Vehicle Efficiency and Electrification

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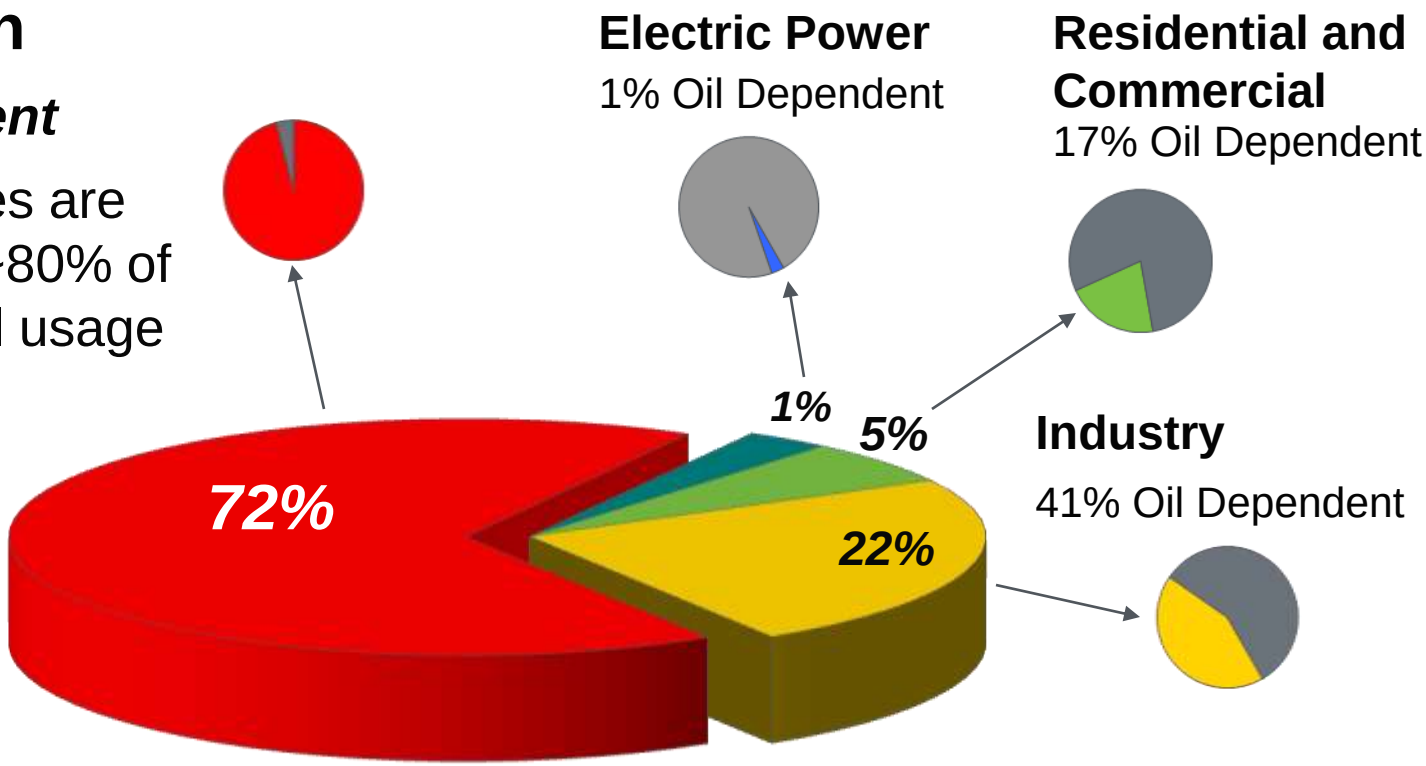
U.S. Oil Dependence Is Driven By Transportation

U.S. Oil Consumption by End-Use Sector
19.1 Million Barrels per Day (2010)

Transportation

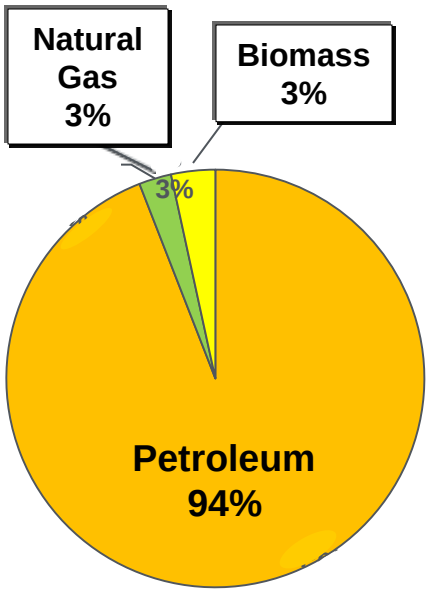
94% Oil Dependent

- On-Road vehicles are responsible for ~80% of transportation oil usage



Source: *DOE/EIA Annual Energy Review*, April 2010

We are Highly Dependent on Oil



U.S. Transportation Fuel Share (2009)

- Transportation is responsible for 2/3 of our petroleum usage
- On-Road vehicles responsible for ~80% of transportation petroleum usage
- 240M vehicles on the road

