

Imagining The Slow Pace of Big Change
The Future of Energy Systems

PDF + Resources:
garrygolden.com/Sept12

Designed for



Designed by
Garry Golden

The *Slow Pace* of Fast Change



20th Century Dynamics

Alternative Futures

Baseline Future

Renewables

Transactive Grid

EVs

?
? Distributed

Energy Storage

?
Design for Behavior Change

P2P

Maintenance, Preservation & Renewal

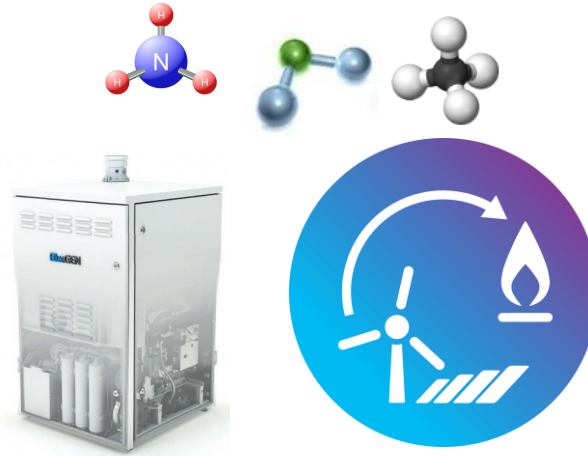
21st Century Dynamics

Start

End



In the News



**Emerging Solutions for
Deep Decarbonization**



Discussion



In the News

Refueling vs Recharging Electronic Devices



Fuel Cells = Electrochemical Conversion

In mid-2019 Tokyo Gas will sell packets of *green gas* in 7-Eleven stores as fuel for portable micro fuel cells used to recharge devices.

True

 TOKYO GAS



False

Dubai Testing Retail based Fuel Distribution for EV Scooters

STOR-H
by AAQIUS



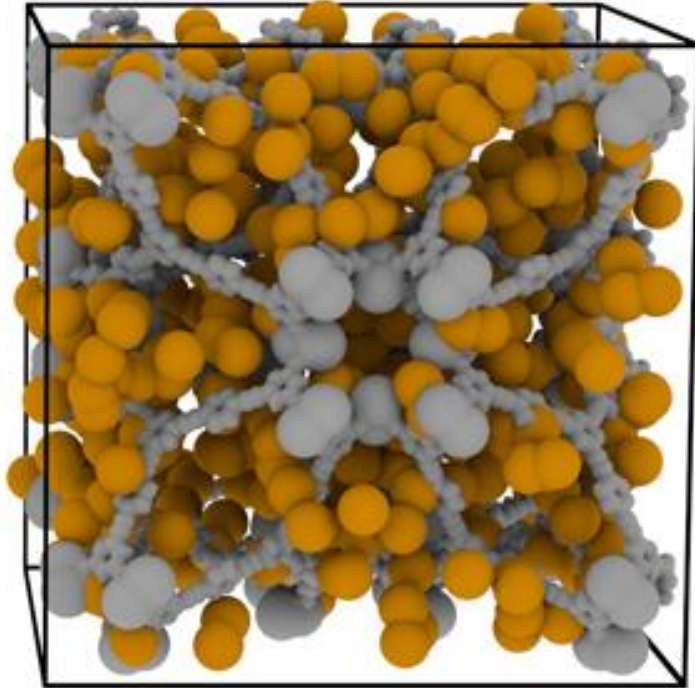
High Surface Area Crystal Sponges

MOFs – Metal Organic Frameworks

Bonus Slide – Learning about MOFs +
'Adsorption' physical storage

My tags here

<http://diigo.com/user/garrygolden/MOFs>



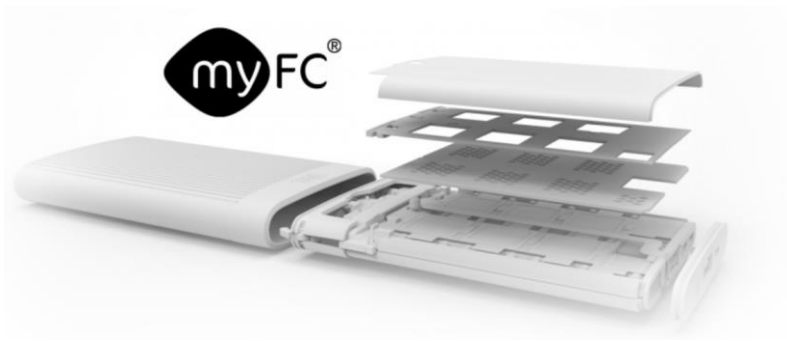
Northwestern
Image by Christopher Wilmer/NuMat Technologies)



Science Journal



Scenario: Embedded Power Plants + Retail-Shelf Distribution of Fuel



**Could fuel-based
micro-power systems
be at same developmental stage
as cell phones in mid 1990s?**

MyFC predicts that fuel cells will surpass batteries in energy density and cost efficiency in a few years

MyFC initiates feasibility study with leading Chinese smartphone manufacturer

"Since we launched the world's smallest fuel cell LAMINA in early 2017, our intention has been to pursue the integration of our fuel cell technology in smartphones. This R&D project marks the start of that initiative, which we refer to as job #3," says Björn Westerholm, CEO of myFC.

Renewables Moving Beyond Electrons to Molecules

What could happen in 12 years?



China Moving Beyond Battery



Acquisitions in Portable Power



Unplugging at Burning Man



Houses without Electrical Sockets



Vision: #1 Fuel Distributors

2023

2025

2028

2030



Embedded Fuel Cell Systems: Fuel Format, Access, & Competition

One week battery life on an iPhone 6? It's possible

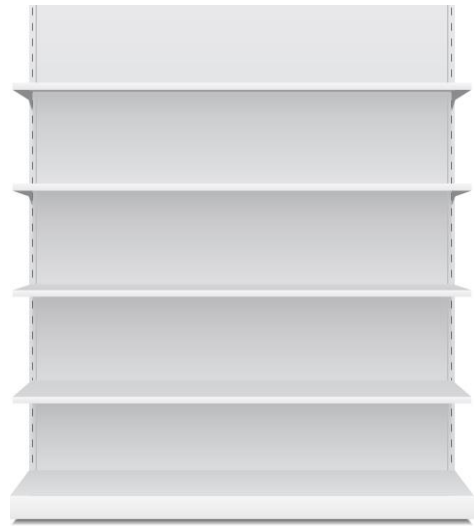
POSTED 1:49 PM, AUGUST 28, 2015, BY CNN WIRE



An Apple iPhone and a quadcopter, both retrofitted with hydrogen fuel cell batteries, and a hydrogen fuel cell are displayed by Intelligent Energy at ShowStoppers. Photo by Ann Singer.



