Weston

US developer NextEra and utility Portland General Electric will build a 380MW wind-solar-storage hybrid project in eastern Oregon, north-west US.

**NV energy plan to add 100 MW storage, 1 GW renewables gets PUC approval**

## Why HECO Drew Such Low Solar-Plus-Storage Prices

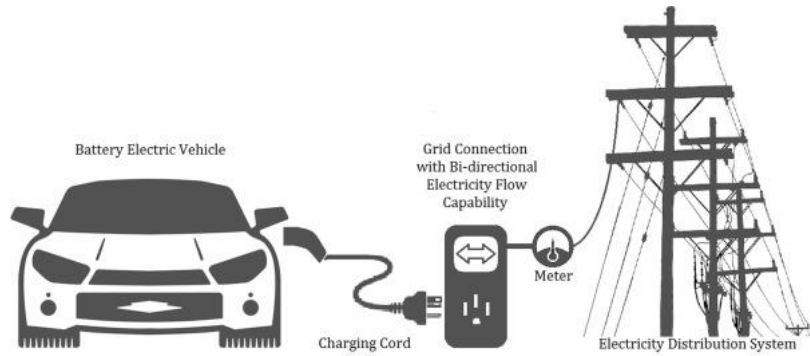
 January 14, 2019 By [Peter Maloney](#) 

## Sunrun Wins Big in New England Capacity Auction With Home Solar and Batteries

The 20-megawatt contract is small by power plant standards, but marks a crucial proof point for the theory that clean, decentralized energy devices can deliver reliable power to the grid.

**JULIAN SPECTOR** | FEBRUARY 07, 2019

# Electrification: Testing Viability of Vehicle to Grid (V2G)



***V2G Vision = EVs as Dispatchable Energy***

Austin Sustainable and Holistic Integration of Energy Storage and Solar Photovoltaics (SHINES)

## **Facilities & Cold chains: Pure Electrification Scenario**



## **Embrace Electrification & Distributed Energy Resources (DER)**

- Onsite Solar & Battery**
- Transactive Grid (Buy & Sell Power)**
- IoT Equipment – Data as Asset  
(Devices Help Balance Demand)**
- Electrified Transportation**

# Wildcard = The Refrigeration Battery

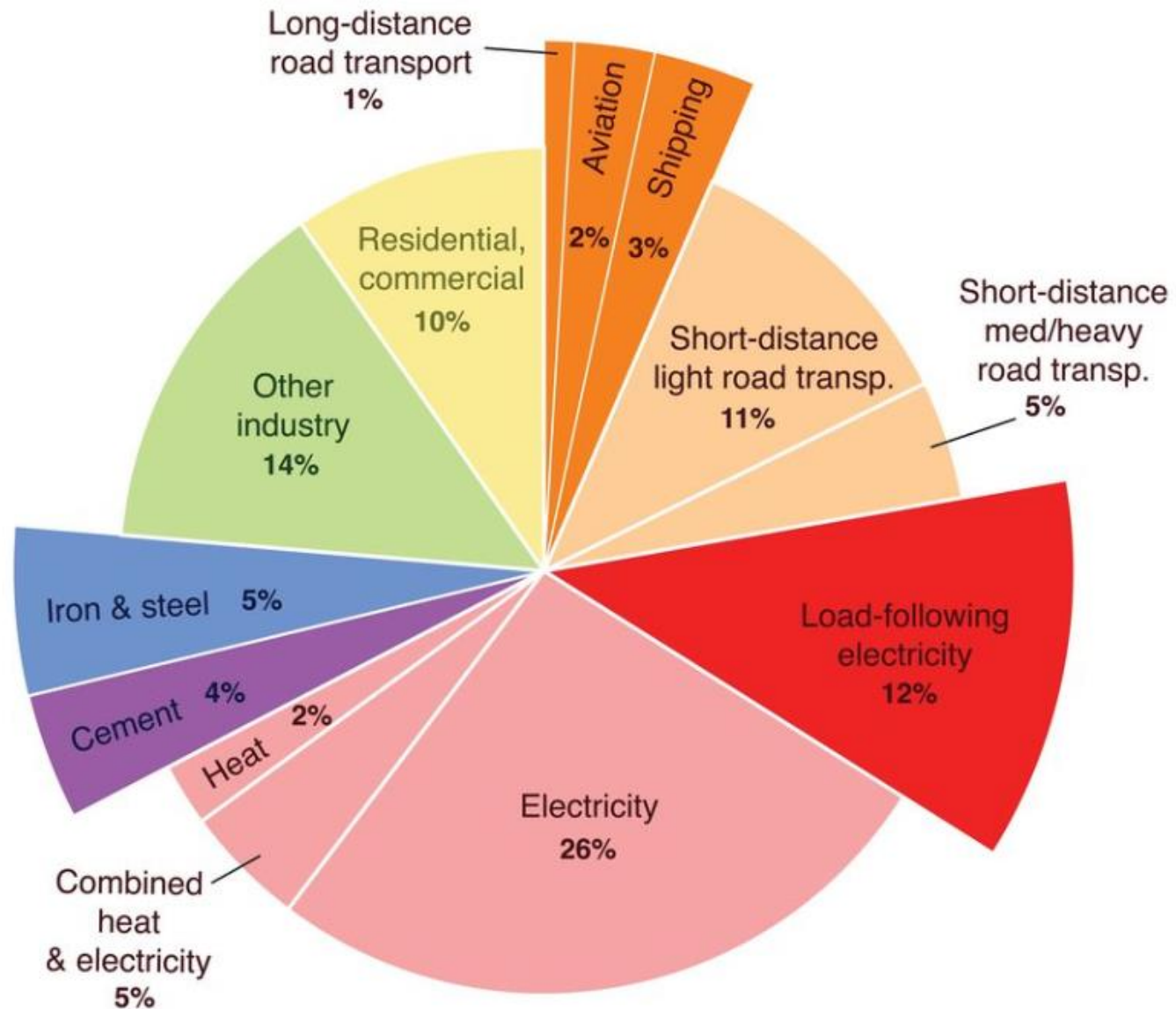


# Utilities & Customers Embrace Thermal Energy Solutions





**...but wait, what if  
Electrify Everything  
Isn't Feasible?**



**A** Global fossil fuel & industry emissions, 2014 (33.9 Gt CO<sub>2</sub>)

2020 – 2030

Deep Decarbonization via:

