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Delivering Renewable Hydrogen Workshop

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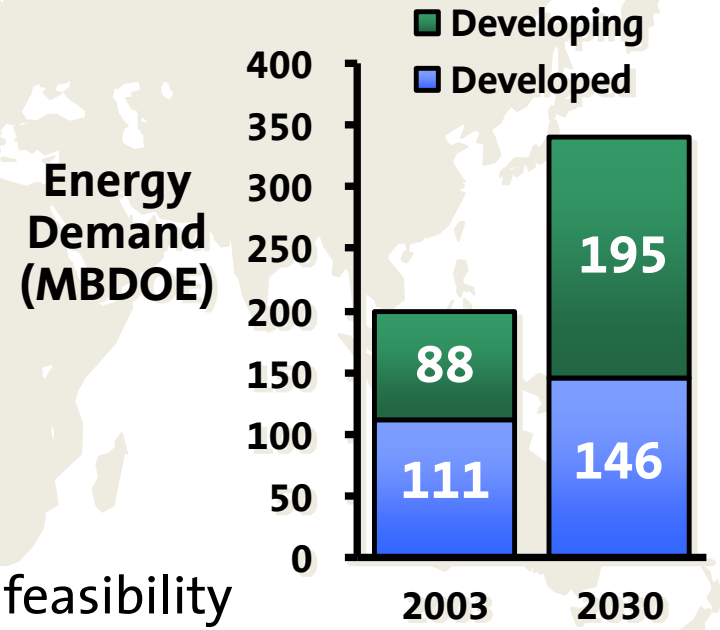
The Power of “AND” vs. “OR”

- **The Challenge**
  - Petroleum AND GHG Reduction
- **Role of Hydrogen**
  - Transportation AND (Renewable) Energy
- **Advanced Propulsion Portfolio**
- **Key Takeaways / “AND” Question**

The Challenge

- Global energy demand exceeds our current glide path for supply
- There are several risks that can disrupt the existing supply
  - Above ground infrastructure
  - Natural disasters
  - Wars
  - Hostile regimes
- Growing concern about global warming due to CO_2
- Potential for regulations that exceed both technical capability and business feasibility

Global increase 2% / year, 71% increase over 2003



Source: DOE Energy Information Agency

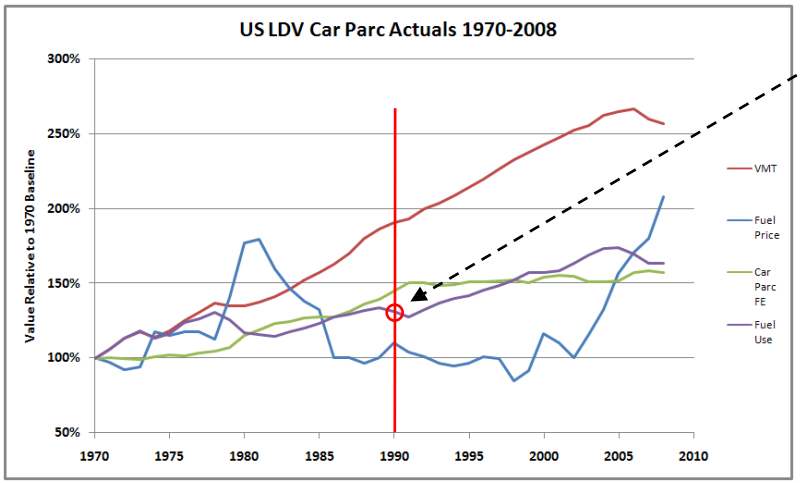
MBDOE: Millions of barrels per day oil equivalent

United States Light Duty Vehicle Transportation

2050 Greenhouse Gas Reduction Goal

U.S. goal is 80% reduction from 1990 levels by 2050

- Assuming light duty transportation must reduce its GHG footprint in equal proportion to other contributing sectors of economy:



1990 fuel use ➡ **1990 GHG**

105 billion gallons

1,220 million tons CO_2 equivalent

80% reduction

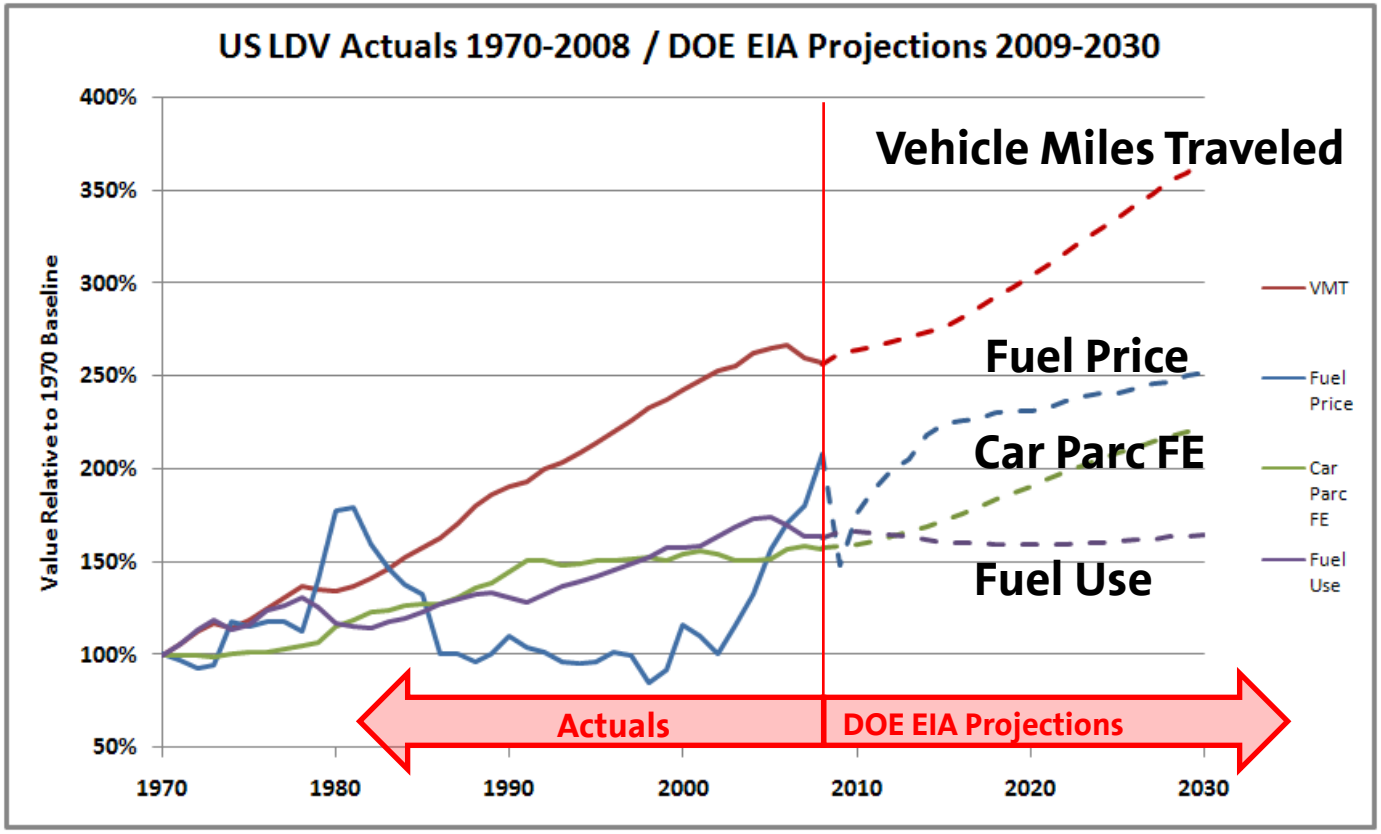
2050 GHG goal

244 million tons CO_2 equivalent (or less)