**Global Access via
Consumerization
Adoption Curves**



**Pipelines/Wires vs
Retail Shelf Simplicity**



SAMSUNG

**Incentives to
Manufacturers**

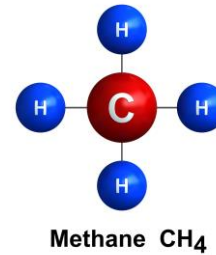
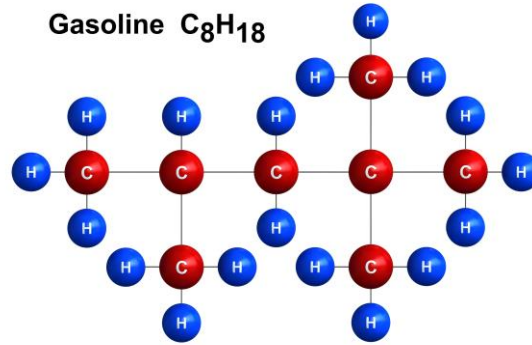


In the News

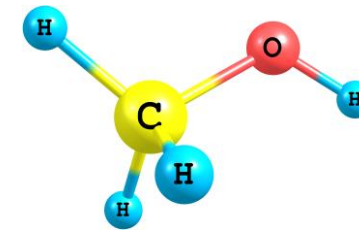


Emerging Solutions for Deep Decarbonization

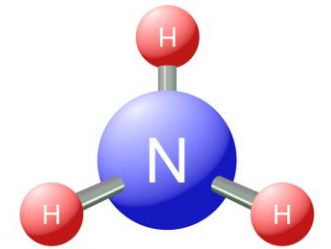
The Long March of Fuel Decarbonization



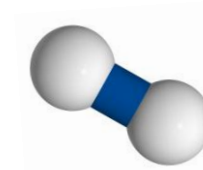
**Era of
Combustion Energy**
(ICE/Diesel; Combined-Cycle)



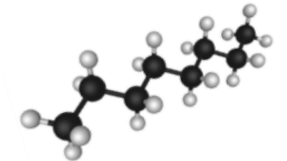
Methanol



Ammonia



Hydrogen



Biofuels /
Synfuels

**Era of
Electrochemical Energy**
(Batteries; Fuel Cells;
Electrolysis; Solar Chemical)

'Electrification' Strategy: Perceptions vs Reality



Noah Smith 
@Noahpinion

Following

To really decarbonize, we need three things:

1. Lots of solar power
2. Good energy storage
3. Lots of electric cars

This is why I think battery technology is the most important technology in the world right now.

BloombergNEF @BloombergNEF

California's energy & emissions diet is working, emissions from its power sector have dropped 35%. However, emissions from transportation fell only slightly - transport substitution is a minuscule new feature in this diet, but has much room to grow. bloom.bg/2onmHRj

1:05 PM - 30 Aug 2018

80 Retweets 390 Likes



68 80 390



Tweet your reply



Noah Smith 
@Noahpinion · 8h

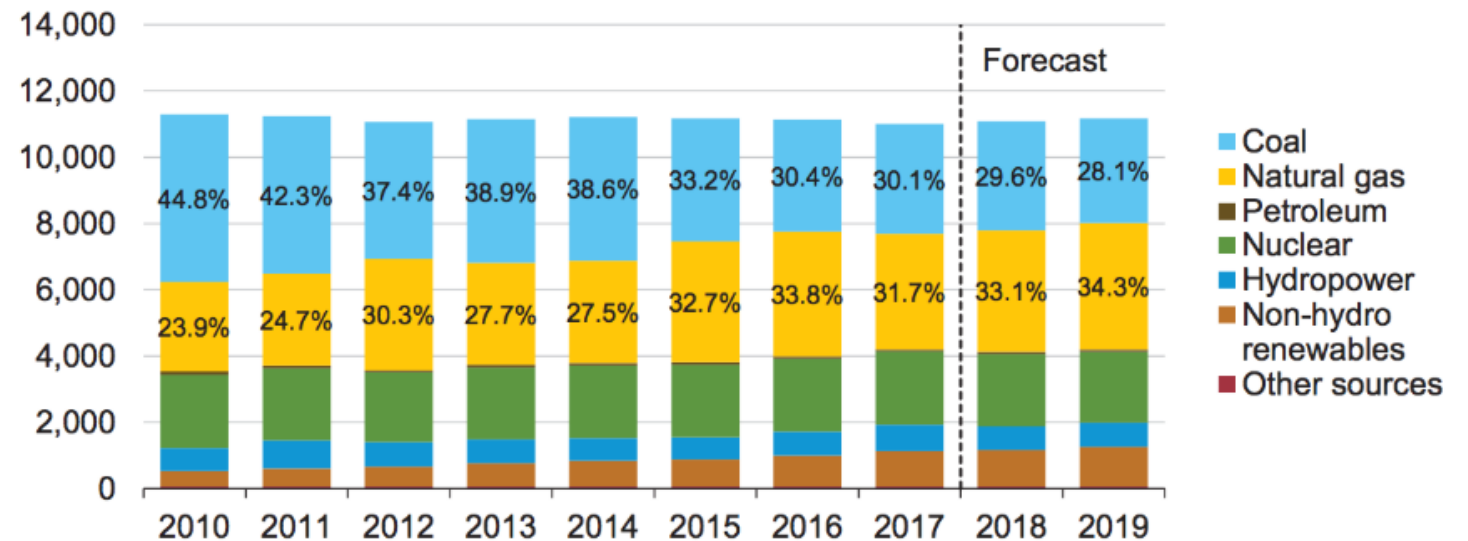
Governments around the world need to be pouring many billions of dollars into battery research, and into energy storage research more generally. There's no more important science or engineering goal right now.