**Distributed Energy (Gas+Grid)**

**Sector Coupling (Mobility)**

**Power-to-Gas (Clean Molecules)**

## Molecules-led Pathway

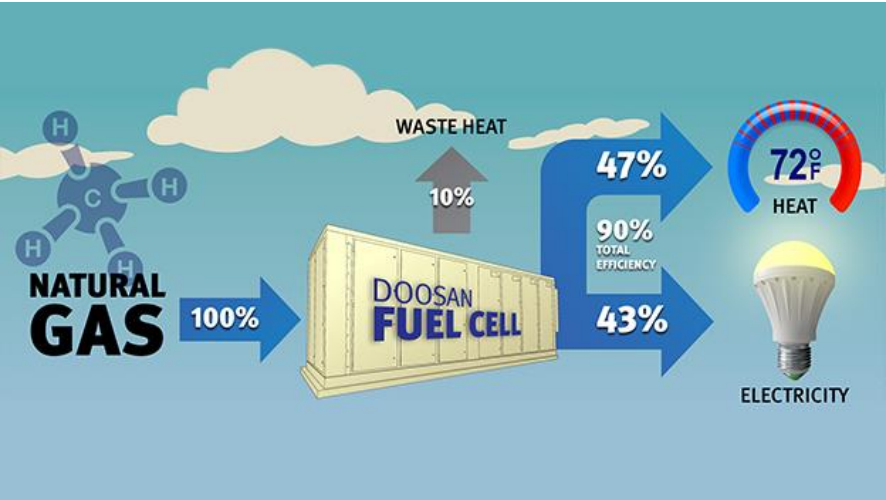


Lingering Scars vs Strengthening Signals

# Natgas + Fuel Cells for Distributed Energy Resources (DER)



Bloomenergy

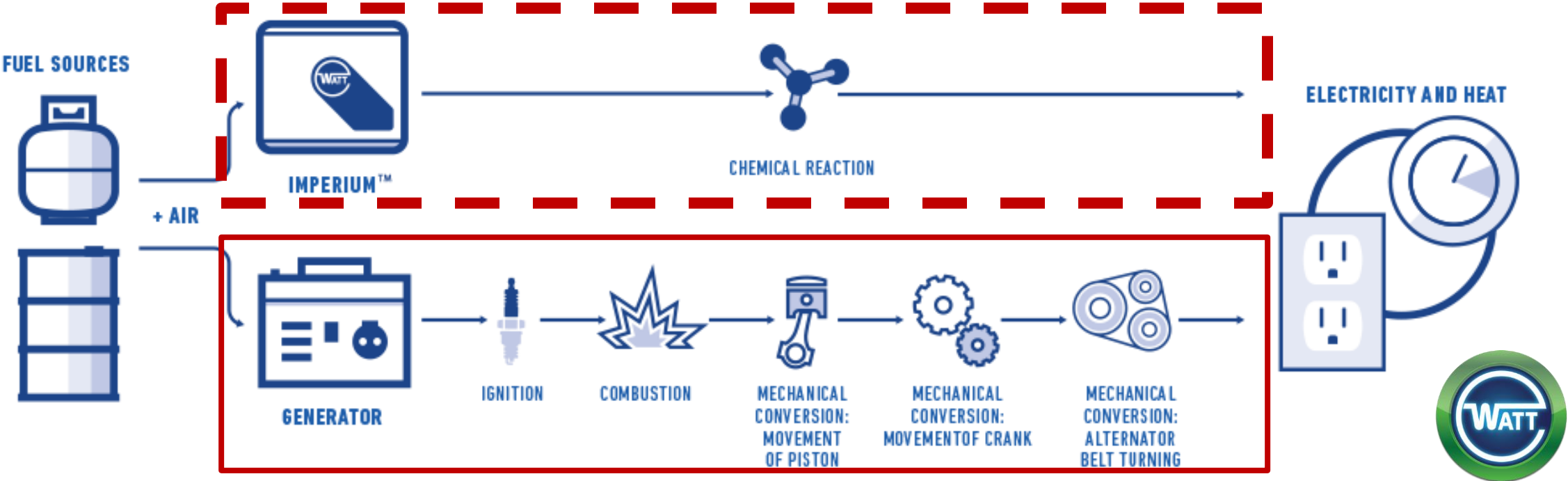


## Rise of *Power Parks*

63 MW Beacon Falls



# The Simplicity of Electrochemical Conversion



21<sup>st</sup> Century

20<sup>th</sup> Century

**NatGas + Fuel Cells = Oil + Combustion Engine**

# Selling New Energy Appliances: SOFCs (Solid Oxide) & PEM Fuel Cells



100-home pilot program



EU Passes 1,000 Installs;  
US Dealerships  
Factory Investments (20K/yr)