LDV 2050 GHG Goal is 244 million tons CO_2 equivalent

US Light Duty Vehicle Transportation

DOE EIA 2030 Outlook



U.S. Car Parc

2010 = 245M

2050 = 363M

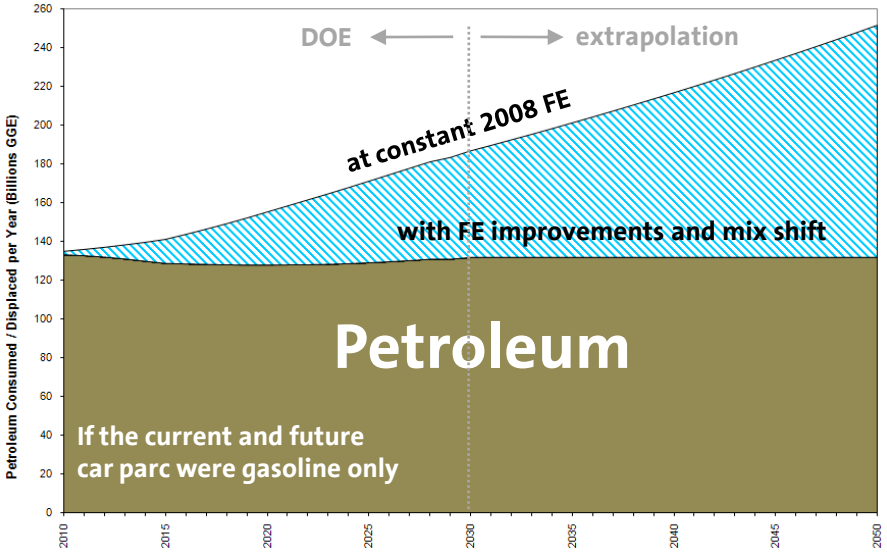
Linear Extrapolation of DoE Projection

DOE EIA 2030 Outlook – Reference Case

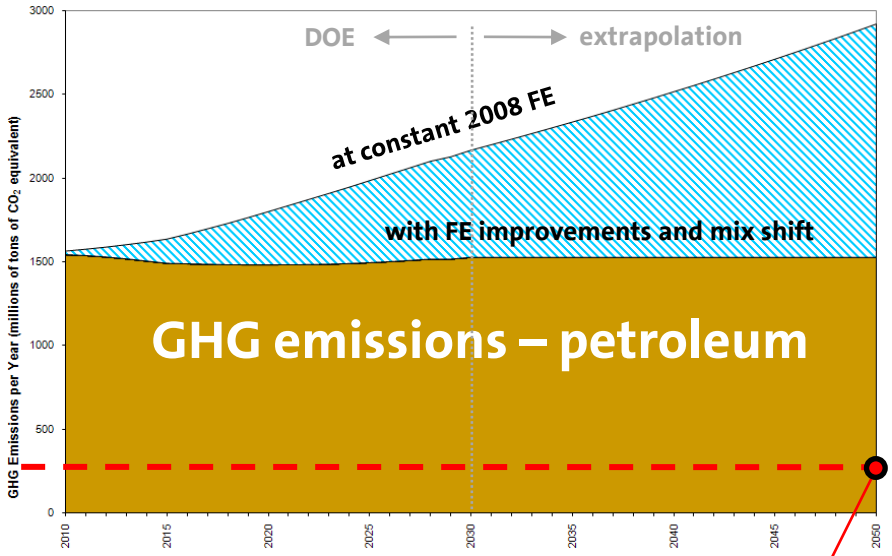
- Continued steady growth in Vehicle Miles Traveled (VMT)
- Upward fuel price trend (highly uncertain)
- Fuel economy improvements offset growth in VMT
- Fuel use remains relatively flat (this is a break from past 40 year trend)

Base Case – Petroleum World (2010-2050)

Petroleum Consumption



GHG Emissions



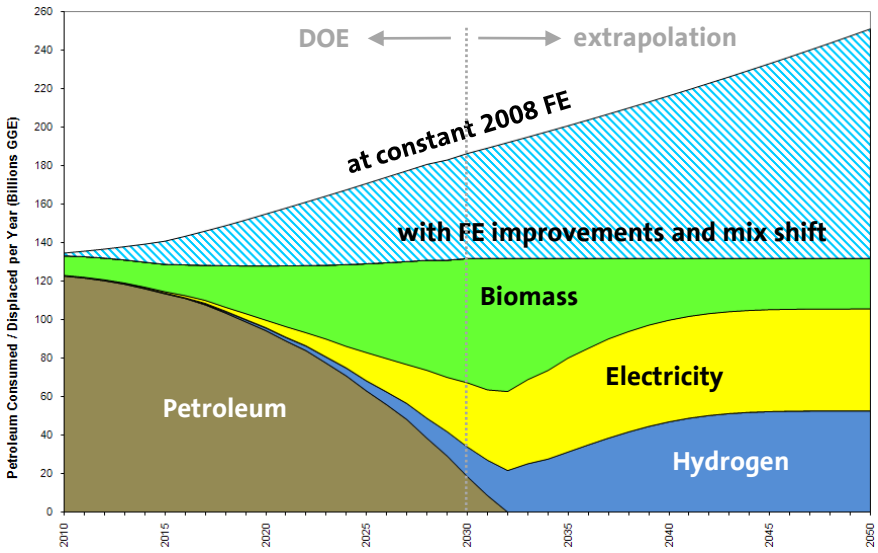
Goal – 80% reduction from 1990 level by 2050

- EIA Annual Energy Outlook 2009 data
  - Includes aggressive fuel economy improvements
  - Includes assumption that higher energy prices drive mix shift from trucks to cars
  - Fuel economy improvement & vehicle-miles-traveled growth rates @ 1.5% / year
  - Petroleum consumption & GHG emissions stay flat 2010 - 2050