Analysis Informs Strategy

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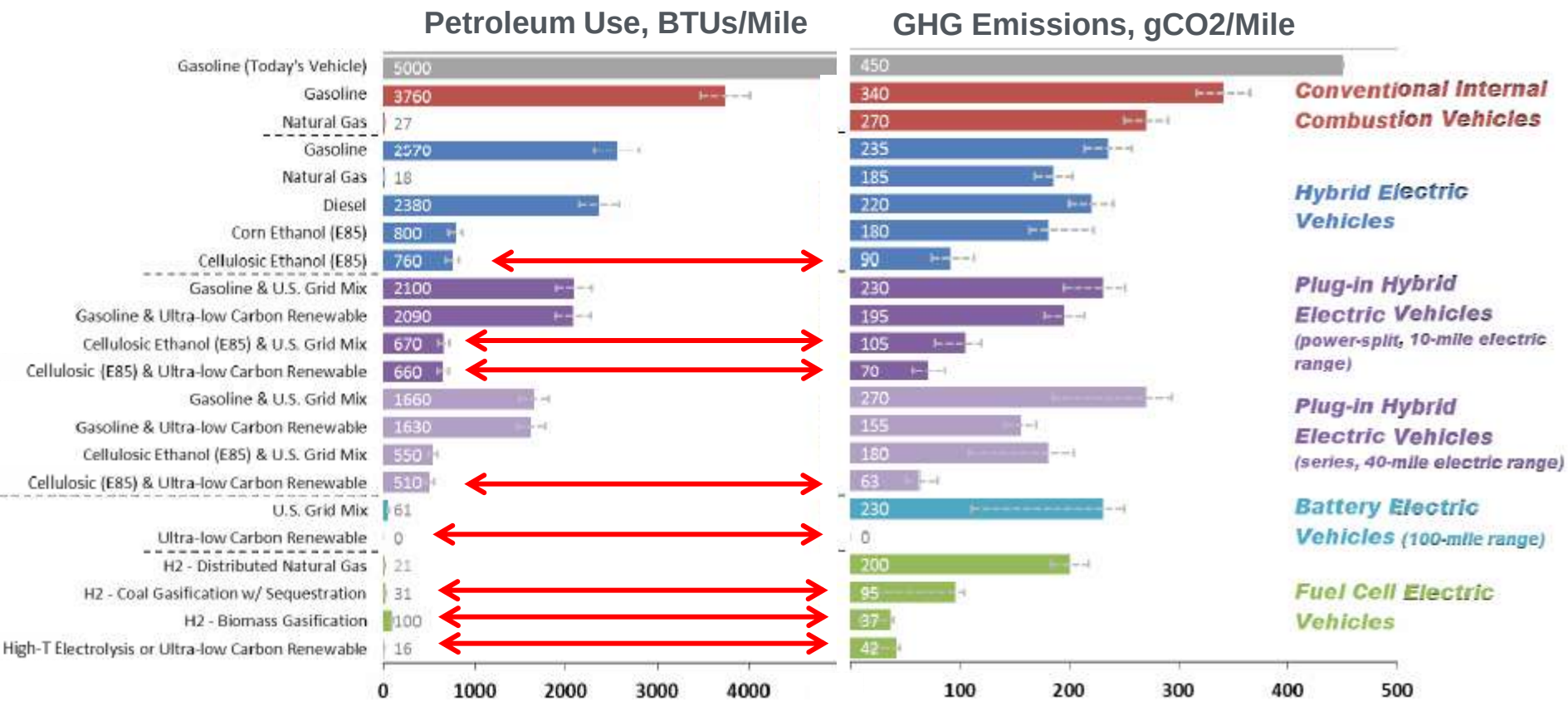
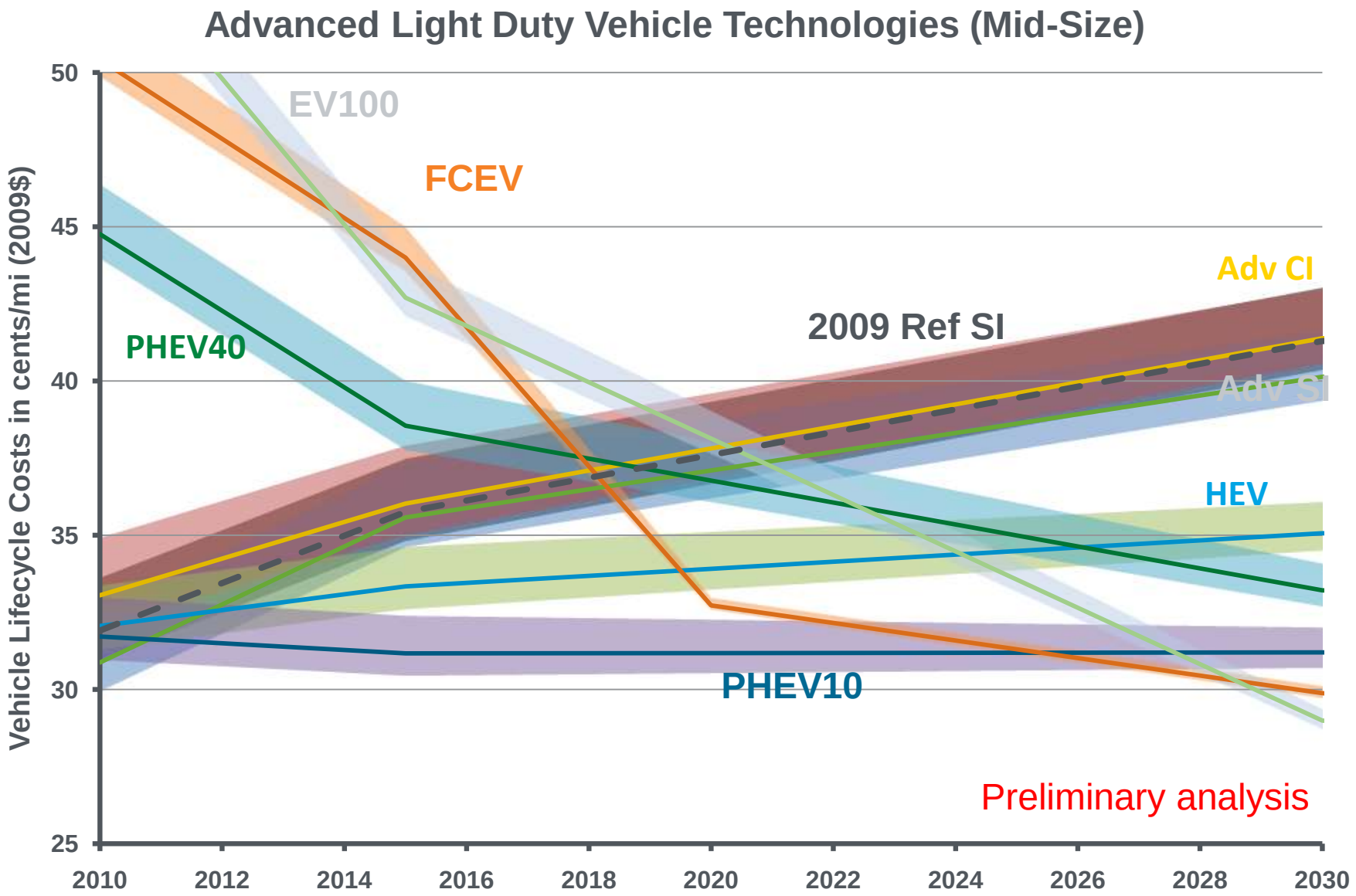
The Only Options That Achieve Very High Petroleum Reductions and Very Low Carbon Emissions Combine Electric Drive With Low Carbon Fuels



Life Cycle Cost Analysis Underway



Vehicle Electrification – What's Included in the QTR Process?

- Hybrids
- Plug-In Hybrids
- Extended Range Electric Vehicles
- Battery Electric Vehicles
- Fuel Cell Vehicles*
- Infrastructure
- Critical Components

A variety of technologies – including EVs, PHEVs, FCEVs, and advanced ICEs/HEVs along with adv. biofuels and natural gas – are included in the portfolio to meet our diverse transportation needs.