THE POWER PLANT  
FOR YOUR HOME

# People Discover Fuel Cells in RVs & Construction Sites



**Propane-fed RV & #Vanlife Generators**

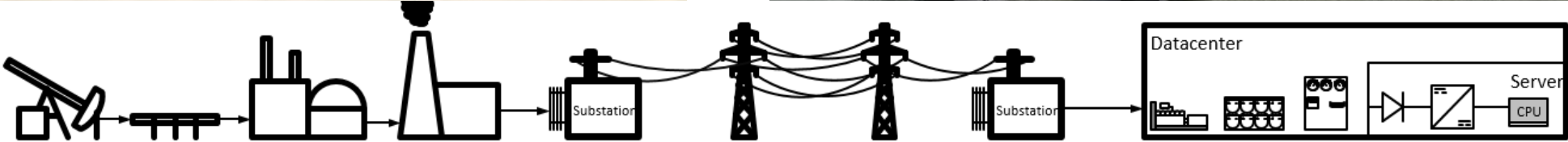


Intelligent Energy

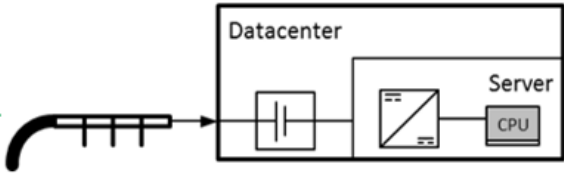


**Construction Site Diesel Generator Alternatives**

# Simplifying Energy Infrastructure for Data Centers



Radically simplified supply chain delivers more data with less resources





# Natgas + Fuel Cells for Distributed Energy Resources (DER)

Gas vs Grid

**Will our facilities & equipment stay grid connected?**

Gas plus Grid

**Will our facilities & equipment expand to gas + grid resources?**



Sector Coupling  
**Pathways to  
Transportation  
'Electrification'**



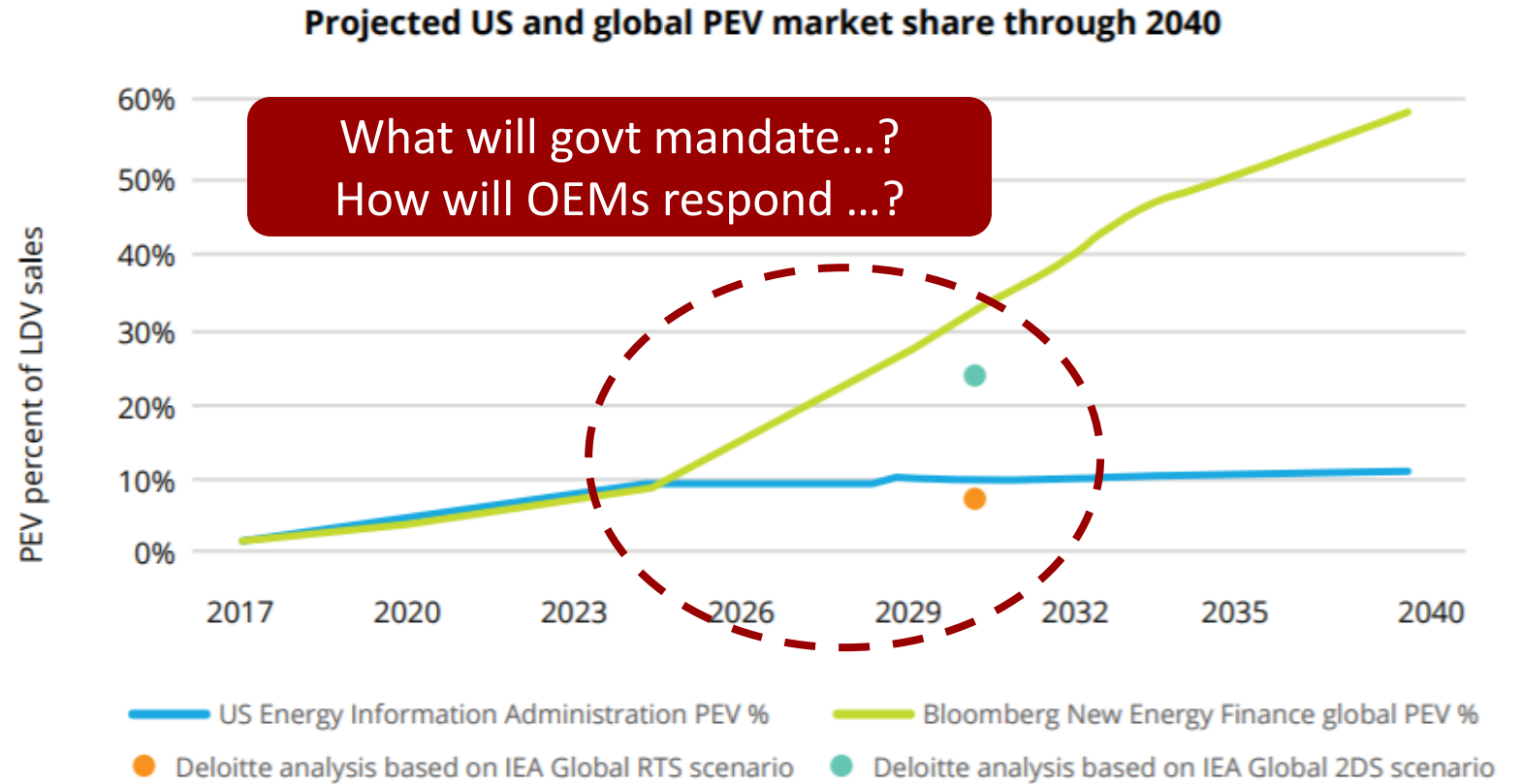
Electrons



Molecules

# Electrification of Vehicle Fleet

Figure 2. Projected PEV share of total light-duty vehicle sales



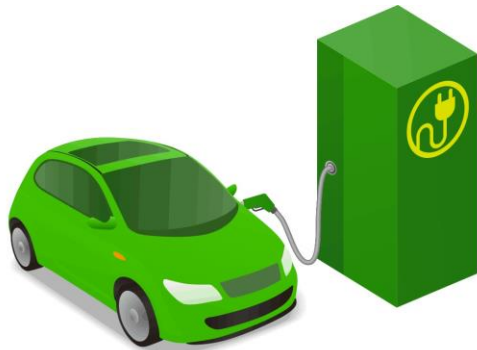
The IEA's Reference Technology Scenario (RTS), projecting 56 million electric cars in circulation by 2030, reflects projections that respond to policies on energy efficiency, energy diversification, air quality, and de-carbonization that have been announced or are under consideration. The IEA's 2DS scenario, projecting 160 million EVs in circulation by 2030, occurs in a context consistent with a 50% probability to limit the expected global average temperature increase to 2°C. We estimated annual sales required to meet IEA's EV stock projections for 2030 and then calculated the EV share of sales as a percent of total light-duty vehicle sales projected by Bloomberg New Energy Finance for 2030.

Source: Deloitte analysis.

# Pathways to 'Electrification' include Electrons + Fuels



*Hybrid ICEs*



*Plug-in EVs*



*Fuel-based EVs*

**Thinking Beyond  
Passenger Vehicles:**

Rail  
Marine  
Trucking  
Aviation/UAVs

Autonomous  
Last Mile / Micro Transit  
Robotics



# Marathon, Not a Sprint



*... Elon Says Game-Over  
Batteries have Won!*



More than three-quarters of executives (78% global; 82% China; 85% U.S.) say fuel-cell electric mobility will be the real breakthrough for electric mobility.

*... meanwhile OEMs betting on  
integration & fuel-based EVs*

# BEVs 'Have Won' vs Real-World Limitations of All Electric Pathway

Battery pack = 400 miles  
Daily Need = 40 miles



**OEM Cost-to-X  
vs Daily Use Demand**

Figure 3: Photos of informal "fly line" charging in Beijing

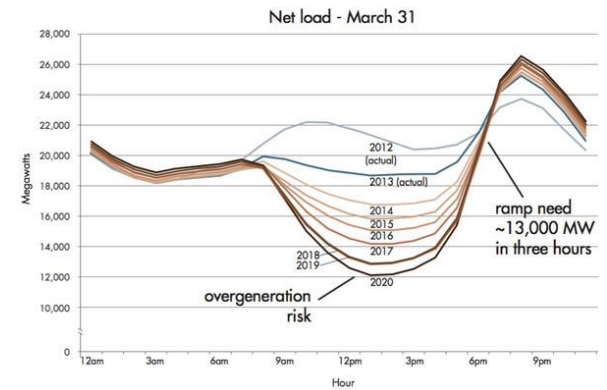


Source: Anders Hove (left, March 2018) and Rob Earley (right, July 2017)

**Uptime for Fleets &  
Recharging in Urban Markets**

'Duck Curve' to 'Dragon Curve'

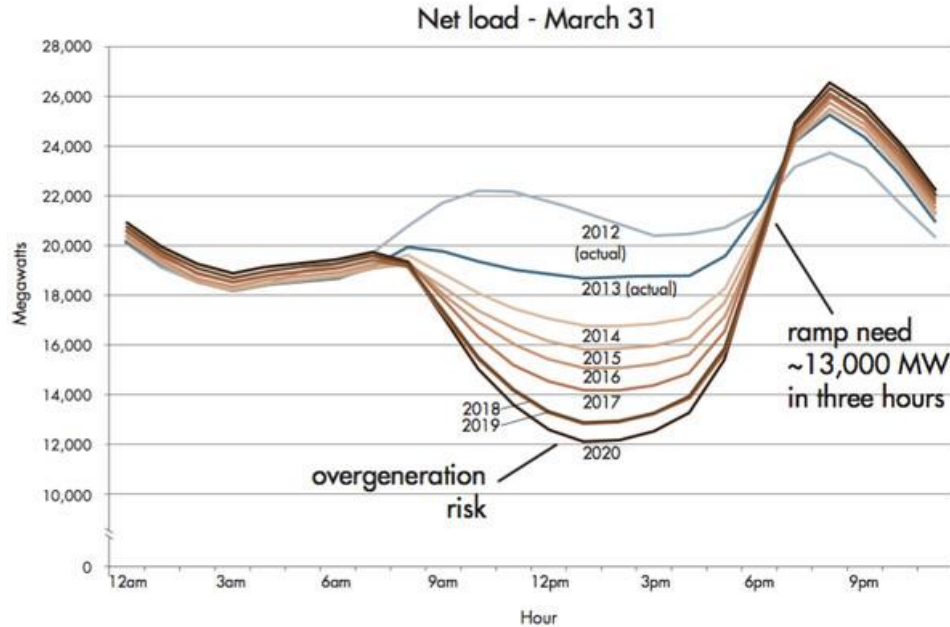
Figure 2: The duck curve shows steep ramping needs and overgeneration risk



**Full Costs of  
Grid Management**

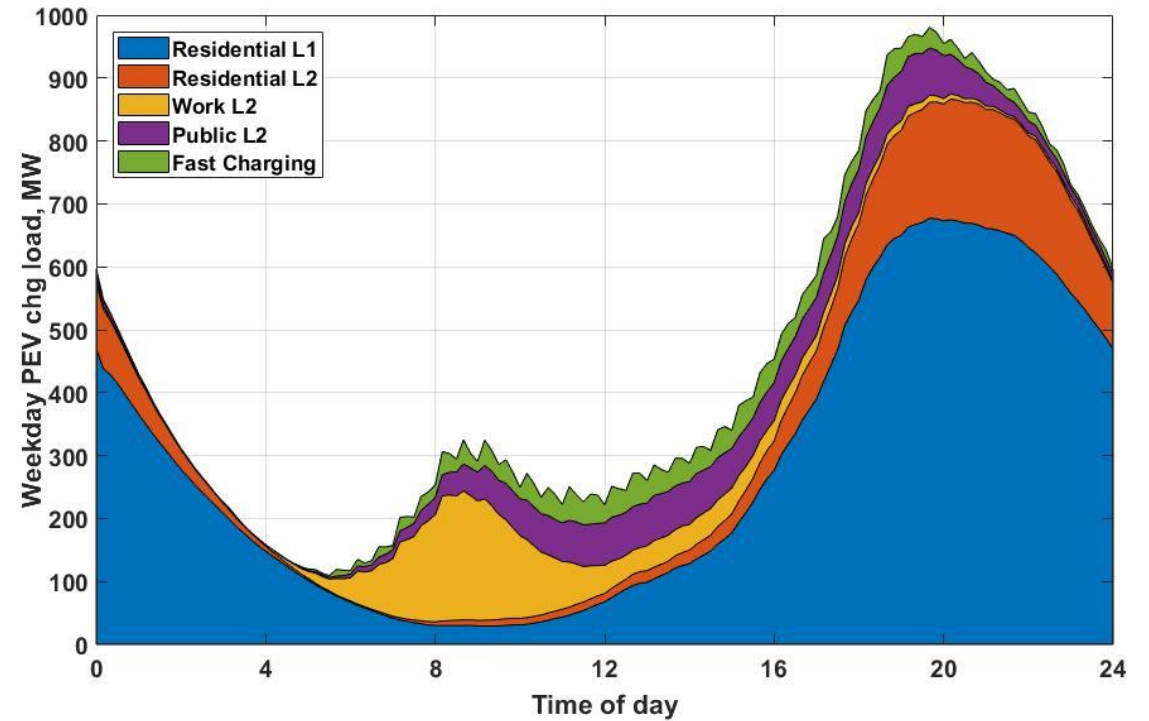
# Total Grid Management Costs 'Duck Curve' to 'Dragon Curve'