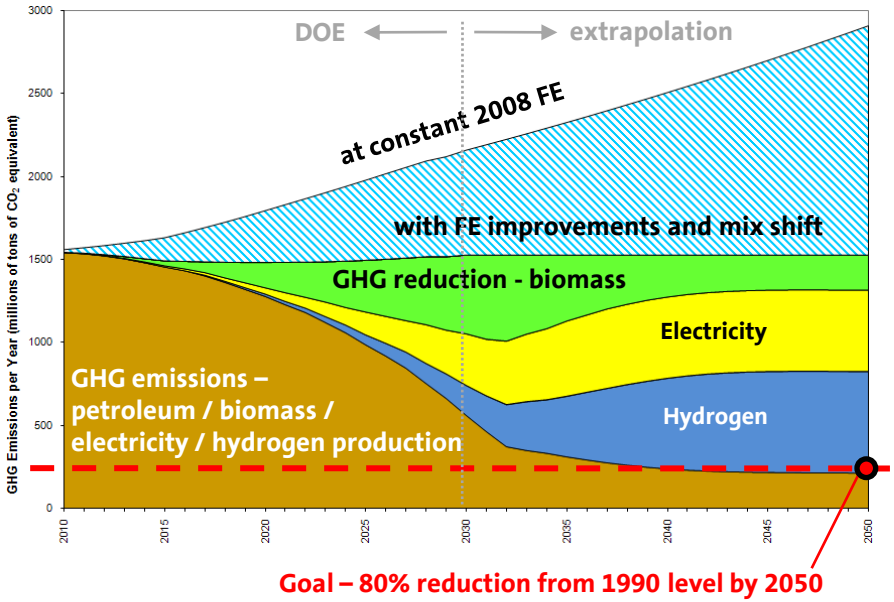
Technology improvement & more efficient market mix hold petroleum consumption & GHG levels constant, but no progress toward goal

All Options in Play - - Power of "AND" (2010-2050)

Petroleum Consumption



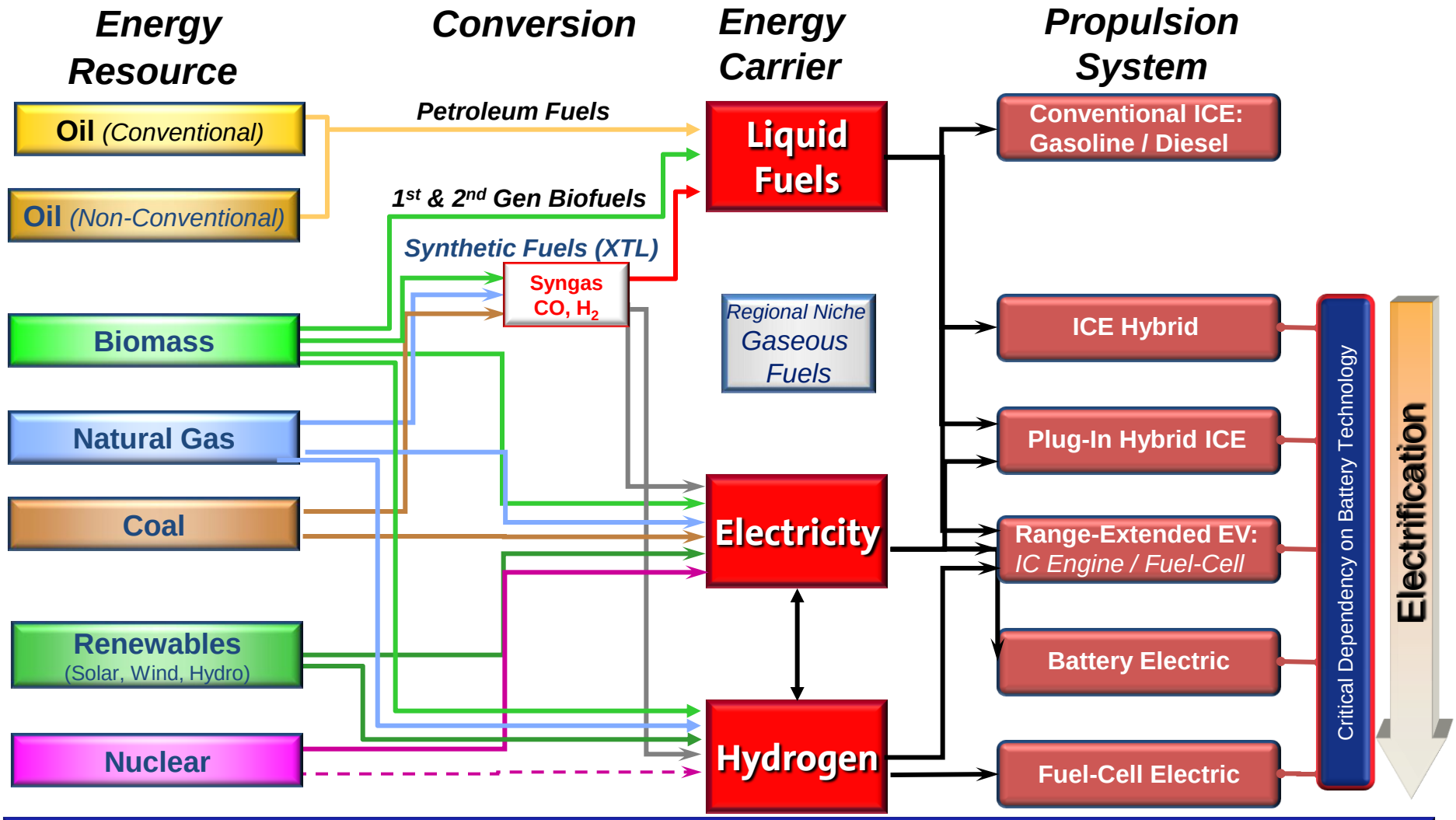
GHG Emissions



- Cellulosic biomass ramps to high volume; BEVs / EREVs make 40% of VMT electric; FCEVs penetrate to 40% of parc by 2050
  - Petroleum out of picture by 2032
  - LDV parc mostly transitioned to electric drive and ZEV solutions
  - US grid GHG modeled at 80% lower than 2008 levels
  - Hydrogen from cellulosic biomass or clean electricity

Start soon with early options; finish with strongest long-term portfolio

Energy & Technology Options

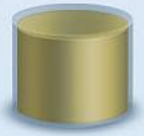
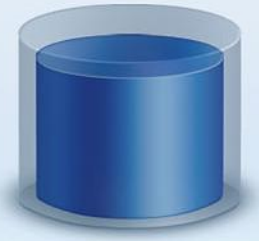
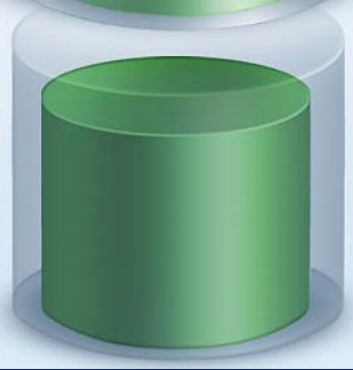


Despite Variety of Resources, 3 Predominant Energy Carriers

Energy Carrier Properties: Onboard Storage

Why is petroleum the dominant transportation fuel?