The most appropriate technology depends on the drive cycle and duty cycle of the application. No one technology meets all markets.

Fuel Cell R&D is in DOE's Fuel Cell Technologies Program (for transportation, stationary and portable applications) but close coordination occurs with DOE's VT Program

Vehicle Electrification – What's Included in the QTR Process?

Vehicle Components – Elec. Energy Storage/Generation:

- Batteries (Li-ion, Li/S, Li metal polymer, Li/air, NiMH)
- Ultracapacitors
- PEM fuel cells/hydrogen storage systems

Vehicle Components – Electric Drive System:

- Power electronics
- Electric motors
- Chargers
- Rare earths alternatives in electric motors

Vehicle Systems:

- Hybrid electric control systems
- Medium- and heavy-duty hybrid electric vehicles
- Auxiliary power units (APUS) for trucks and planes

Infrastructure:

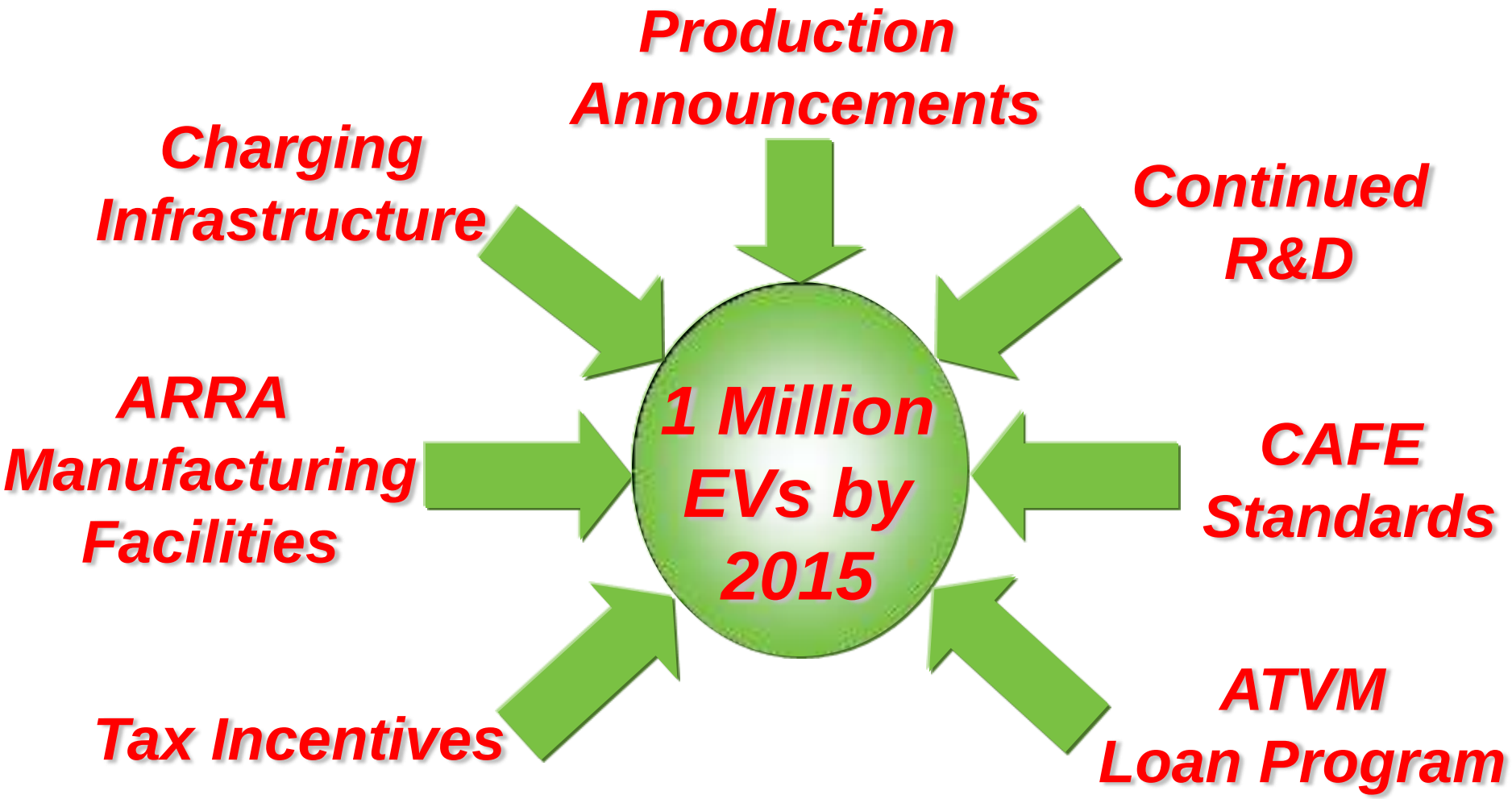
- Charging infrastructure
- Battery swapping, secondary use, and recycling
- Hydrogen production, delivery, and refueling stations
- Truck stop electrification

"To make sure we stay on this goal we're going to need to do more" President Obama remarks at Georgetown University, March 30, 2011

President calls out goal of 1 million PHEVs on the road by 2015 in State of the Union address

Vice President Biden announces community infrastructure project

Reaching 1 Million EVs by 2015



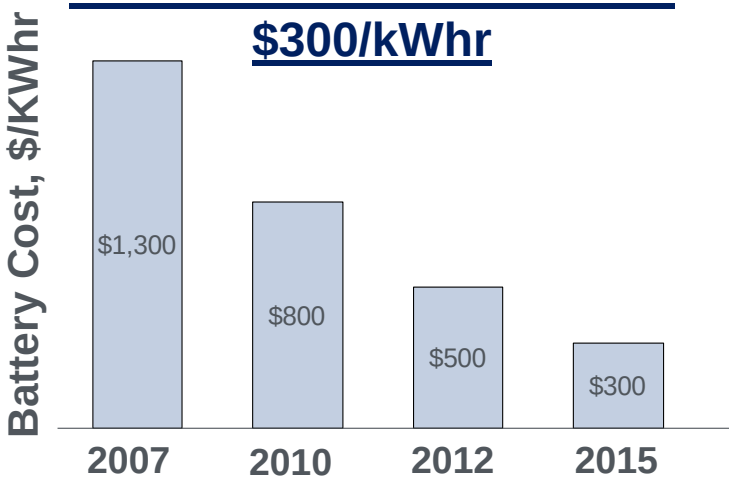
1 Million EV Goal is a Milestone, not a Finish Line