24 32 121



Matt Gurney 
@mattgurney · 8h

U.S. electricity generation by fuel, all sectors
thousand megawatthours per day



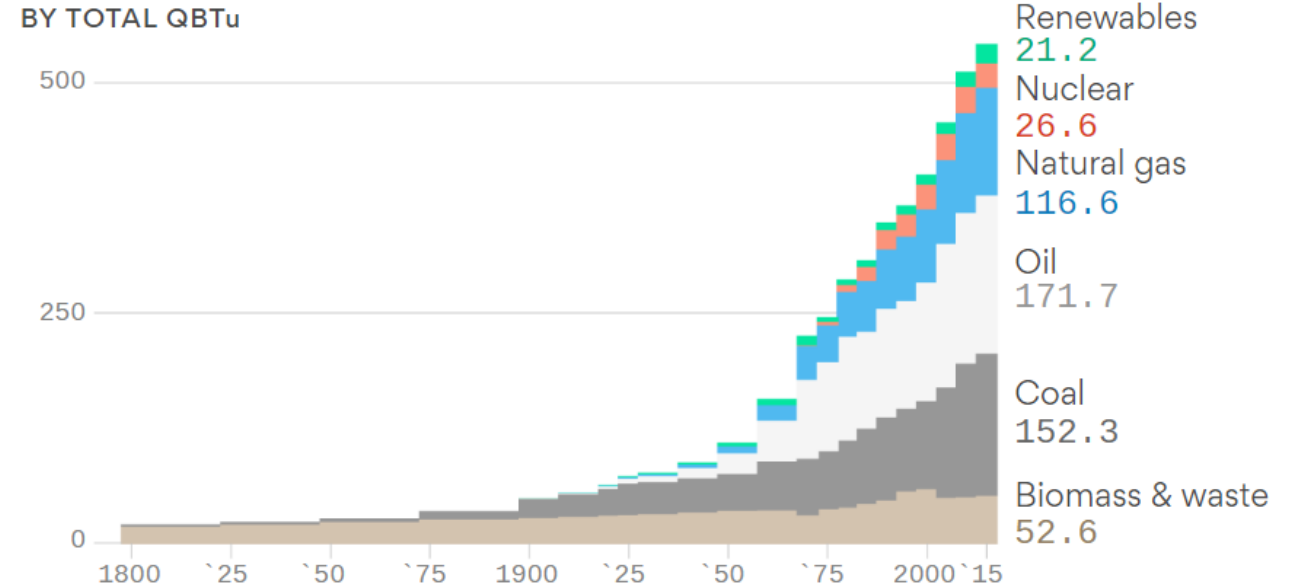
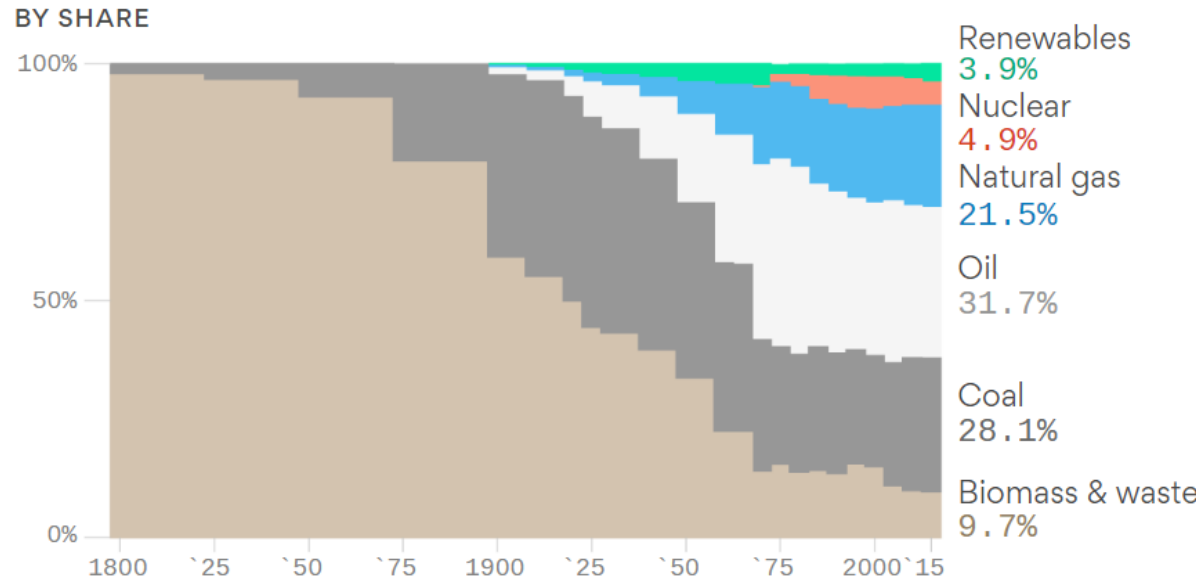
Note: Labels show percentage share of total generation provided by coal and natural gas.

Source: Short-Term Energy Outlook, January 2018.



Despite renewables growth, there has never been an energy transition

Global energy sources, 1800–2015



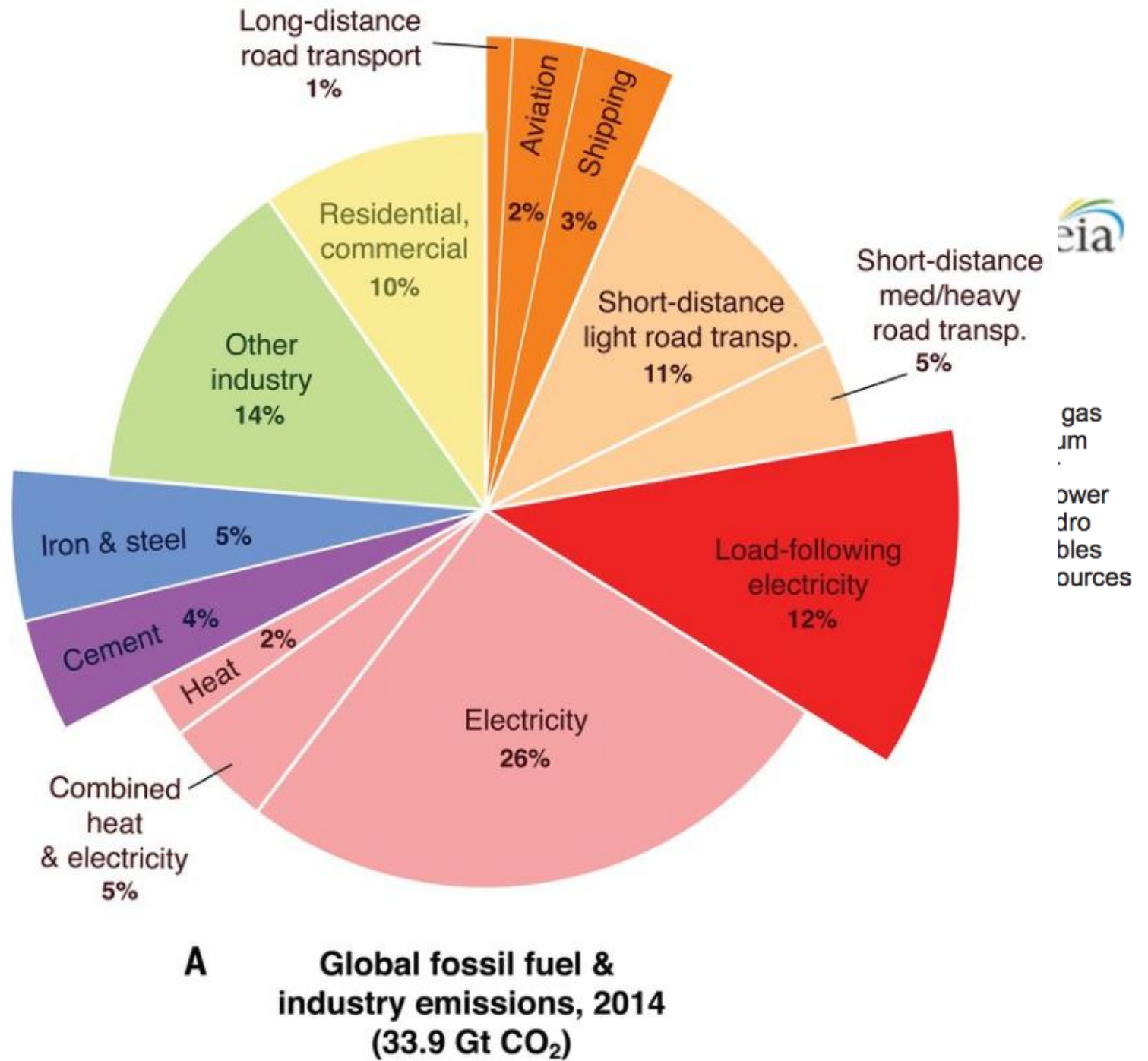
Note: 1800–1900 data shown at 25-year intervals, 1900–1920 & 1930–1970 data shown at 10-year intervals, and 1920–1930 & 1970–2015 data shown at 5-year intervals. Data: Arnulf Grubler (2008), International Energy Agency (2017). Reproduced from charts by Richard Newell and Daniel Raimi. Chart: Axios Visuals