Weight & Volume of Energy Storage System for 300 mile Range

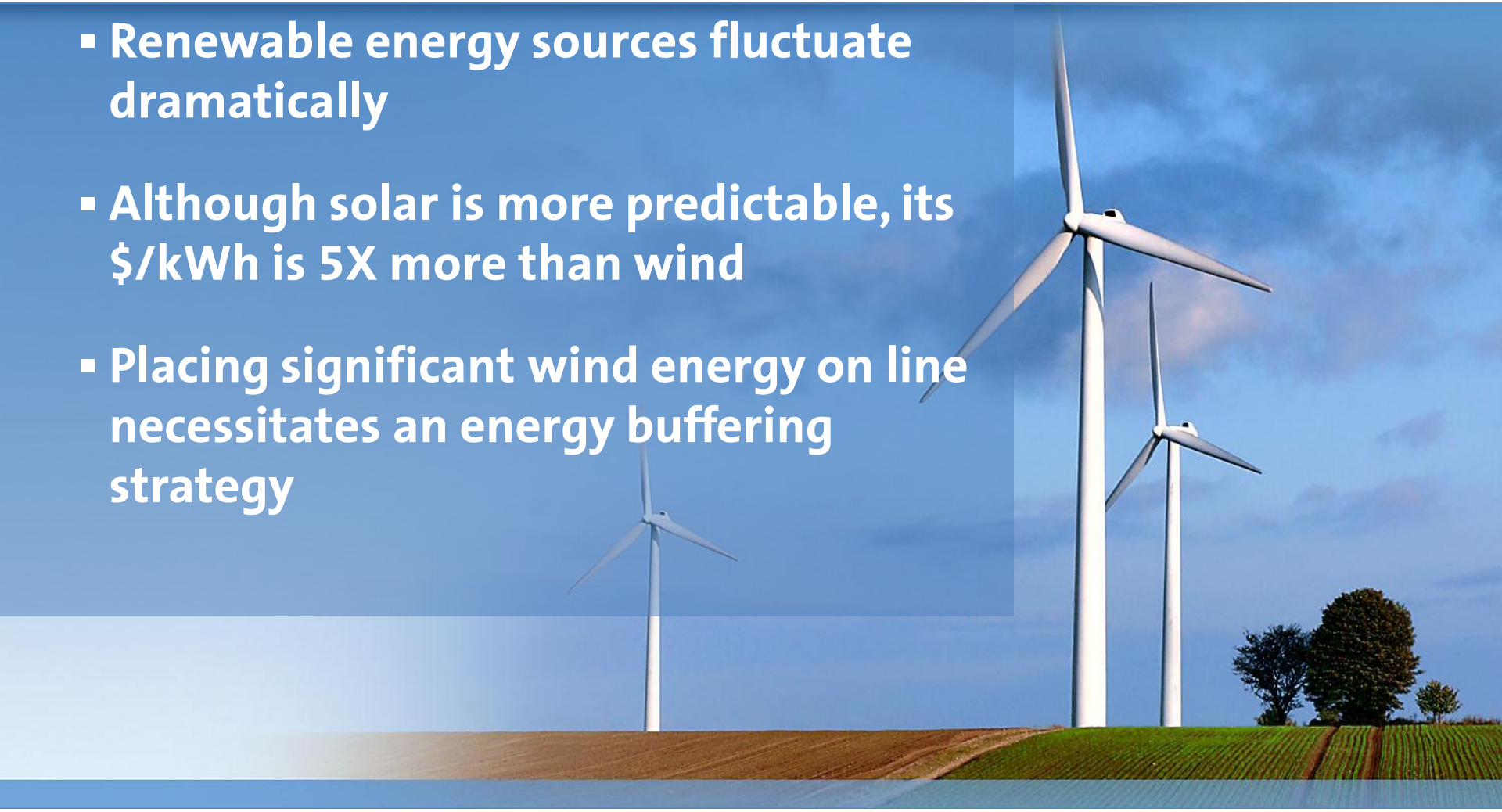
Diesel		Compressed Hydrogen 700 bar 6 kg H_2 = 200 kWh chemical energy		Lithium Ion Battery 100 kWh electrical energy	
	System Fuel		System Fuel		System Cell
	43 kg 33 kg		125 kg 6 kg		830 kg 540 kg
	46 L 37 L		260 L 170 L		670 L 360 L

The challenge is to balance electric drive efficiency and energy cost advantages vs. energy system storage mass, volume & refuel time penalties

Relationship between H_2 & Renewables

Germany Case Study – Wind Energy in Germany 2008

- Renewable energy sources fluctuate dramatically
- Although solar is more predictable, its $/kWh is 5X more than wind
- Placing significant wind energy on line necessitates an energy buffering strategy



1) DEWI-Report, 30.6.2008
2) Bundesverband Windenergie e.V., 20.11.2008

Germany - Case Study

Wind Energy and the Electric Grid

- German Wind Energy Example
- Quantity: 19,868 turbines
- Capacity: 23,044 MW[1)]
- Electricity production 2007: 39.6 TWh[2)] (7.2% of annual consumption)