DOE Battery Innovation, Market Acceptance and Cost Reduction

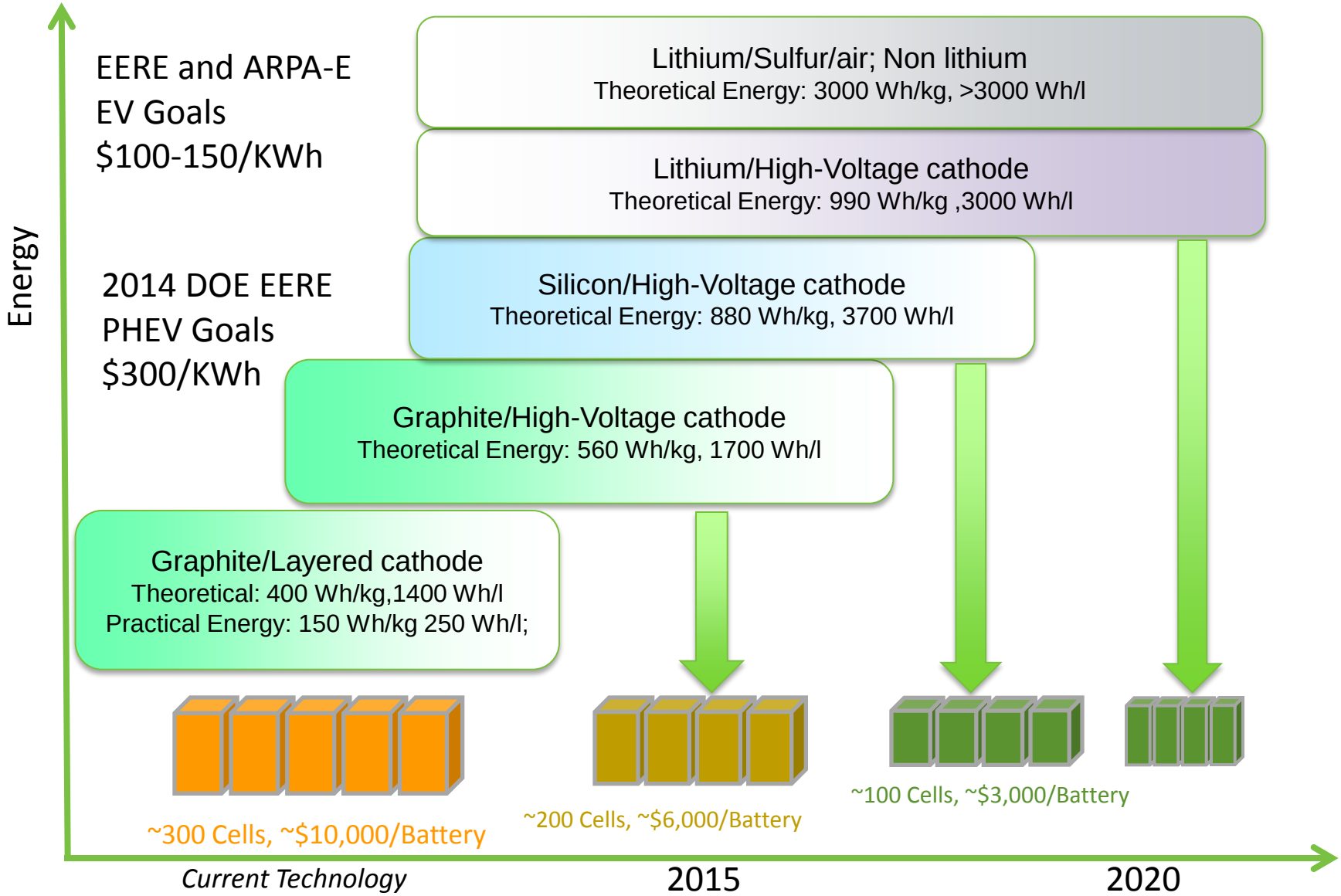
- 1990's → Nickel Metal Hydride (NiMH) batteries enable commercial introduction of HEVs
- 2000 – 2010's → Li-ion batteries enable next generation HEVs, PHEVs and EREVs
- Future → Next Generation Chemistry with 3x energy density: Li(metal) battery

DOE Energy Storage Goals	PHEV (2015)	
	PHEV-10	PHEV-40
Electric Range (miles)	10	40
Disch. Pulse Power: 10 sec (kW)	50	38
Regen Pulse Power: 10 sec (kW)	25	30
Recharge Rate (kW)	1.4	2.8
Cold Crank Power:-30 ºC/2sec (kW)	7	
Available Energy (kWh)	3.5	11.6
Calendar Life (year)	10+	
Cycle Life (cycles)	3,000-5,000 (deep)	
Maximum System Weight (kg)	60	120
Maximum System Volume (l)	40	80
Operating Temp. Range (ºC)	-30 to +52	

Plug-In Hybrid Battery Cost on Track to Meet 2015 Goal of $300/kWhr



Research Roadmap for 2015 and Beyond



Next Generation Lithium-Ion

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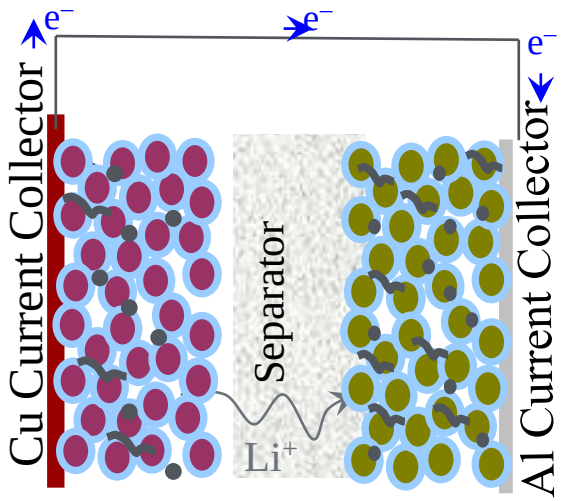
Next generation lithium-ion can increase the power and energy by 2X while decreasing cost by 70%

Anode

Today's Technology
(300 mAh/g)
-Graphite
-Hard carbon

Next Generation
(600 mAh/g)
-Intermetallics and new binders
-Nanophase metal oxides
-Conductive additives
-Tailored SEI



Electrolyte

Today's Tech (4 volt)
Liquid organic solvents & gels

Next Generation (5 volt)
-High voltage electrolytes
-Electrolytes for Li metal
-Non-flammable electrolytes