*Richard Newell - CEO of Resources for the Future.
Daniel Raimi - Senior Research Associate*

Rethinking the Role of Molecules



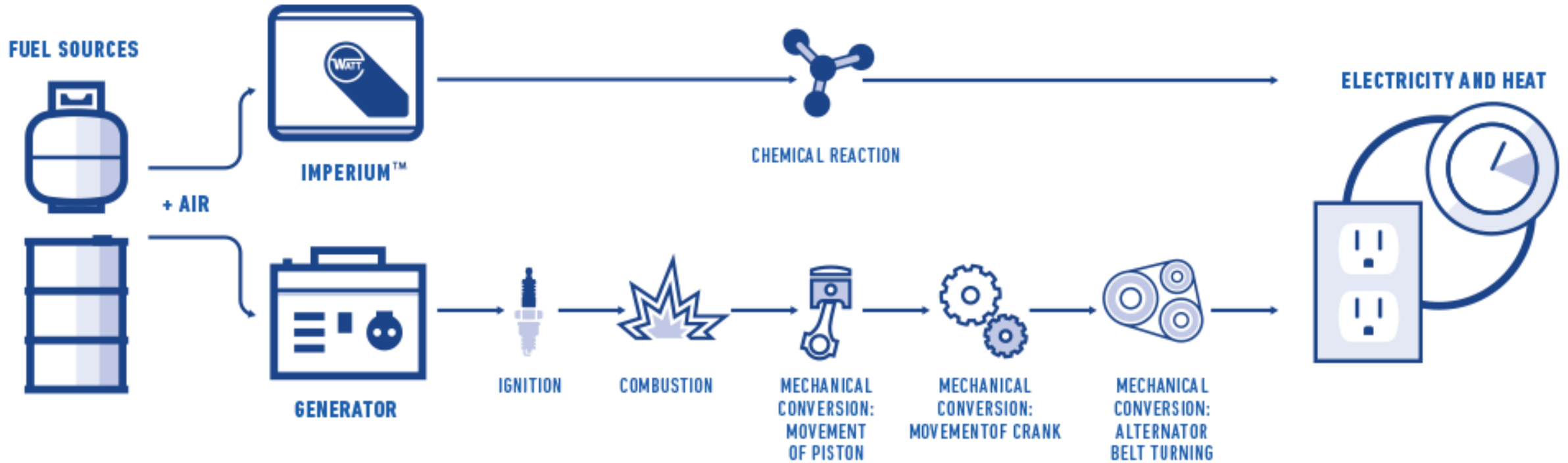
Decarbonization of Power Sector (Stage Two)



21st Century

20th Century

Natgas + Fuel Cells (PEM; SOFC; MFC) = Oil + Combustion Engine



Micro CHP via Solid Oxide Fuel Cells = 21st Century Energy Appliance



Peoples launches a 100-home pilot program



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

***Public Debates:
Gas vs Power?
Gas + Power?***



Power Parks
63 MW Beacon Falls

fuelcellenergy

Engaging Incumbents in Decarbonization Compromise on Coal

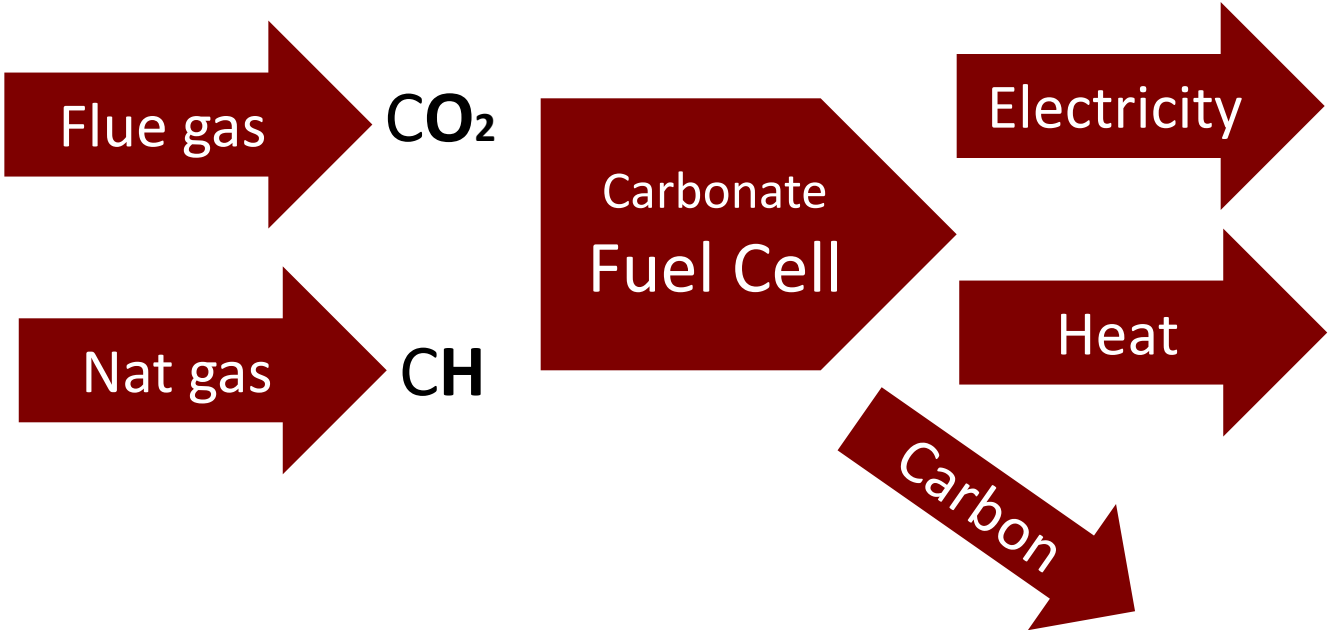
Coal comeback? Cleaner Natgas? Asset Utilization?

ExxonMobil



Coal plant – no CO2 capture	500 MW	.06 (\$/kWh)
90% amine capture	400 MW	.11 (\$/kWh)
90% CO2 capture w/ fuel cell	900 MW	.08 (\$/kWh)
5% CO2 capture with fuel cell	522 MW	.06 (\$/kWh)

(Source: Fuelcell Energy & ExxonMobil)



Transport demand continues to be dominated by oil...