Figure 2: The duck curve shows steep ramping needs and overgeneration risk



'Duck Curve'

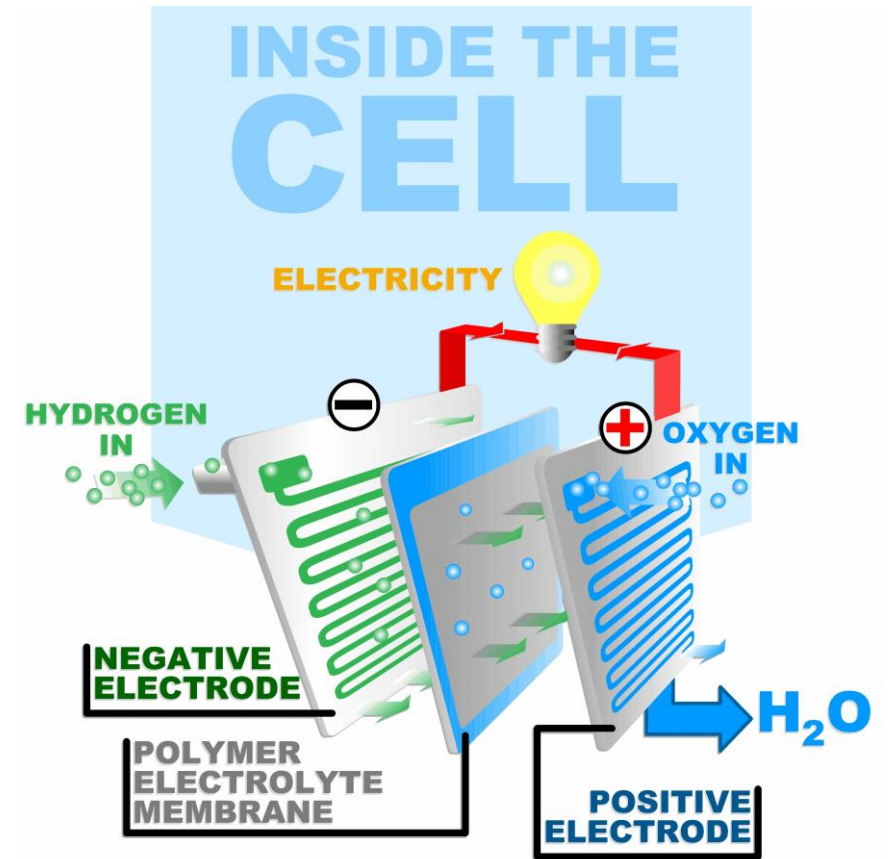
Illustrative



'Dragon Curve'

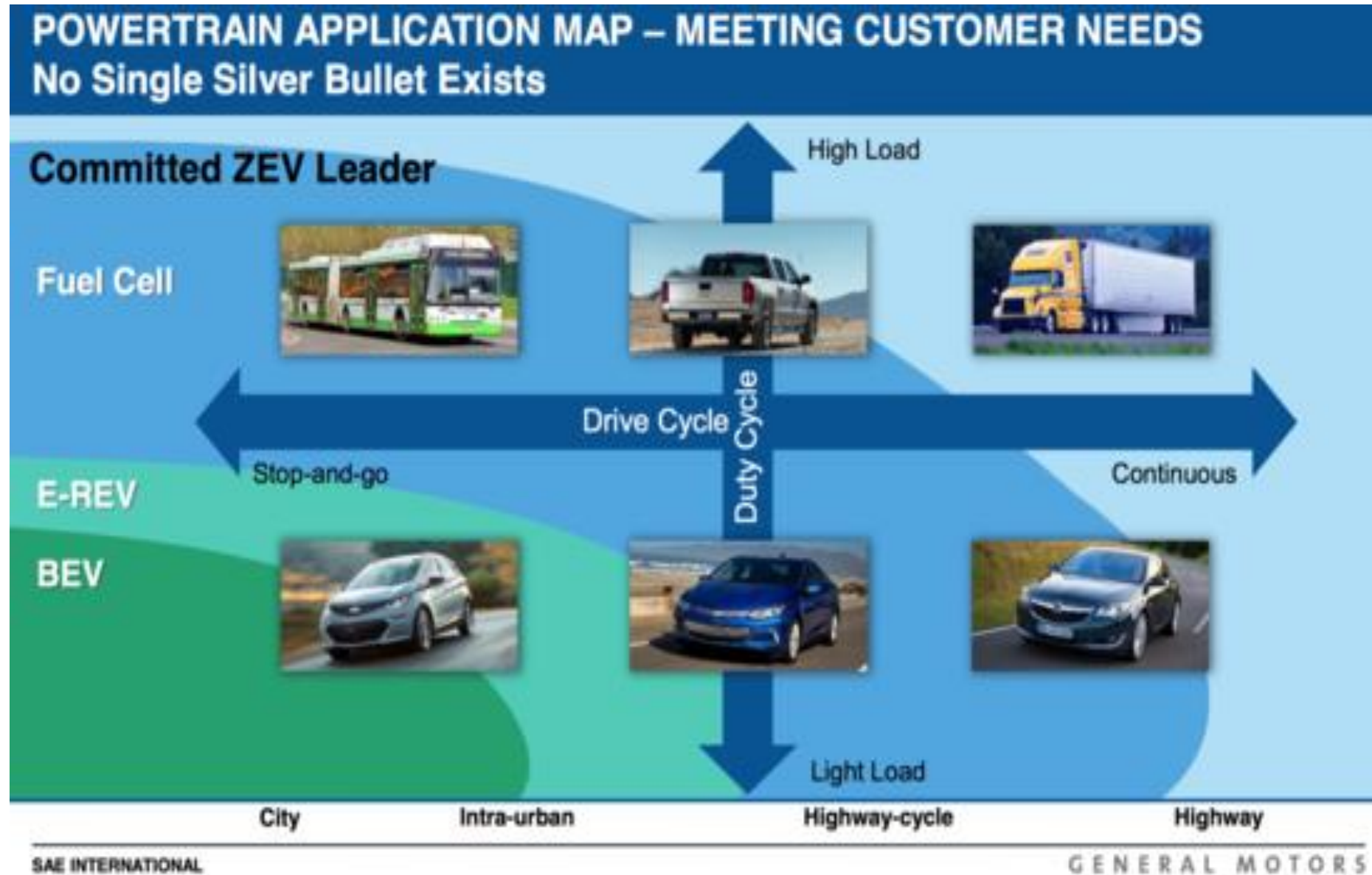
# The Case for Fuel Cell + Battery Integration