Cathode

Today's Technology
(120-160 mAh/g)
-Layered oxides
-Spinels
-Olivines

Next Generation
(300 mAh/g)
-Layered-layered oxides
-Metal phosphates
-Tailored Surfaces

Outlook for Battery Cost and EV Production Capacity

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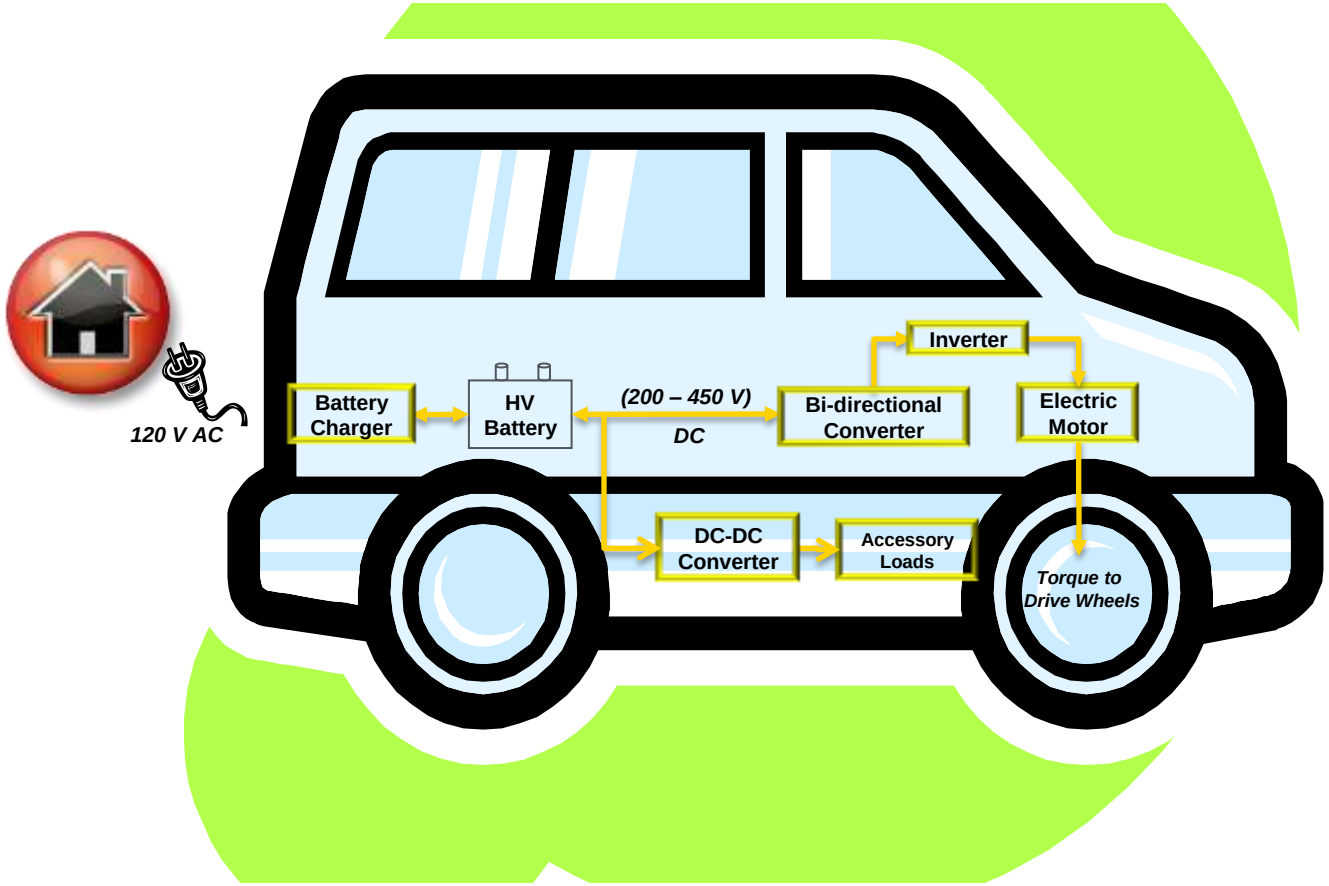
On Track to Meet Administration's Goal of 1 Million EVs by 2015

	Battery Cost ($ per kWh)	Battery Production Capacity (10 kWh packs) ARRA	Battery Production Capacity (10 kWh packs) ATVM	Vehicle Production Capacity (announced,cumulative)
2008 2009	$1,000-$1,200	0	0	0
2010 2011	$700-$950	50,000		45,600
2012	Goal = $500	150,000	144,000	223,200
2013				486,200
2014	Goal = $300			854,200
2015		500,000	488,000	1,222,200

9.88M kWh per year production capacity in 2015

>7.7M kWh per year capacity demand in 2015

Power Electronics & Electric Machines Components are Critical



Traction Drive Components

(varying with vehicle architectures)

- ***Battery charger*** – PEVs vehicles require a battery charger.
- ***Bi-directional converter*** – step up the battery voltage for the motor and step down the bus voltage for regeneration to the battery.
- ***Inverter*** – convert direct current (DC) to alternating current (AC) to provide phased power for vehicle traction motors and generators.
- ***Electric motor*** - provide power for driving.

Power Management

(varies with vehicle architectures)

- ***DC-DC converter*** – provides power to auxiliary vehicle buses to operate accessories, lighting, air conditioning, brake assist, power steering, etc.

Current power electronics and electric machine technologies must advance to achieve lower cost, smaller and lighter footprints, and higher efficiency to meet marketplace demands.