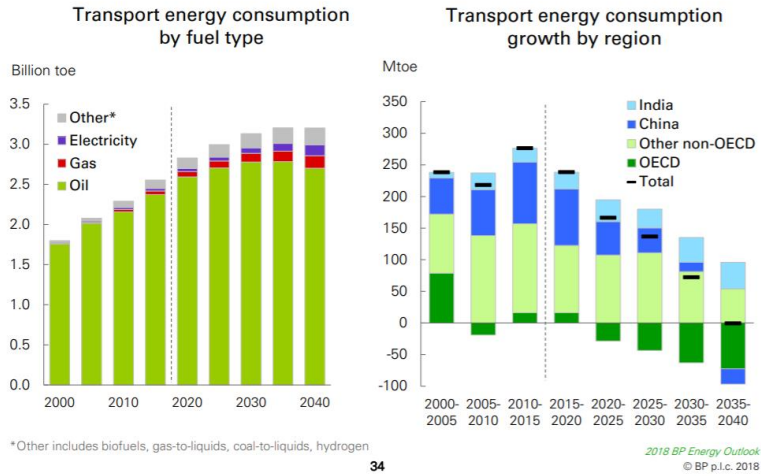
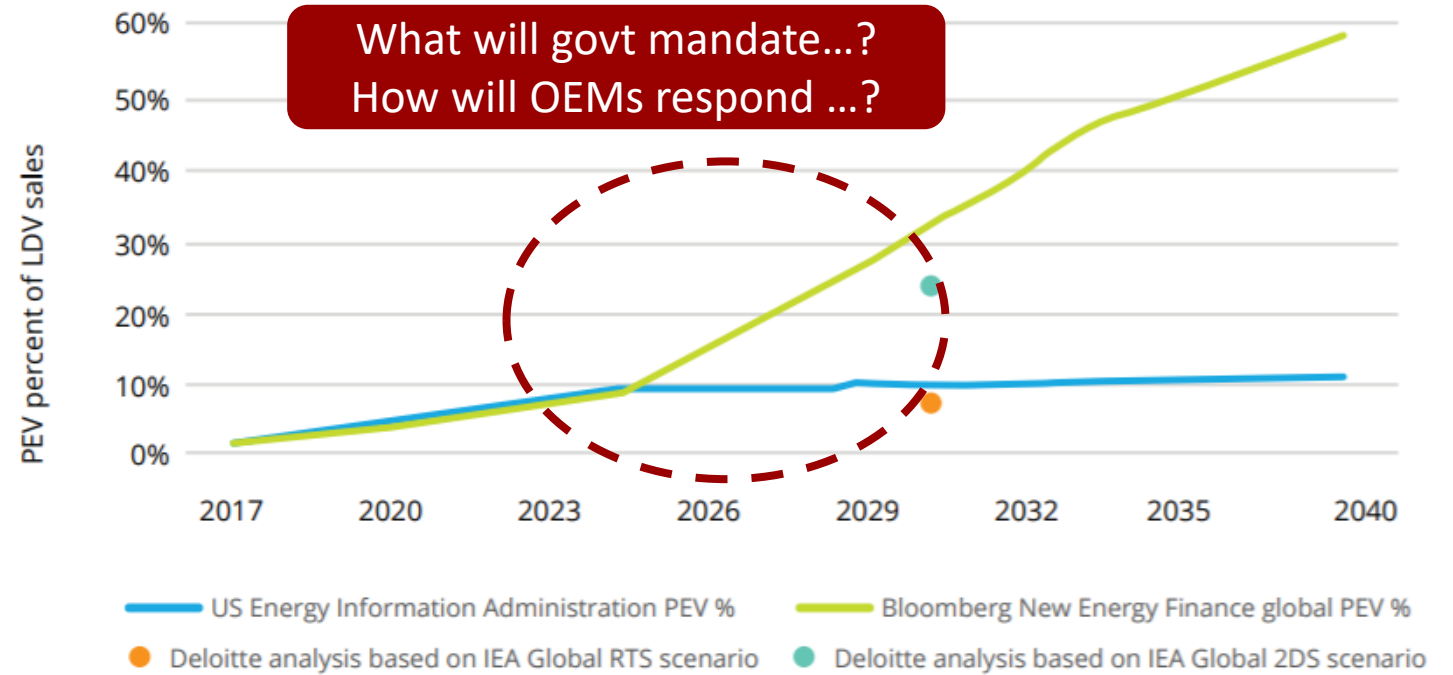


Figure 2. Projected PEV share of total light-duty vehicle sales

Projected US and global PEV market share through 2040



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.

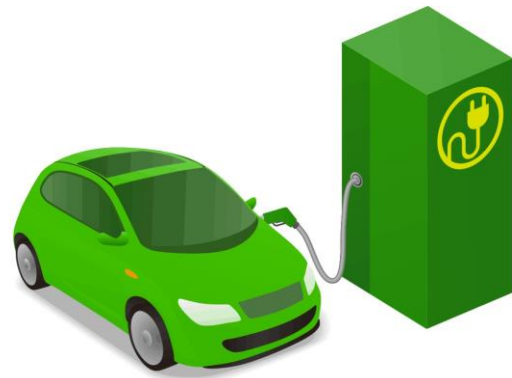
Source: Deloitte analysis.

Decarbonization of Transportation Fleets

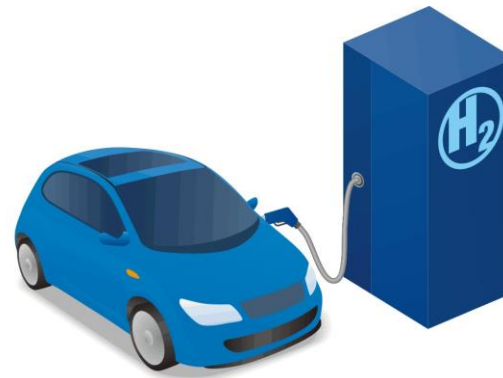
'Electrification' of Vehicle Fleets – Electrons vs Fuels?



Hybrid ICEs



Plug-in EVs



Fuel-based EVs

Thinking Beyond
Passenger Vehicles:

Rail
Marine
Trucking
Aviation/UAVs

Autonomous
Last Mile / Micro
Transit
Indoor Robotics
Outdoor Robotics

BEVs 'Have Won' vs Limitations of All Electric Pathway

Battery pack = 400 miles
Daily Need = 40 miles

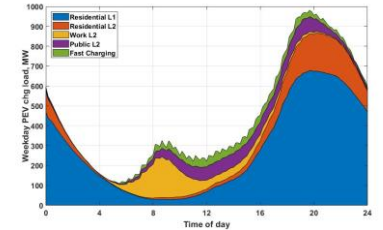
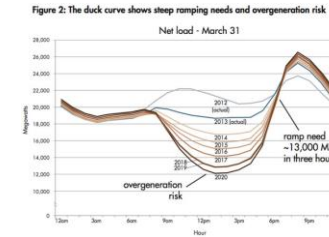