E.ON control area: 40% of installed wind energy in Germany

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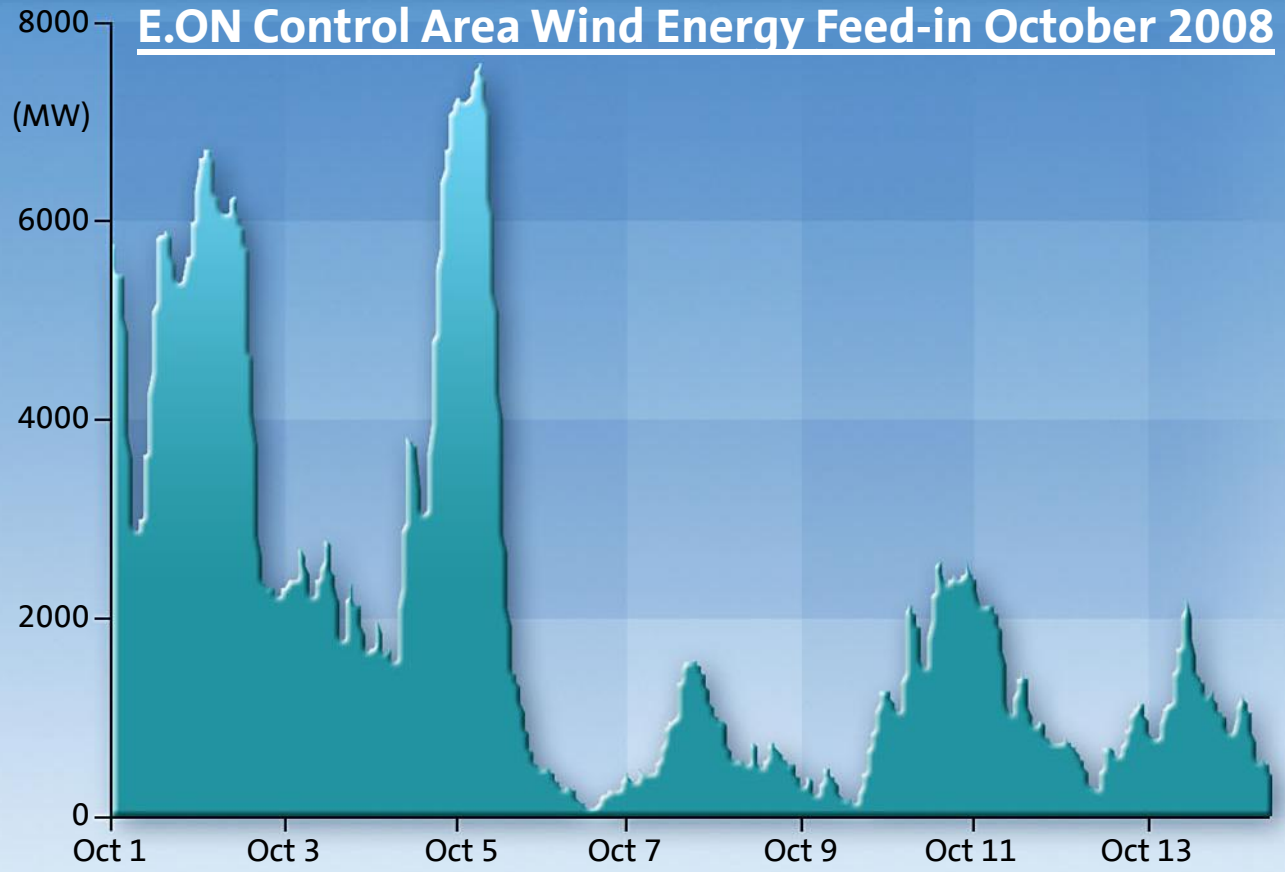
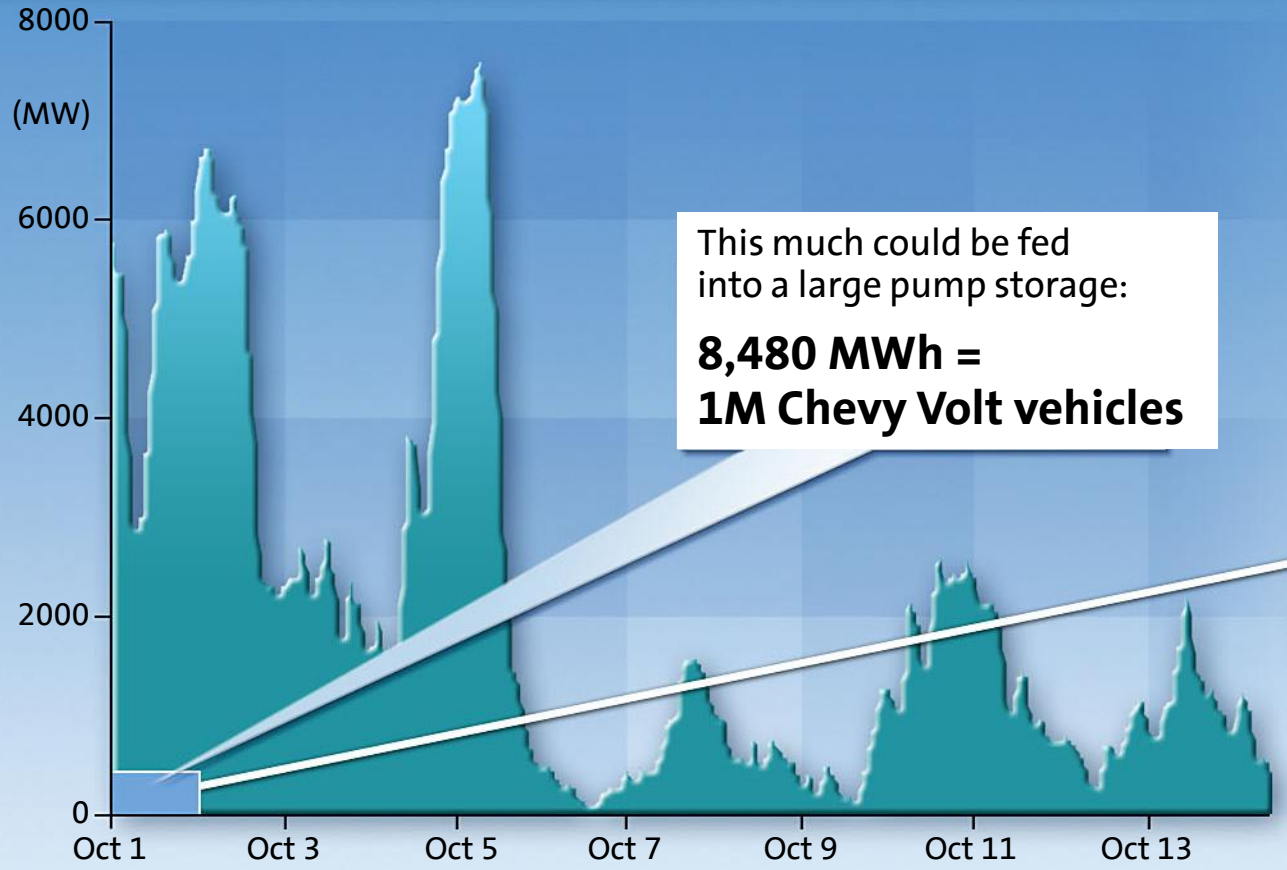
Germany - Case Study