Research Targets, Challenges, and Research Areas

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Requirements: 55 kW peak for 18 sec; 30 kW continuous; 15-year life

Technical Targets

Year	Traction Drive System ($/kW)	Traction Drive System (kW/kg)	Traction Drive System (kW/l)	Traction Drive System Efficiency	=	Power Electronics ($/kW)	Power Electronics (kW/kg)	Power Electronics (kW/l)	+	Motors ($/kW)	Motors (kW/kg)	Motors (kW/l)
2010	19	1.06	2.6	>90%		7.9	10.8	8.7		11.1	1.2	3.7
2015	12	1.2	3.5	>93%		5	12	12		7	1.3	5
2020	8	1.4	4	>94%		3.3	14.1	13.4		4.7	1.6	5.7

Traction Drive System

Sub-system and integrated systems meeting targets

Power Electronics

New topologies for inverters & converters, temperature tolerant designs

Electric Motors

Cost reduction, minimization / elimination of rare earth materials

PEEM Thermal Management

Thermal system integration, heat management & thermal stress / reliability

Fuel Cell R&D — *Progress*

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Reduced high-volume cost of fuel cells to $51/kW*, on track to meet $30/kW by 2015

- More than 30% reduction since 2008, 80% reduction since 2002

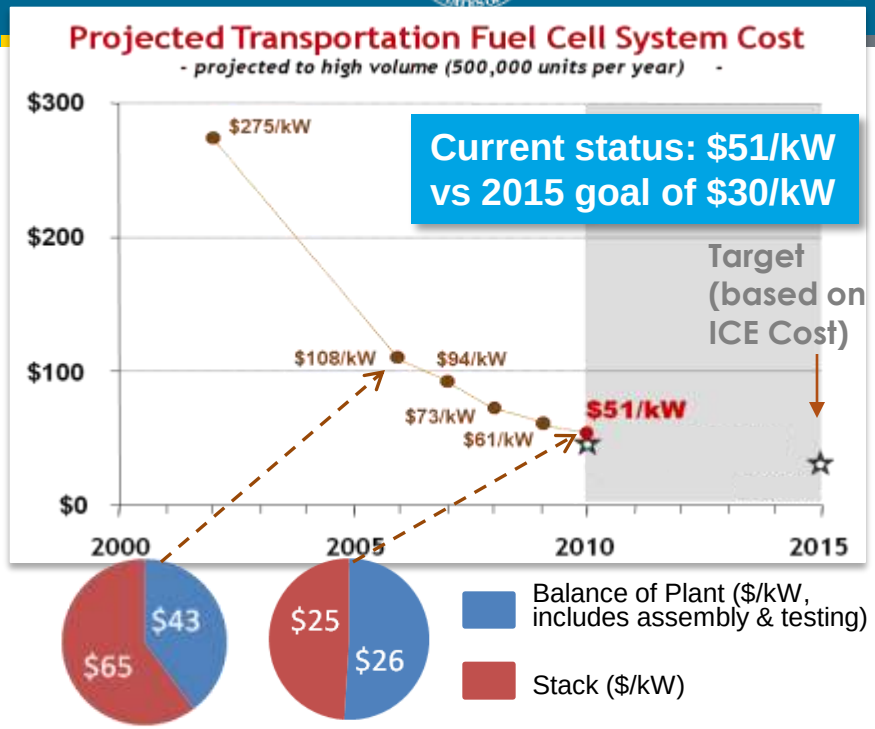
Demonstrated 155 FCEVs and 24 H2 Stations

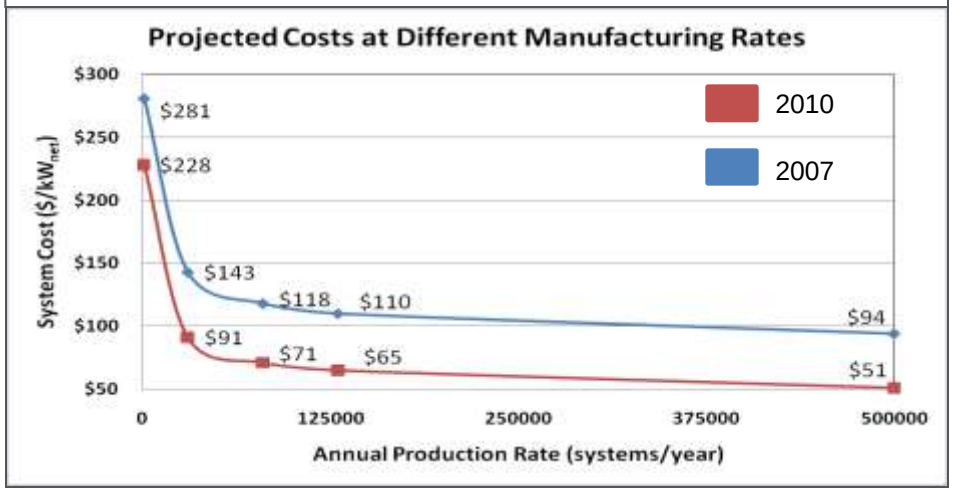
- >3 million miles traveled
- 2,500 (75K miles) durability
- Validated up to 59% efficiency

Validated vehicle that can achieve 430 mi range

***Based on projection to high-volume manufacturing (500,000 units/year).**

Panel found $60 – $80/kW to be a "valid estimate" in 2008: http://hydrogendoedev.nrel.gov/peer_reviews.html





Source: US DOE 10/2010

Hydrogen R&D – Production, Delivery, Storage

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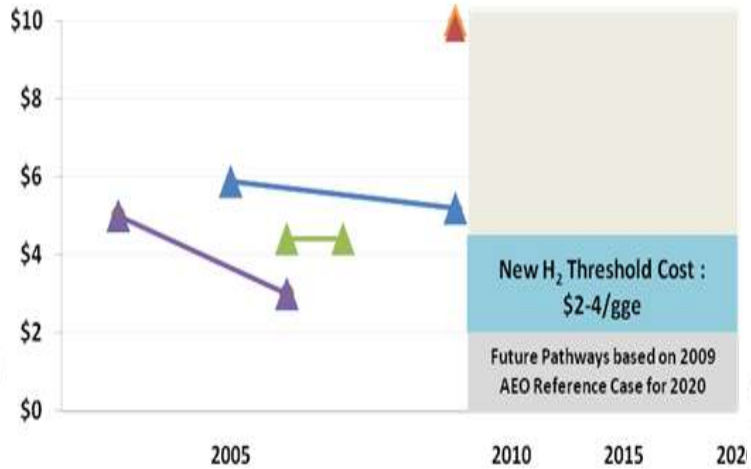
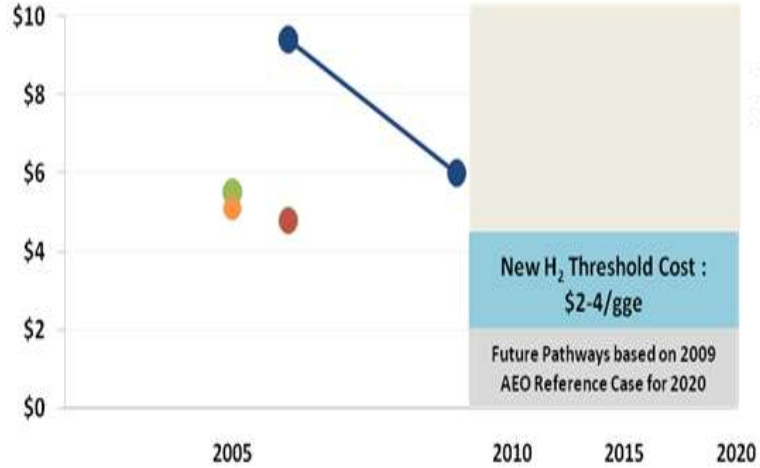
Projections of high-volume / nth plant production and delivery of hydrogen can meet targets for some pathways