- **Long-term Cost Curve (kW)**  
Battery \$80-100 kW (at volume)  
Fuel Cells \$20-30 kW (at volume)
- Total Cost of Ownership plus  
**Total Cost of System Management**
- Lower Infrastructure Costs at Scale  
(Julich Study, 2017)
- Market Incentives for Existing Incumbents





# The Shared Strategy for Integration & Fuel-based EV Fleet



# The Shared Strategy for Integration & Fuel-based EV Fleet



NIKOLA ONE™



POWERCELL  
BOSCH

## Trucking



## Maritime



## Hydrail



Ultra Electronics USSI Protonex® a Ballard® company flyH2 AEROSPACE

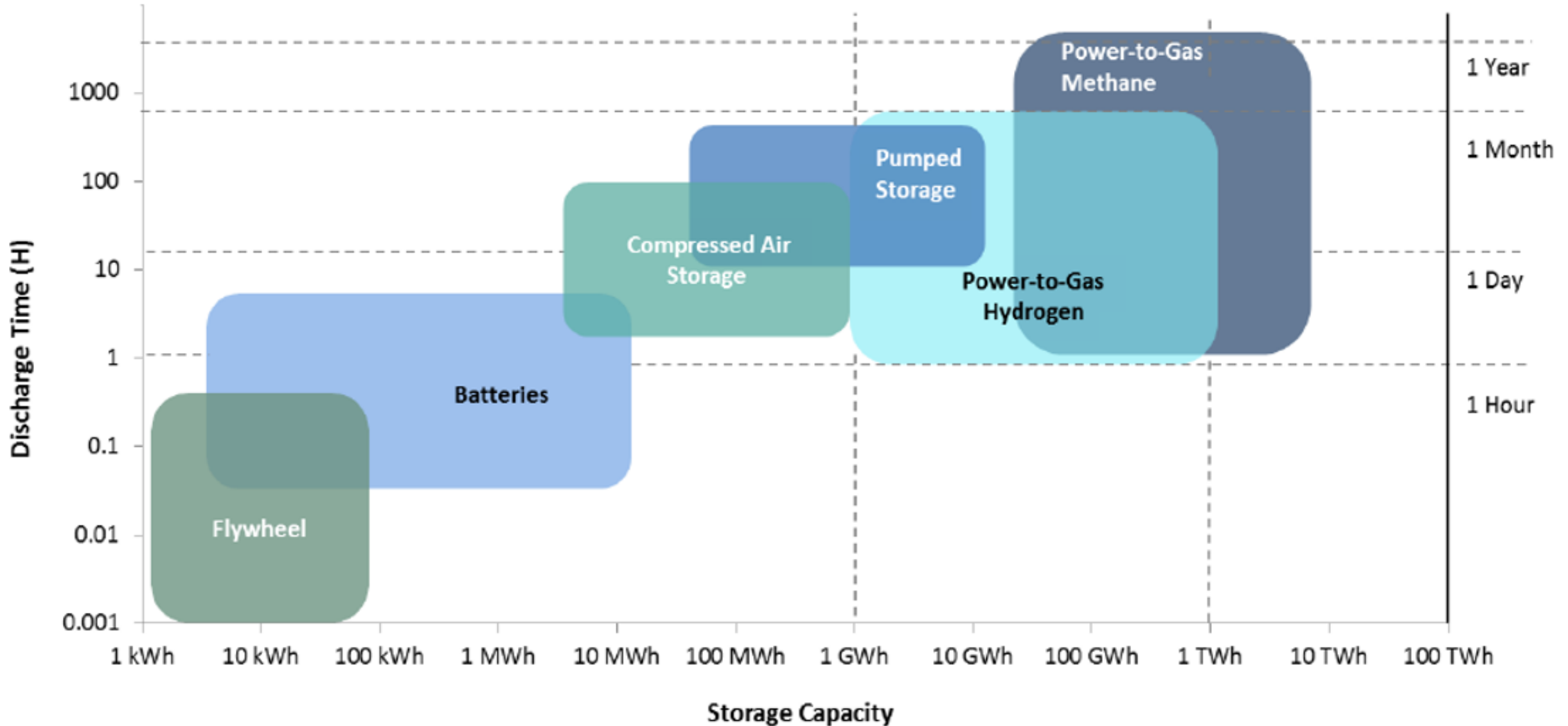
## Aviation / UAVs

## Need Methods to Scale up Clean Hydrogen Value Chain

Why does this matter?



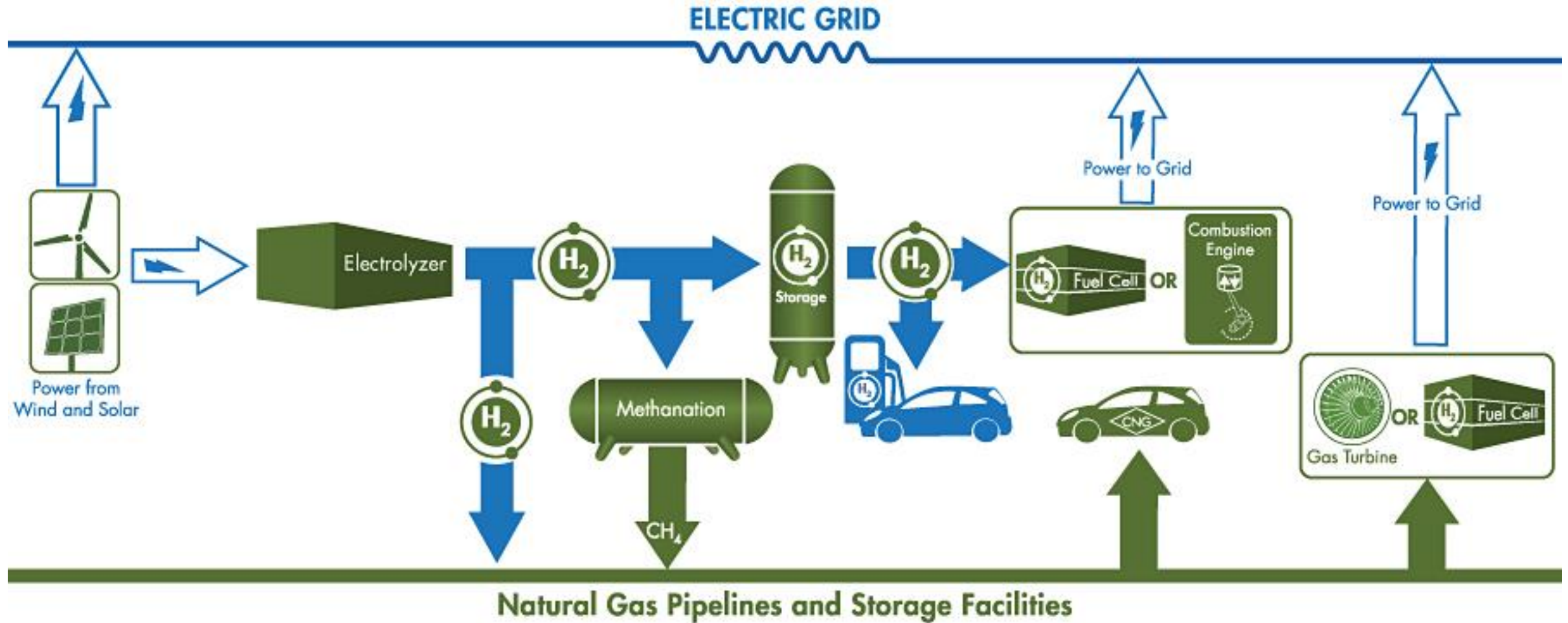
# The Case for Power-to-Gas: Energy Storage vs Sector Coupling (Integration)