Sustainables & Fluctuating Energy Availability



Fluctuating Wind Energy

Compared to Conventional Pump Storage Capacity



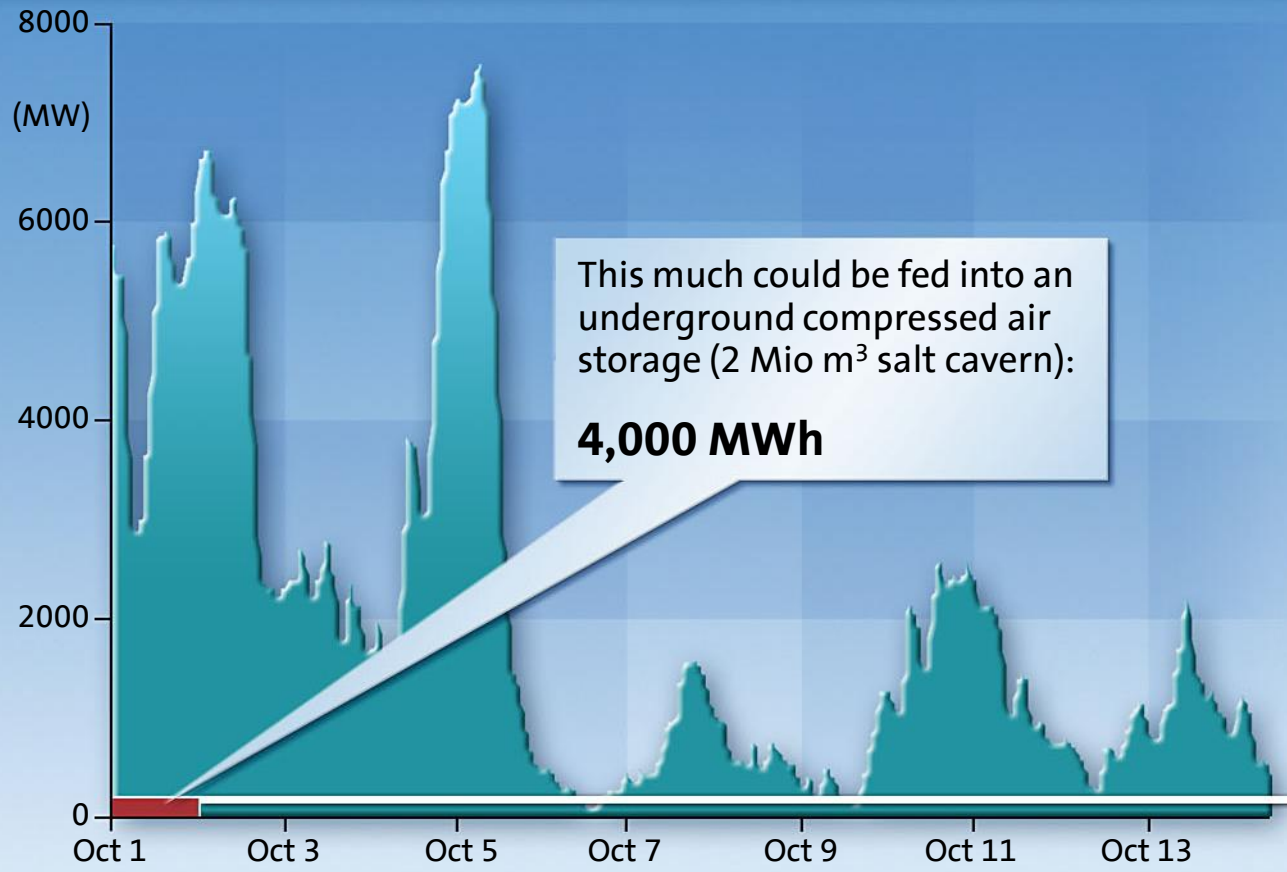
This much could be fed into a large pump storage:

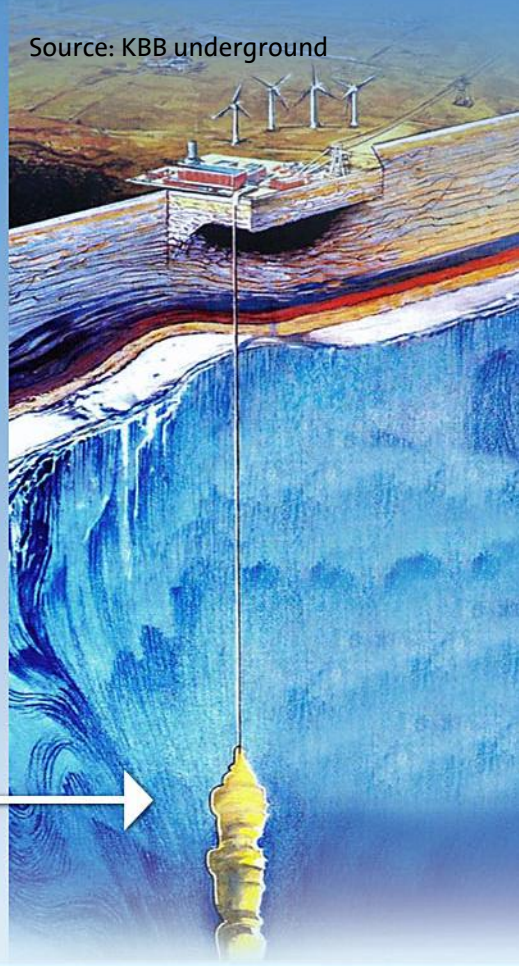
8,480 MWh = 1M Chevy Volt vehicles

Pump storage Goldisthal, Thüringen

➔ Buffer capacity for some minutes / hours

Store Fluctuating Wind Energy:
Storage of Compressed Air in Salt Caverns

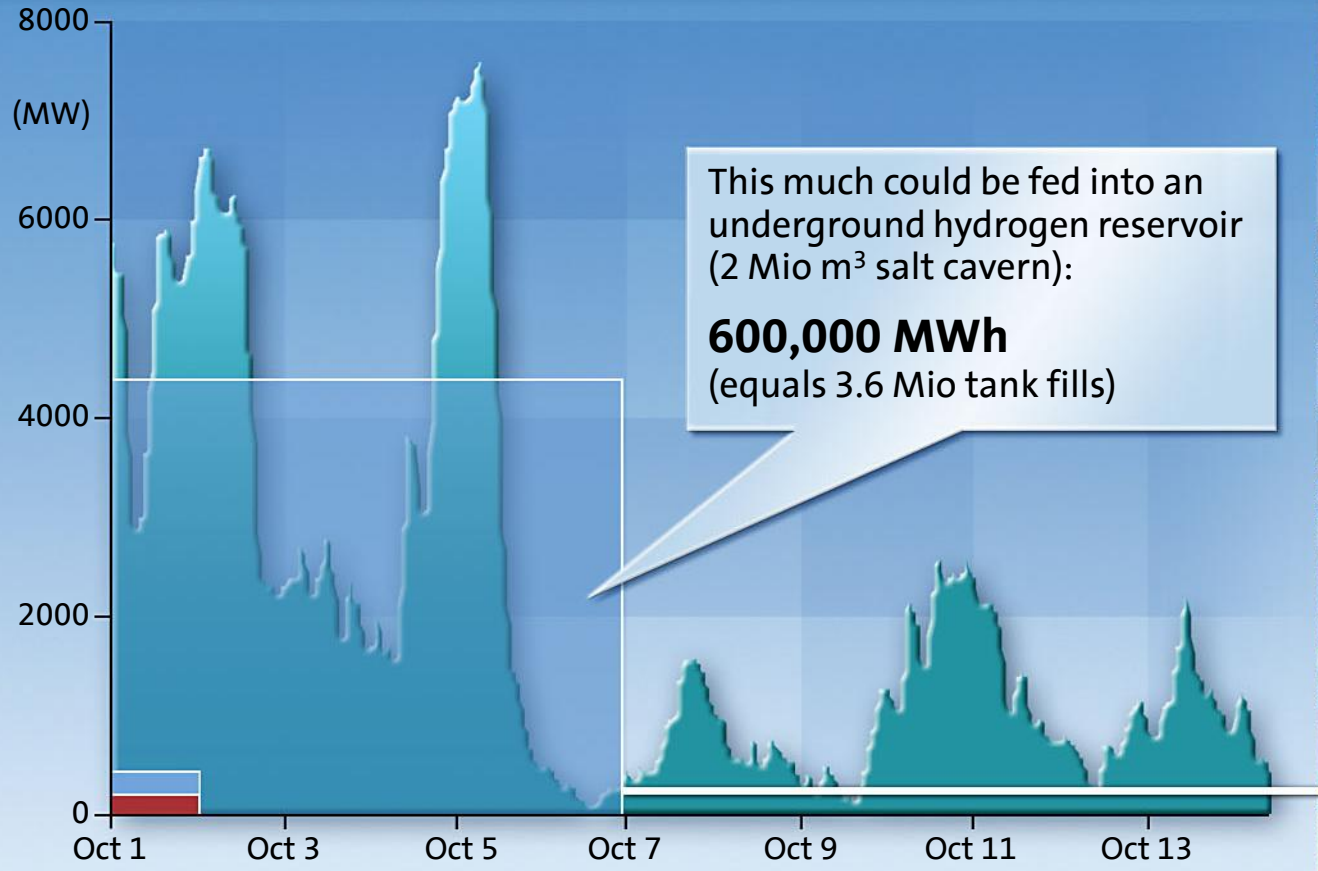


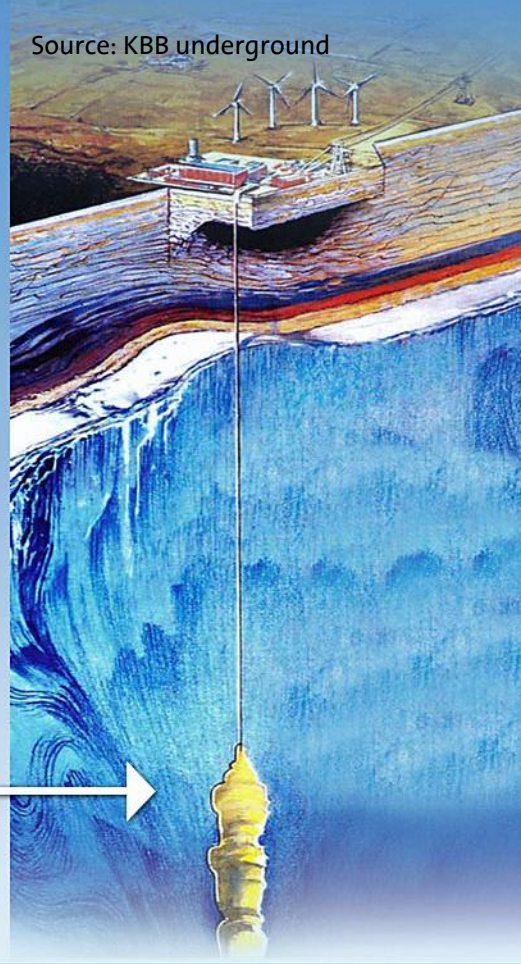


➔ Buffer capacity for some minutes / hours

Hydrogen

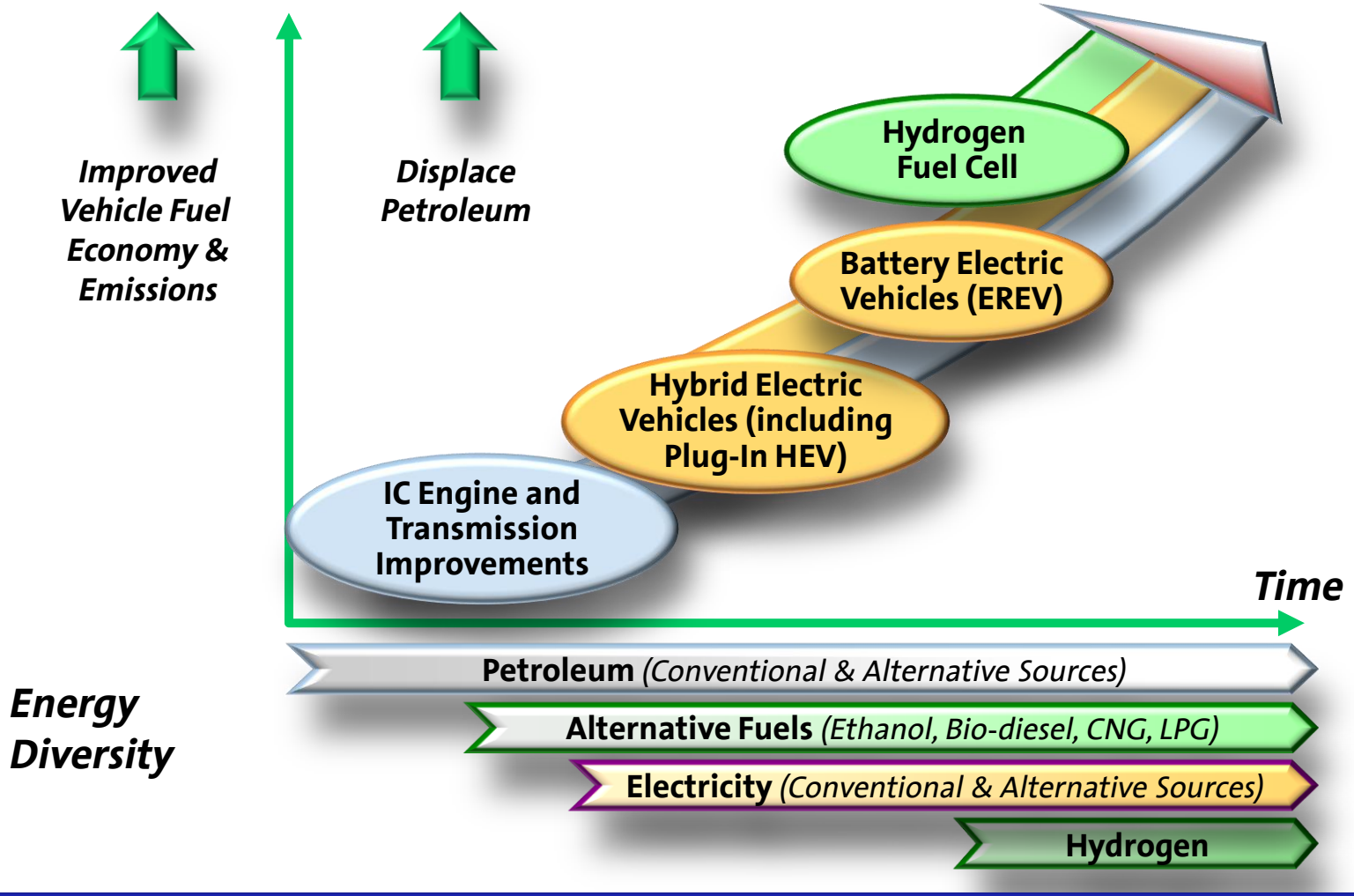
The Energy Buffer in the Renewable Energy System