OEM Cost-to-X
vs Daily Use Demand



Uptime &
Recharging for
Urban Markets

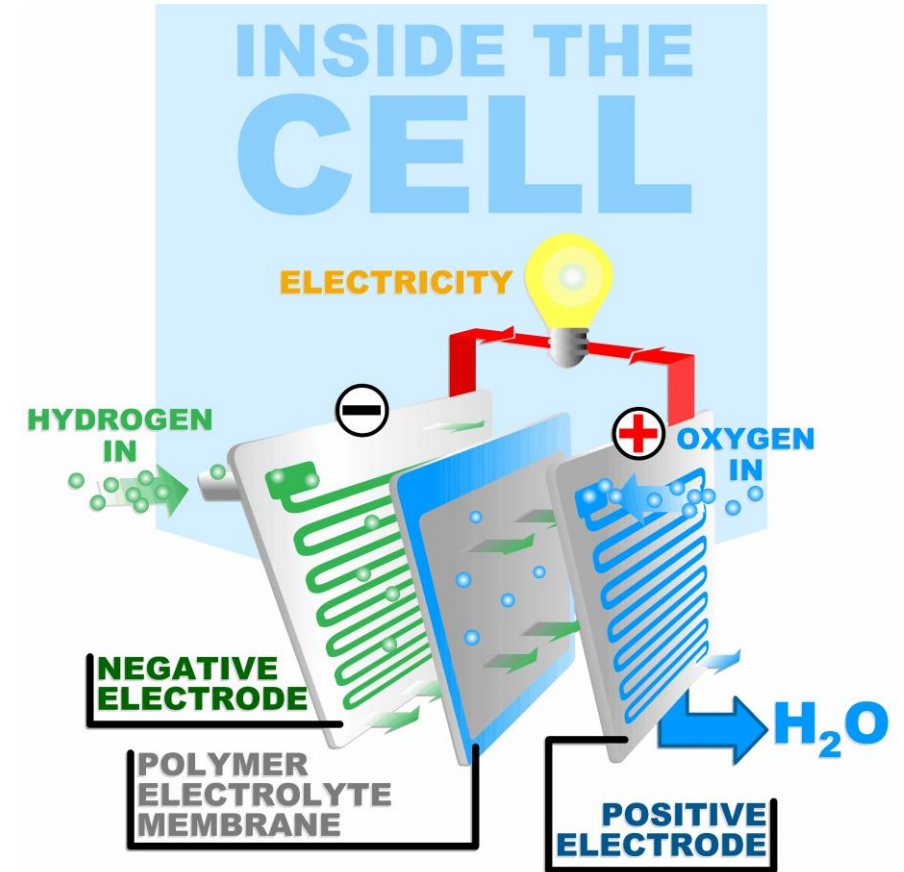
'Duck Curve' to 'Dragon Curve'



Full Costs of
Grid Management

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
- Fueling Model Allows Scaling to Billions of Vehicles
- Preservation of Loose Coupling to Electricity Grid
- Market Incentives for Existing Incumbents



POWERTRAIN APPLICATION MAP – MEETING CUSTOMER NEEDS

No Single Silver Bullet Exists

Committed ZEV Leader

Fuel Cell



E-REV

BEV



Stop-and-go

Drive Cycle

Duty Cycle

Continuous

High Load

Light Load

City

Intra-urban

Highway-cycle

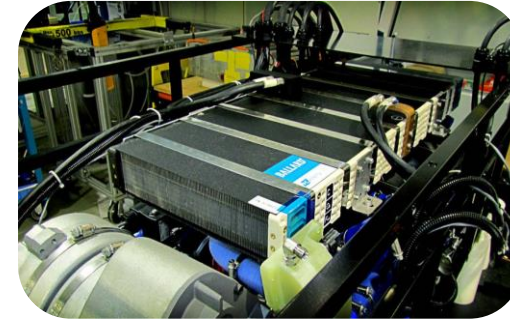
Highway

Decarbonization Requires a Shared Strategy for Supply Chains



NIKOLA ONE™

Trucking



Maritime

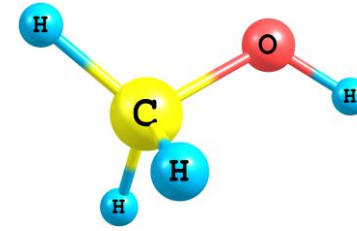
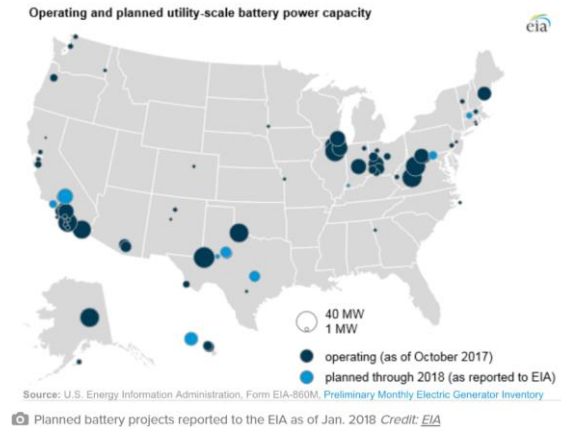


ALSTOM

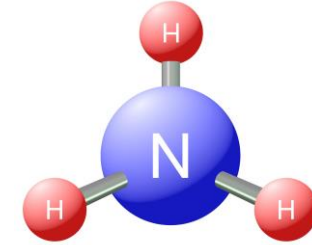
Hydrail



Aviation / UAVs



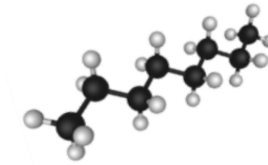
Methanol



Ammonia



Hydrogen



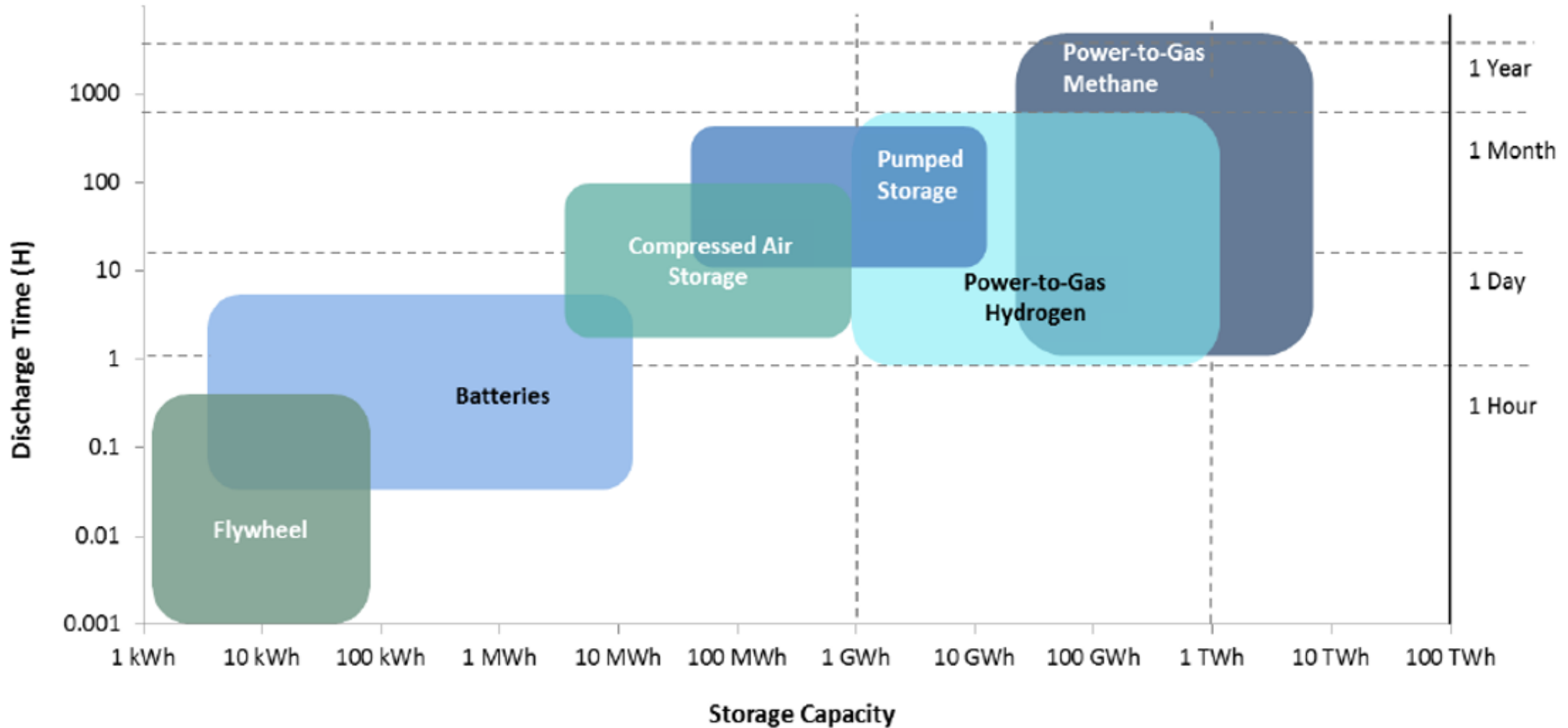
Biofuels /
Synfuels

Decarbonization: Energy Storage AND Versatility of Power to Gas (PtG)