After Fraunhofer ISE, 2015



# Power to Gas (PtG) Delivers Scale & Versatility



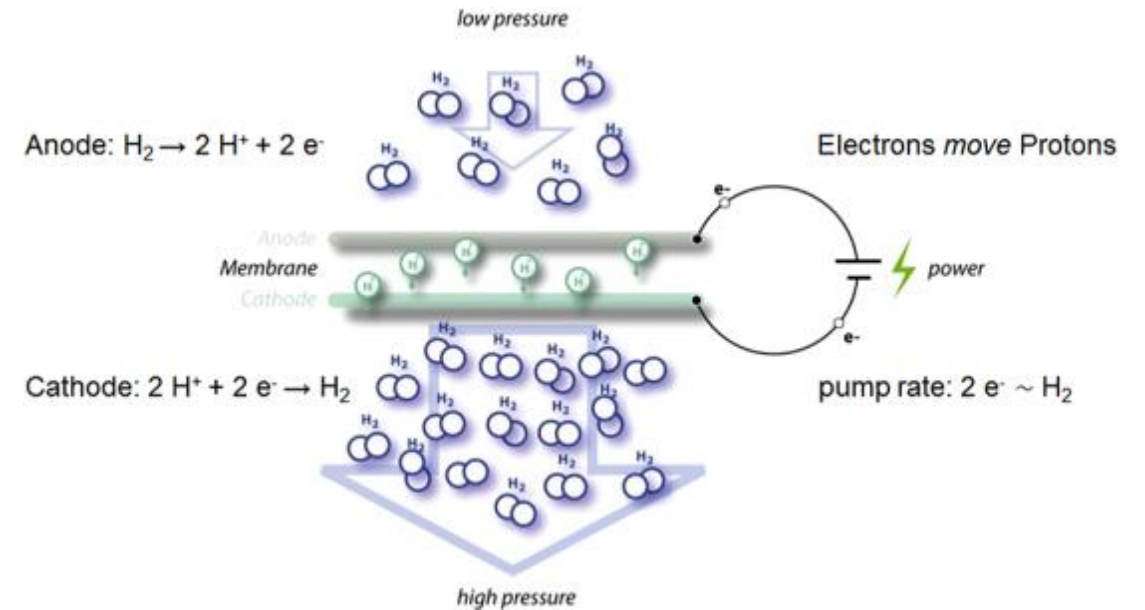
The National Fuel Cell Research Center's Research and Development on "Power-to-Gas"

# PtG Innovations in Clean Molecules

## HyET Hydrogen

The new standard.

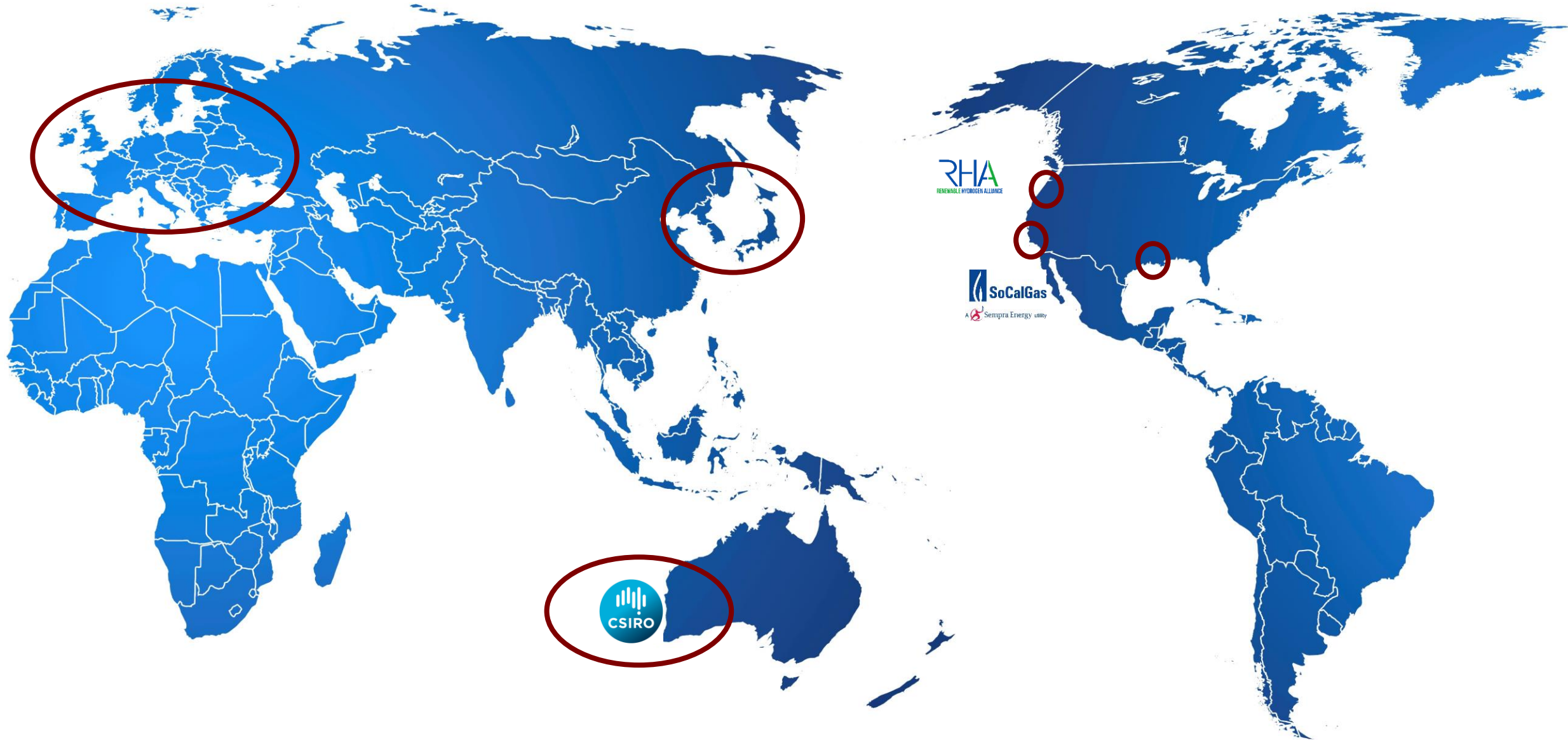
**HyET HCS 100**  
Electrochemical compressor