NEAR TERM:
Distributed Production
- Natural Gas Reforming
- Ethanol Reforming
- Electrolysis

Low-volume (200 kg/day)
- Steam Methane Reforming
- H_2 from Combined Heat, Hydrogen, and Power Fuel Cell



LONGER TERM:
Centralized Production
- Biomass Gasification
- Central Wind Electrolysis
- Coal Gasification with Sequestration
- Nuclear



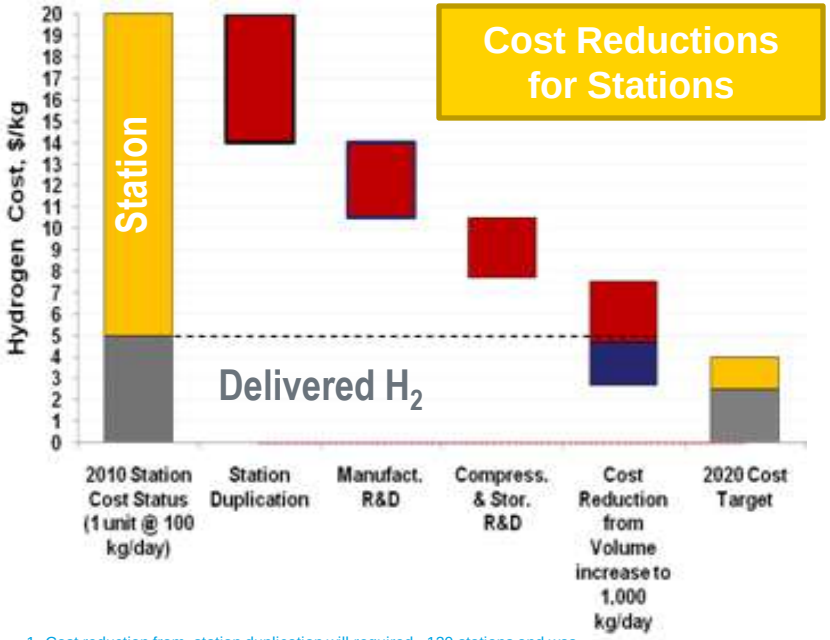
Notes: Data points are being updated to the 2009 AEO reference case. The 2010 Technology Validation results show a cost range of $8-$10/gge for a 1,500 kg/day distributed natural gas and $10-$13/gge for a 1,500 kg/day distributed electrolysis hydrogen station.

We've reduced the cost of H2 delivery*

- ~30% reduction in tube trailer costs
- >20% reduction in pipeline costs
- ~15% reduction liquid hydrogen delivery costs

**Projected cost, based on analysis of state-of-the-art technology*

Cost Reductions for Stations



1. Cost reduction from station duplication will required ~120 stations and was based on 3% reduction for a doubling of capacity. Reference: "A portfolio of power-trains for Europe: a fact-based analysis" by McKinsey & Co.
2. Cost of hydrogen delivered to station is ~$5/kg based on TTC Hydrogen Market Study 2009.
3. Station cost reductions based on ANL Hydrogen Delivery Systems Analysis Model (HDSAM). 4. The Current station cost is based on costs from the current California state funded stations. The capital cost for the station is $2.5 million.. 5. The starting station capacity is 100 kg/day.

H2 Infrastructure Needs to be Addressed

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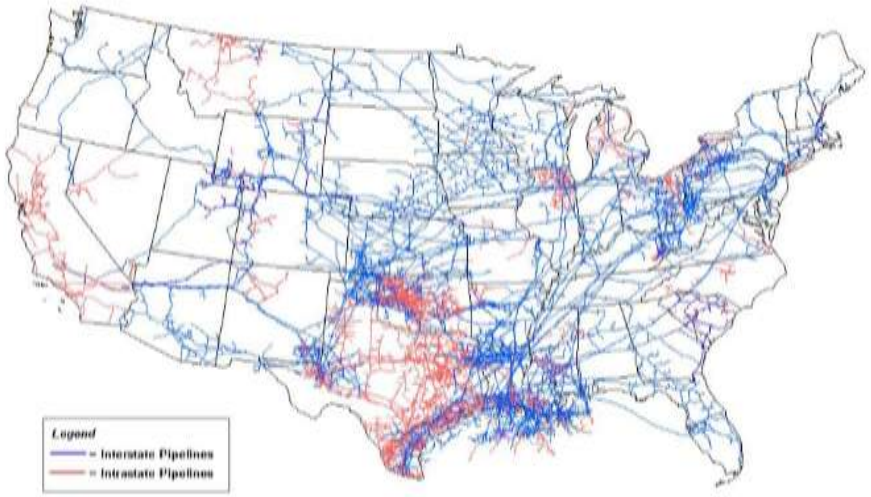
Production & Delivery of Hydrogen

In the U.S., there are:

- ***~9 million metric tons*** *of H_2 produced annually*
- ***> 1,200 miles*** *of H_2 pipelines*

U.S. Natural Gas Pipeline Network, 2009



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

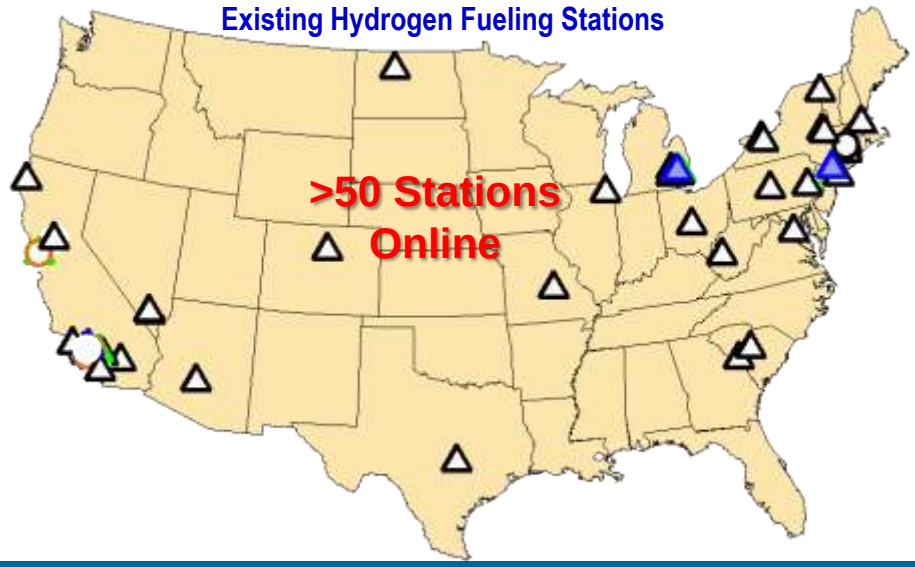
Near Term Strategy

- Use distributed natural gas to produce H2/delivered H2 (H2 and NG infrastructure are similar)

