# *Transportation Technology Research and Development*

*Don Hillebrand, Energy Systems Division Director*

*Secretary of Energy Advisory Board Meeting*
*Energy Engineering and Systems Analysis*
*April 2012*

# Argonne's Transportation Research Is Focused on DOE's Energy Resources Goal

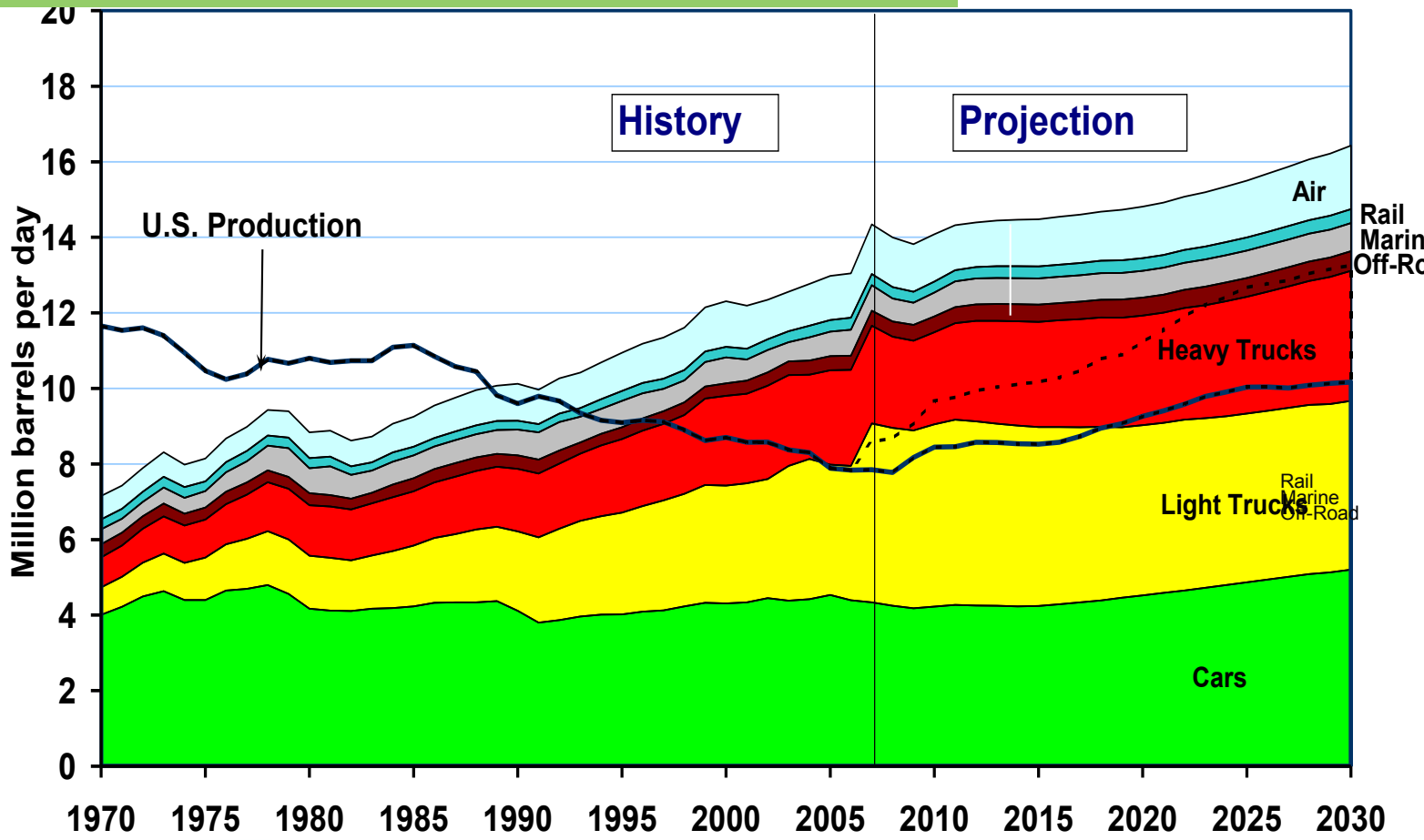
- Improving energy productivity across all sectors, including transportation, is a goal in the Energy Security Theme of the DOE Strategic Plan.

- A strategy to meet that goal is to develop technologies that enable cars and trucks to be fuel efficient, while remaining cost and performance competitive.