## Electrochemical Compression & Purification



# Current State Power to X Plans

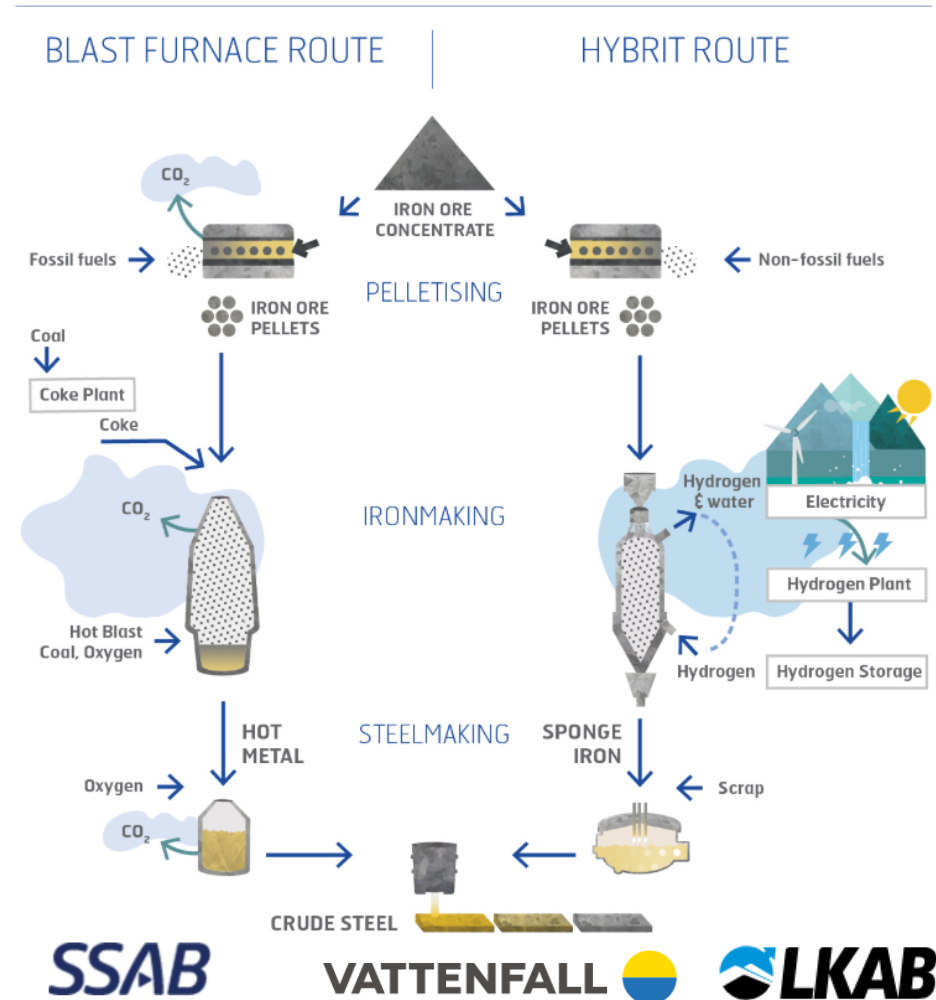


# Power to Gas (PtG) = Decarbonization of Heavy Industry

## Decarbonization for Steel Making

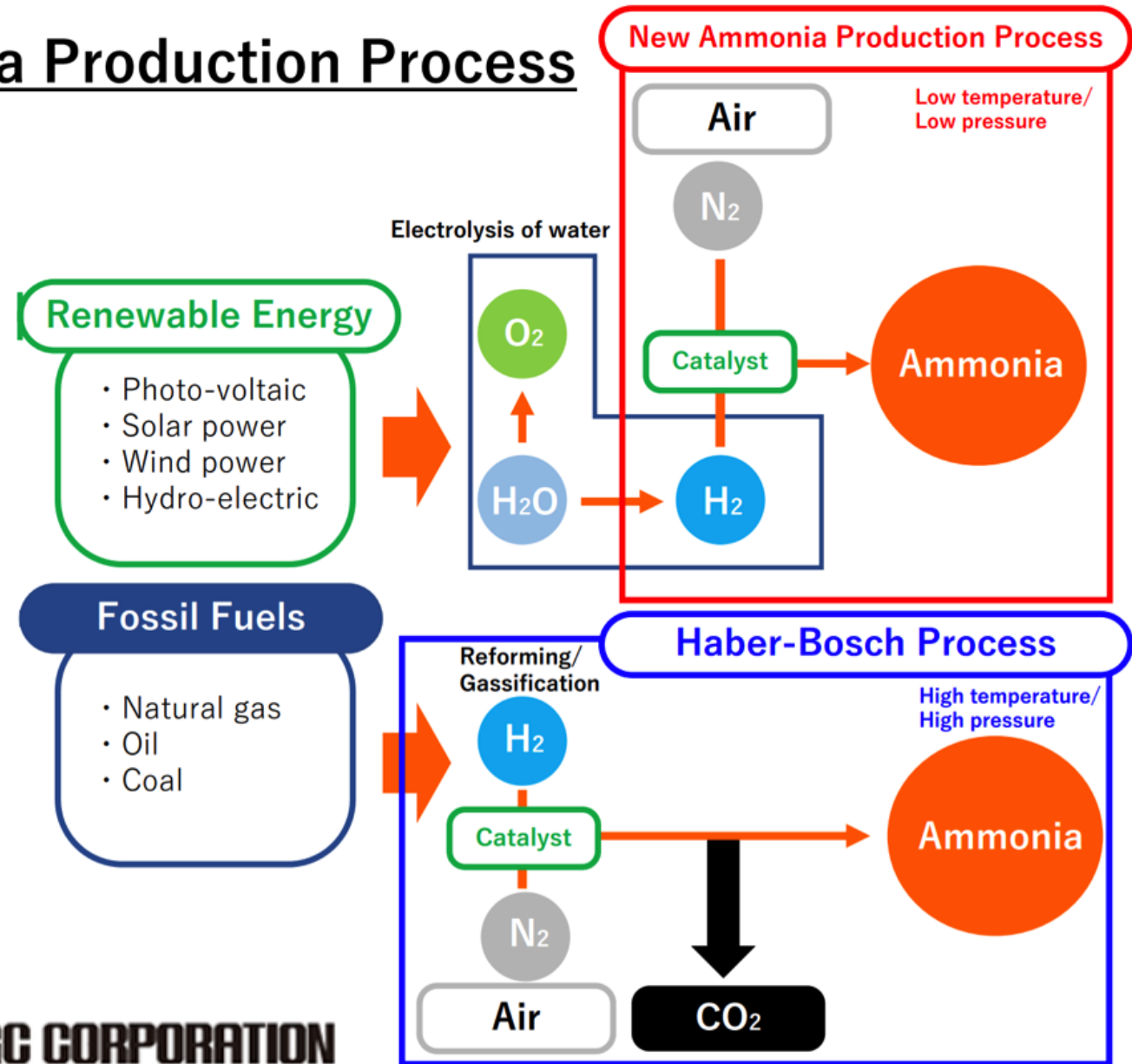
Cut CO2 by 25% by 2025  
Remaining CO2 emissions by 2045

### HYBRIT (Hydrogen Breakthrough Iron Technology)



# Accelerate Arrival CO<sub>2</sub>-free Ammonia

## Ammonia Production Process





# Accelerate Arrival CO<sub>2</sub>-free Ammonia

**Power to Ammonia**

Feasibility study for the value chains and business cases to produce CO<sub>2</sub>-free ammonia suitable for various market applications

**ISPT**  
Institute for Sustainable Process Technology

**STEDIN**

**CE Delft**

**AKZO**

**UNION**

**Power2Ammonia**

**UNIVERSITY OF TWENTE**

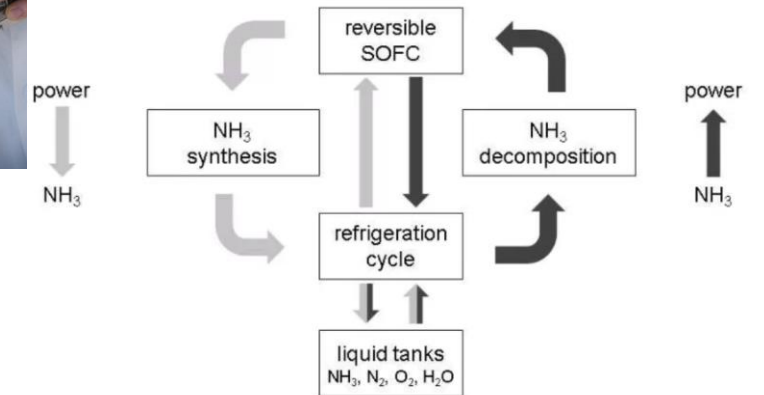
**Proton**

**OCI NITROGEN**

**ECN**  
Your energy. Our passion.

**TU Delft**

## Solid Oxide Cell SOC4NH3



**Accelerate Arrival  
CO<sub>2</sub>-free Ammonia  
Fuel & Energy Storage**

**HALDOR TOPSØE**   
CATALYSING YOUR BUSINESS

Renewable Electricity based electrolysis cell makes gas that is used in the production of ammonia for fertilizer or fuel.