**Era of
Electrochemical Energy**
(Batteries; Fuel Cells; Electrolysis; Solar Chemical)

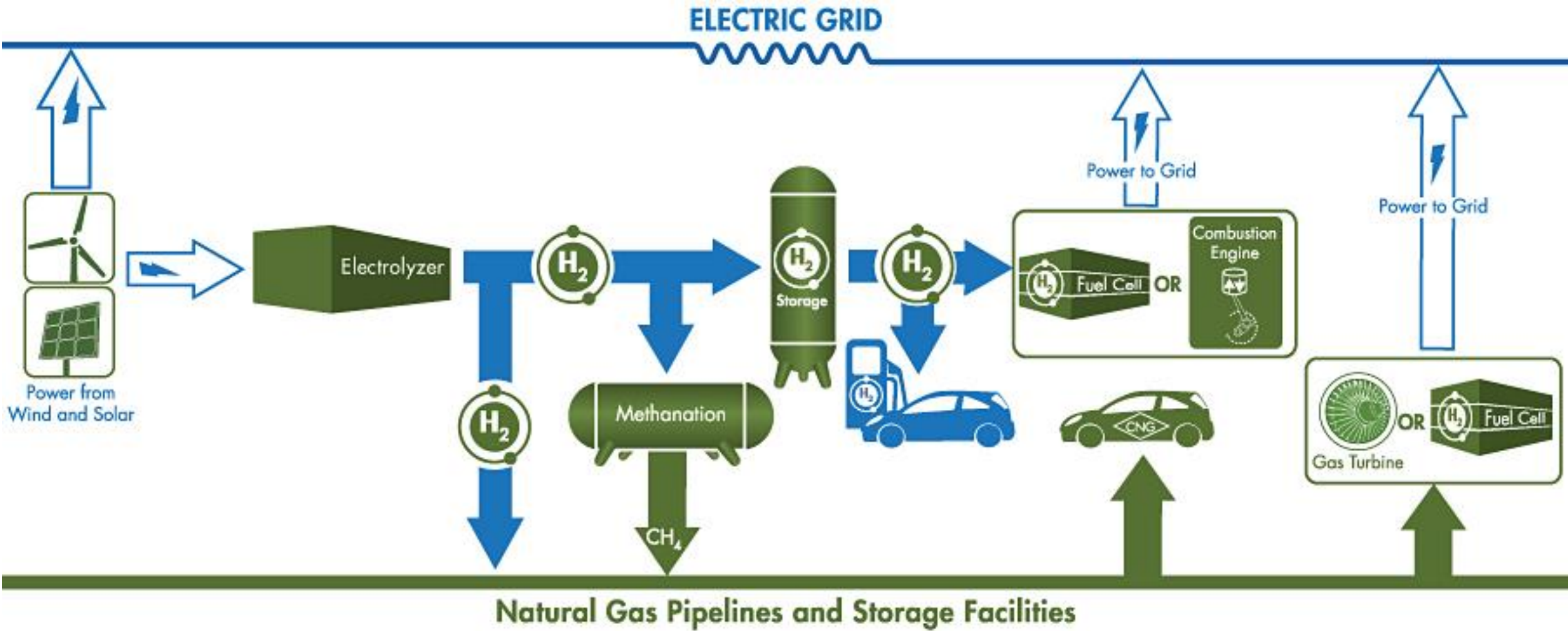
Renewables♥PtG - Scale & Versatility of Hydrogen

Will Natgas Sector Assume Role in H2-rich Fuels & 'Renewable Gas'?

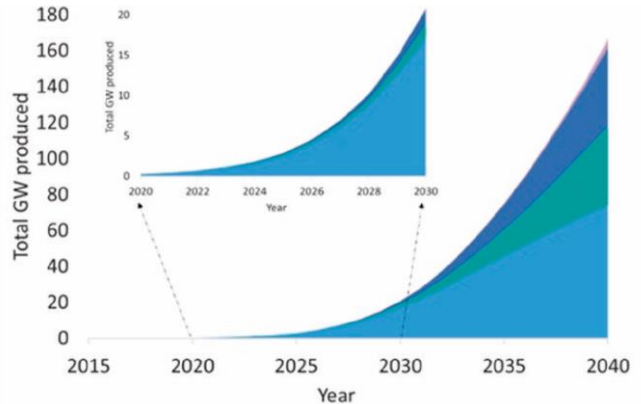


After Fraunhofer ISE, 2015

Power to Gas Gains Momentum with Scale & Versatility



PtG by Incumbents Who Do Scale, Versatility & Business Model Design



■ PEM electrolysis ■ AEM electrolysis ■ SOEC electrolysis ■ PEC ■ STCH
Projected hydrogen capacity (energy input) from advanced water splitting technologies in the next 25 years
 PEM = proton exchange membrane; AEM = anion exchange membrane; SOEC = solid oxide electrolysis cell; PEC = photoelectrochemical; STCH = solar thermochemical.

Katherine Ayers © Materials Research Society, 2017

Production



Compression

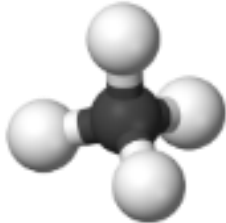
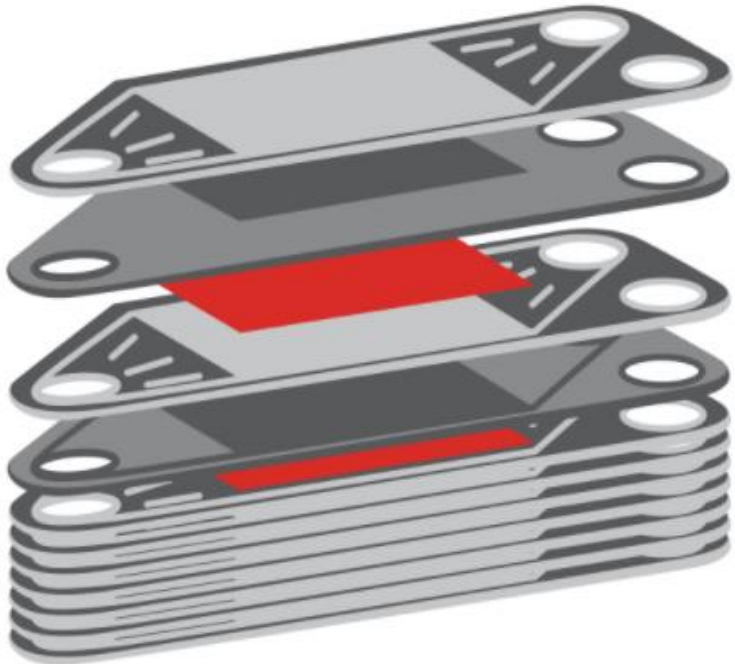