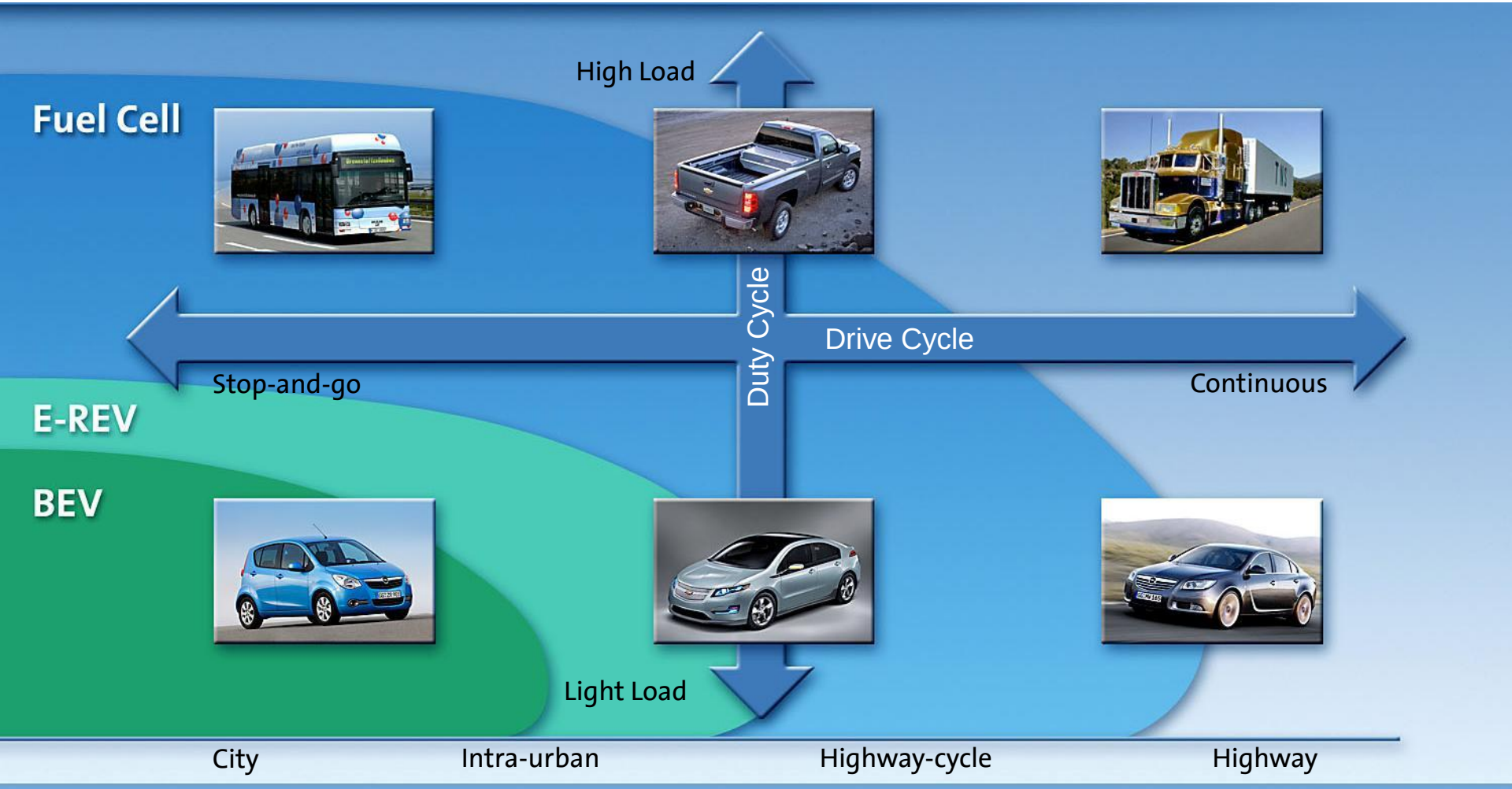
➔ Only hydrogen offers storage capacity for several days

The Power of "AND" - Advanced Propulsion Portfolio



GM's Advanced Propulsion Strategy comprehends the Power of "AND"

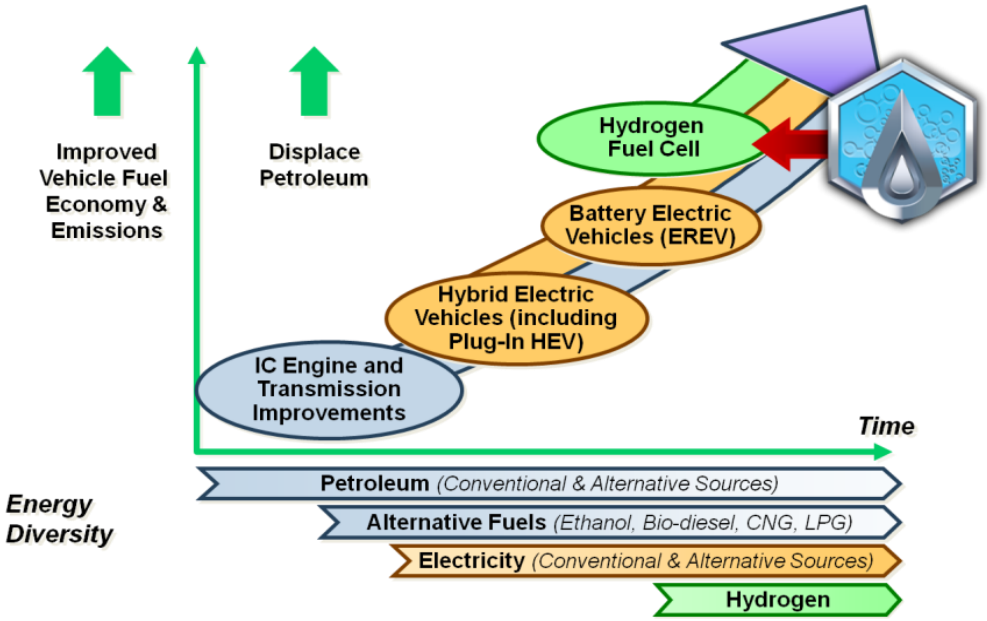
Application Map



There is no single silver bullet technology

GM's Hydrogen Fuel Cell Technology

Zero Emissions, Zero Petroleum, 2X Efficiency



FUEL CELL TECHNOLOGY

- Zero emissions & zero petroleum
- Compared to internal combustion engine:
  - More than twice as efficient
  - Comparable precious metal content
  - Comparable durability, range (300 miles), & performance
  - Fast refueling – within 3 minutes
  - 60% fewer part numbers
  - 90% fewer moving parts
- Cold & hot operation capability
- Family sized vehicles
- Synergy with renewable energy sources

Project Driveway – World's Largest Fuel Cell Vehicle Fleet

REAL WORLD DATA

- Over 80,000 customers applied
- 116 vehicles in four countries
- 80 customer drivers
- Over 10,000 people total have driven the vehicles
- 13,000 fills/30,000 kg of H_2 = 60,000 gal of gasoline saved
- Performed through 2 winters
- Vehicles with over 25,000 miles

Over 1 MILLION miles and Counting

Takeaways

- Meeting customer requirements AND GHG reduction goals AND reducing petroleum use requires a Portfolio of propulsion technologies
- Energy diversity key for BOTH energy AND transportation - - Hydrogen plays a key role
- Stable government policy is key to infrastructure & vehicle programs

Key AND Question:

"How can we work together with a collective will to enable all promising technology solutions to quickly and efficiently reach market "tipping points" and deliver their optimal interdependent value to consumers and the world?"

Larry Burns, retired GM VP, GM R&D & Planning