# Ammonia will be rising in the Headlines

POWER

TECHNOLOGY

9 AUGUST 2018

**Could ammonia be the next key player in energy storage?**

gtm:

JUNE 27, 2018

## **Siemens Tests Ammonia as a Form of Energy Storage for Renewables**

The company has opened a novel new facility to study the efficiency of converting electricity to hydrogen, and then to ammonia, and back.

Science

Jul. 12, 2018

**Ammonia—a renewable fuel made from sun, air, and water—could power the globe without carbon**

# Embracing the Clean Molecules Pathway Of Deep Decarbonization





*Surfacing  
Uncertainties*



**Energy  
Transitions**

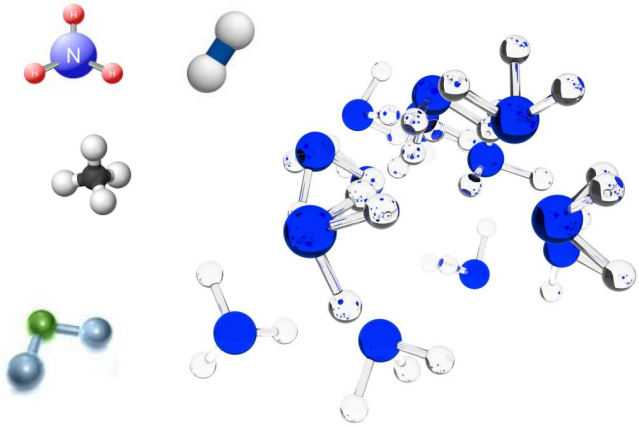


**Next  
Steps**



**Every day I make an effort to move toward  
what I do not understand.**

**- Cellist, Yo-Yo Ma**



**Elevate Brand of  
Clean Molecules**



**Non-Traditional  
Policy & Technology  
Partnerships**



***Look to Non-Wire  
(Data) Solutions***

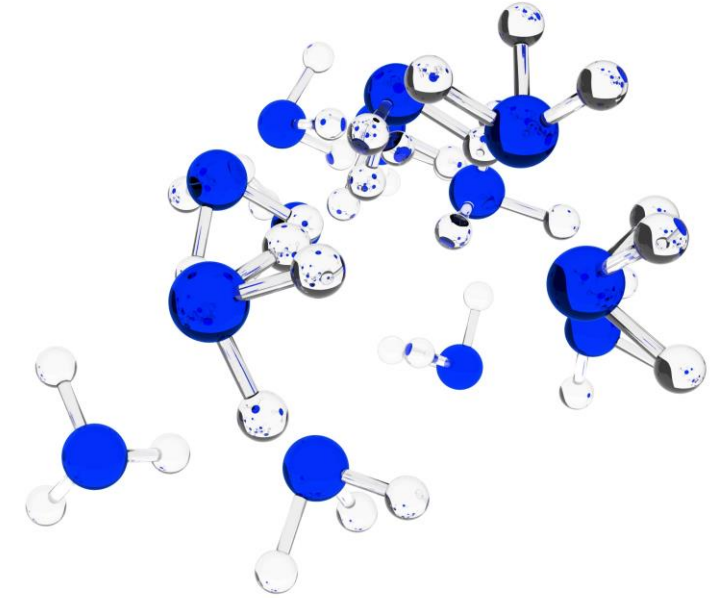
**Thank You!!**

PDF + Resources

**[garrygolden.com/March4](http://garrygolden.com/March4)**

**[garrygolden@gmail.com](mailto:garrygolden@gmail.com)**

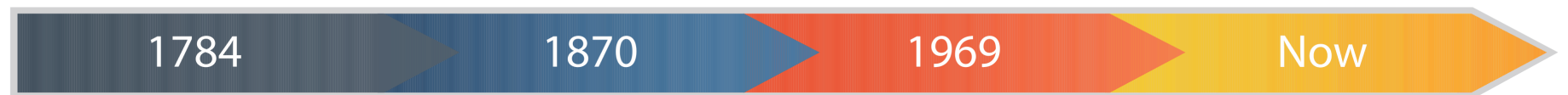
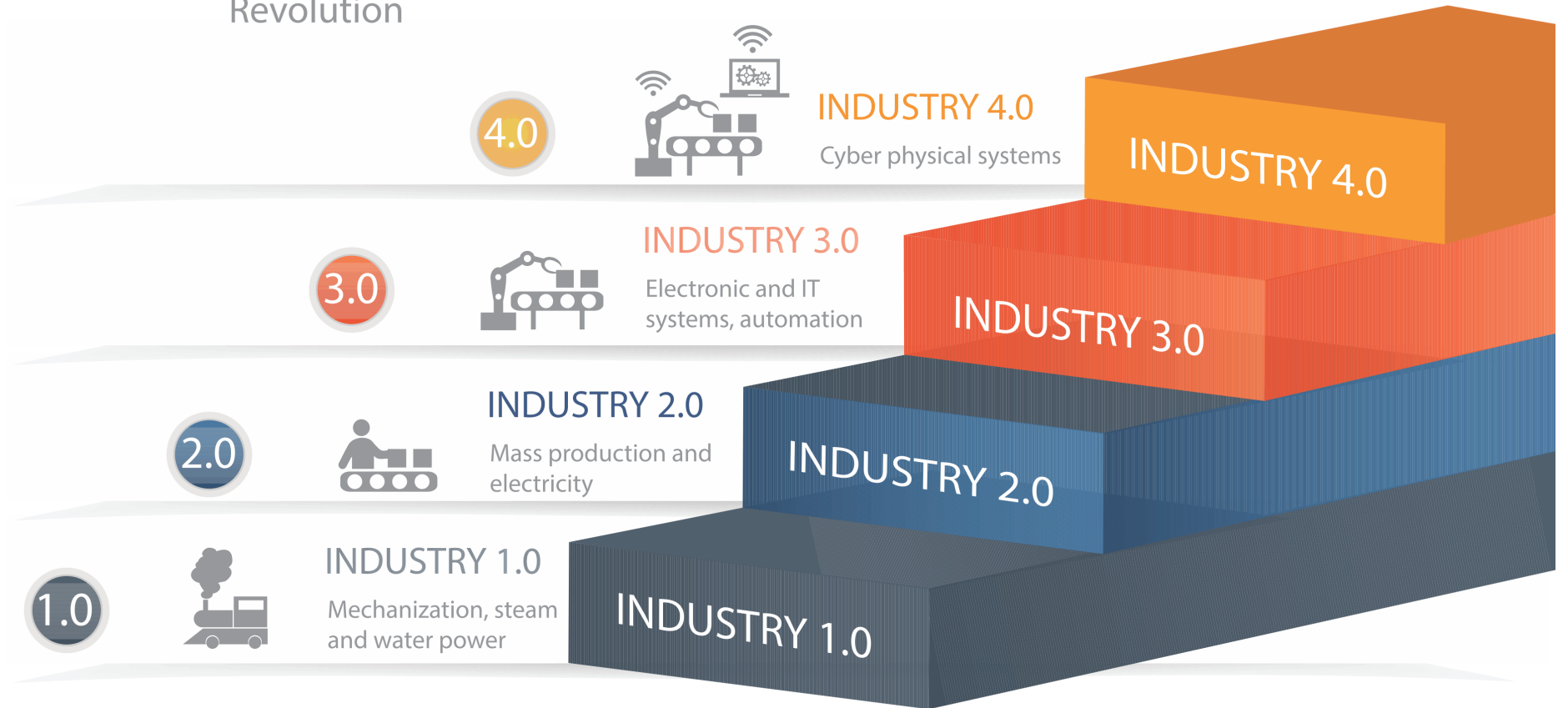
Two Rs





# INDUSTRY 4.0

The Fourth Industrial  
Revolution



INDUSTRY 1.0

INDUSTRY 2.0

INDUSTRY 3.0

INDUSTRY 4.0



# Gartner®

## Hype Cycle

### Internet of Things (IoT)