Storage

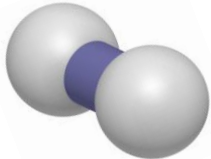
Scenario: Natural Gas Expands into Hydrogen or *Green Gas*



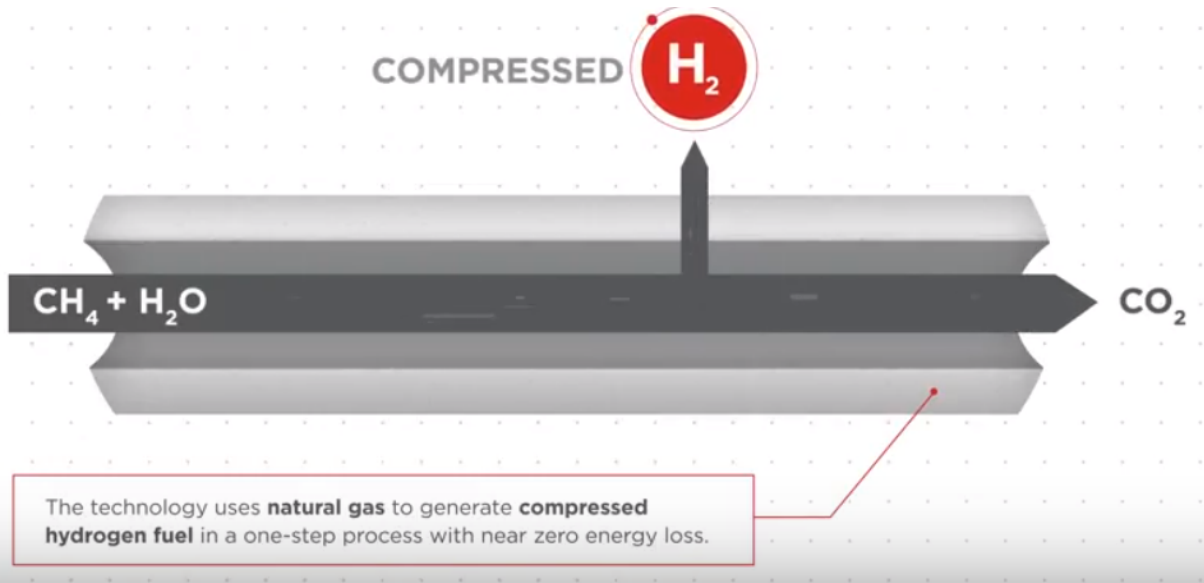
ACTIVE CERAMIC MEMBRANES



Near Zero Loss
Energy Conversion



Compact Hydrogen Generators via Natural Gas



Driving Cost
\$/100km



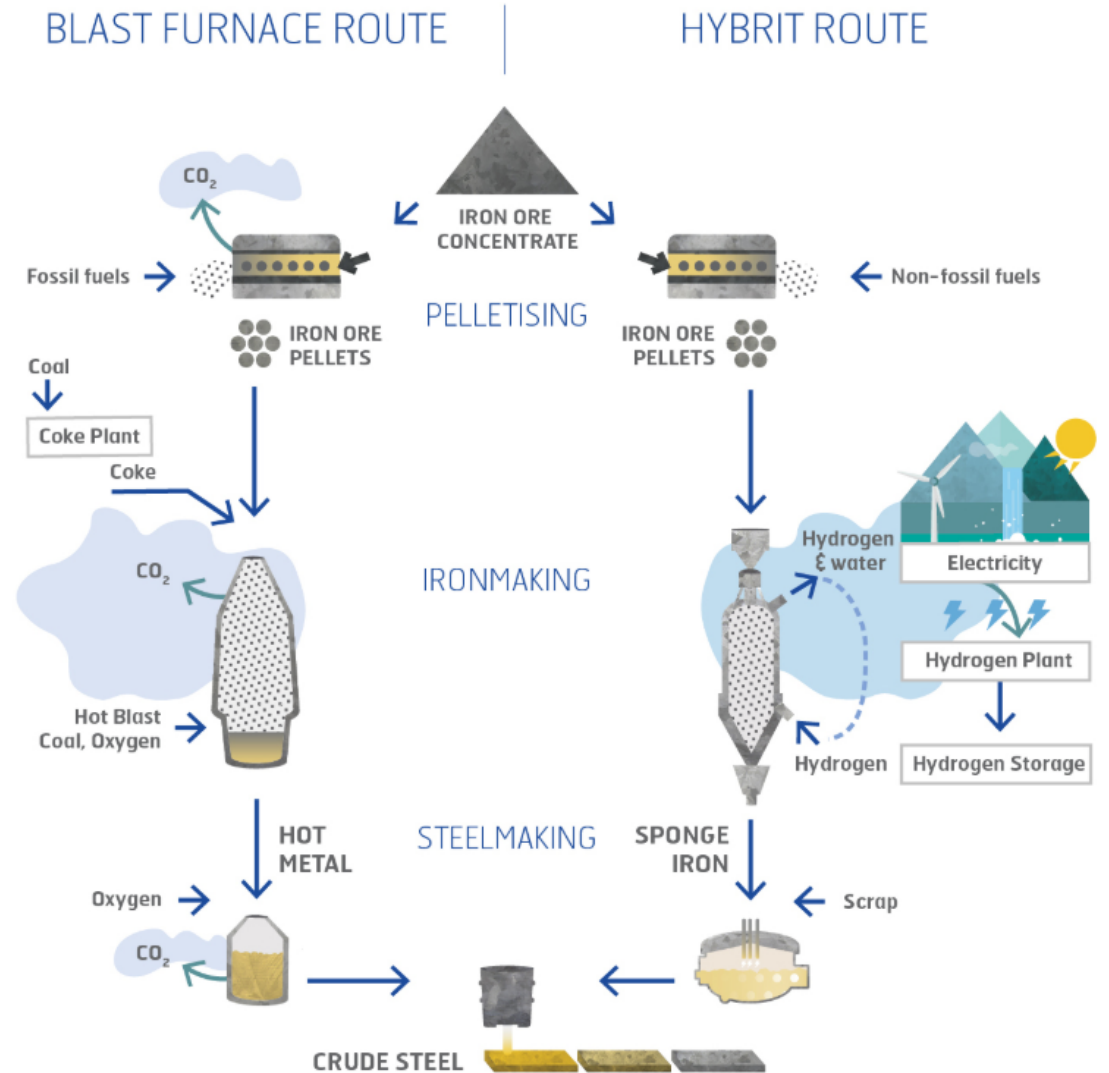
Source



Decarbonization for Steel Making

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

HYBRIT (Hydrogen Breakthrough Iron Technology)



Global & Regional Stories of Decarbonization



Thank you!



Learn More:
garrygolden.com/Sept12

Garry Golden
garrygolden@gmail.com (Two Rs)