Long Term Strategy

- H2 from diverse renewable and low C sources

Existing Hydrogen Fueling Stations



Recovery Act : $2.0 Billion Manufacturing Supporting Electric Drive

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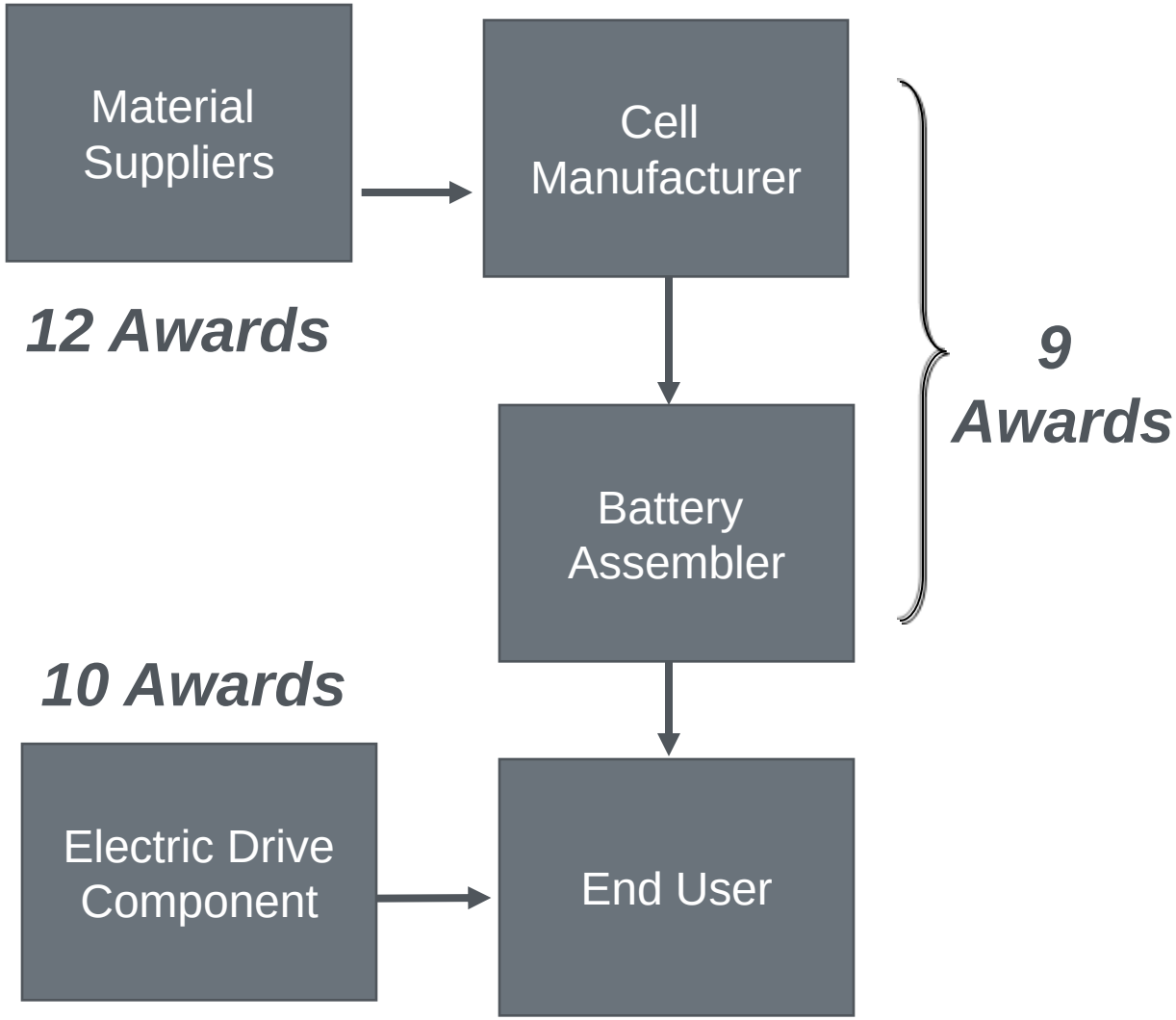
$1.5 Billion in funding to accelerate the manufacturing and deployment of the next generation of U.S. batteries

$500 Million in funding for electric-drive components manufacturing

Integrated Supply Chain



Recovery Act – Infrastructure Activities

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Transportation Electrification Demonstration Projects

Deployment of electric-drive vehicles and charging infrastructure

- Deployment of 13,000 electric-drive vehicles, light-duty through heavy-duty vehicles
- Installation of over 22,000 Level 2 charging sites and 350 (500VDC) Fast Chargers
- Collection of detailed operational data from vehicles and charging infrastructure
  - Driving and charge event data
  - Available via internet
  - Detailed data not available to DOE or through FOIA requests

10 Grants to establish comprehensive educational and outreach programs focused on electric-drive vehicles

- Funding of the first programs to educate first responders and emergency personnel in how to deal with accidents involving EVs and PHEVs

Working with Cities to Install Infrastructure

- On January 26, 2011 Vice-President Biden announced a $200M program to help cities establish charging infrastructure:
  - Establish a comprehensive infrastructure plan
  - Encourage locally-based public and private sector collaboration
  - Leverage federal resources
  - Streamline building permit approval and installation procedures.
  - Initial build-out of the infrastructure.

Summary

- Petroleum dependency and environmental drivers strongly point toward vehicle electrification
- Battery technology and progress is a strong enabler
- FCEVs are also part of the portfolio, longer term
- Recovery Act is establishing required manufacturing base
- Policy initiatives in place
  - CAFE
  - Vehicle Tax Incentive
  - ATVM Program
- Infrastructure build-out has started and new plans are in place to expand
- Meeting 1M EV goal by 2015 does not appear to be constrained by manufacturing capacity – consumer acceptance and existing R&D and policy measures are important to reaching the goal

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