# Market Snapshot – Auto Sales have Recovered

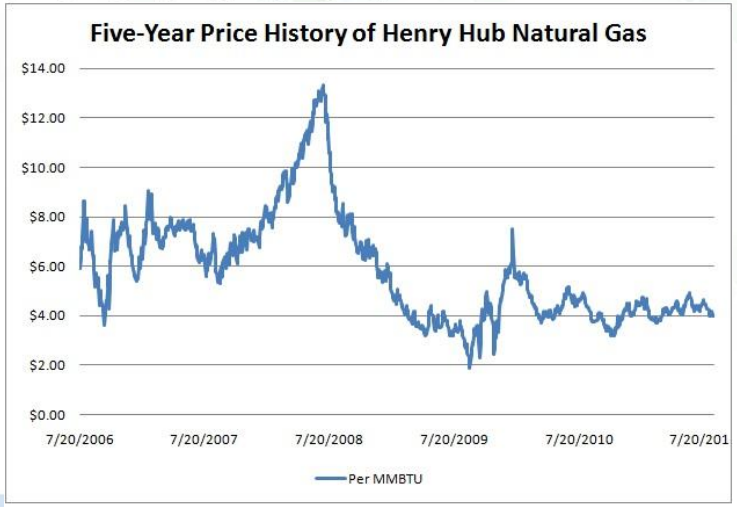
**U.S. Vehicle Market**

- 240 million vehicles on the road
- Approximately 14.5 M new cars & light trucks projected for 2012. Average is 15.7 M/yr 2002-2007
- Hybrid vehicles over 3% of sales



# But Oil Price Volatility Remains


(And Natural Gas appears to be heading down)



# Issues on the Horizon

- Battery Electric vehicle sales disappointments
  - How are they performing?
  - Need time for the energy storage technology to develop and prices to drop
- New White Space in combustion science.
  - Computation Combustion and the opportunities
- Materials advances
  - Battery and Material Scale-up
- Natural gas and oil discoveries.
  - Carbon emissions – is the atmosphere big enough to hold all that carbon?
  - Natural Gas based fuels – How do we use our natural gas resource?

# Among the National Labs, Argonne Has the Lead R&D Role in Several Automotive Fields

- **Hybrid vehicle systems, incl PHEVs**
  - Modeling
  - Benchmarking and evaluation
  - Component integration
- **Engine emissions control**
  - In-cylinder combustion
  - Bio-fuels
  - Natural gas engines
- **Batteries**
- **Fuel cells**
- **Vehicle recycling**
  - Rare Earths
  - Battery Reman
- **Applied materials research**
  - Tribology
  - Nanofluids
- **High-performance computing**
- **Analysis and assessments**

4-wheel drive dynamometer for hybrid vehicle evaluation

Hydrogen Engine Test Stand

MATT HIL
Mobile Automotive Technology Testbed Hardware-In-the-Loop

# ARGONNE'S OBJECTIVE: Provide to DOE and Partners the Best Advanced Vehicle Test Data and Analysis

- **Advanced Powertrain Research Facility (APRF)**
  - Purpose built for DOE benchmarking
  - State-of-the-art 4WD chassis dynamometer
  - Custom multi-input data acquisition specific to hybrid vehicle instrumentation
- Staff at cutting edge of test procedures for new advanced vehicles
- Inventing new and novel instrumentation techniques

**Benchmark**

"Be the eyes and ears of automotive technology development"

APRF since 2002


**Codes and Standards**

Assist in codes and standards development with public and independent data

# Advanced Powertrain Research Facility

- *Enable cold/hot environment for vehicle research and EPA drive cycles, Argonne will be the only DOE-lab with this controlled temperature capability*
- *Study hot and cold effects on batteries, powertrain and influence on vehicle-level control:*
  - *Battery pack system performance*
  - *Thermal management investigations*
  - *Powertrain component and system efficiencies*
- *Investigate accessory use and power consumption impacts of BEV and PHEV energy consumption*
- *DOE – Office of Vehicle Technologies funded facility modification in FY10: $5M Total, $3.5M Capital + $1.5M Equipment*

**EPA 5-Cycle Requirements:**

- **+20 °F (Cold test)**
- **+95 °F (Hot SC03 test)**
  - **Solar Load**
  - **Proportional Air Flow**
- **+72 °F UDDS, HWFE and US06 drive cycles**

# Samples of Advanced Technology Vehicles tested in the APRF

- Hybrid vehicles
- Plug-in hybrid vehicles
- Battery Electric vehicles
  - Mini E
  - Tesla
  - Auto X
  - Leafs
- Alternative fuel vehicles
  - Biofuels, Diesels, Hydrogen…
- OEM proprietary prototypes
- Plug-in hybrid conversion vehicles
- Conventional vehicles

BEV Tesla

Mini-E

ANL PHEV prototype

Prototype

Leaf

Many different EVs

PROGRESSIVE AUTOMOTIVE X PRIZE

Supplier BEV prototype

Ford TADA PHEV

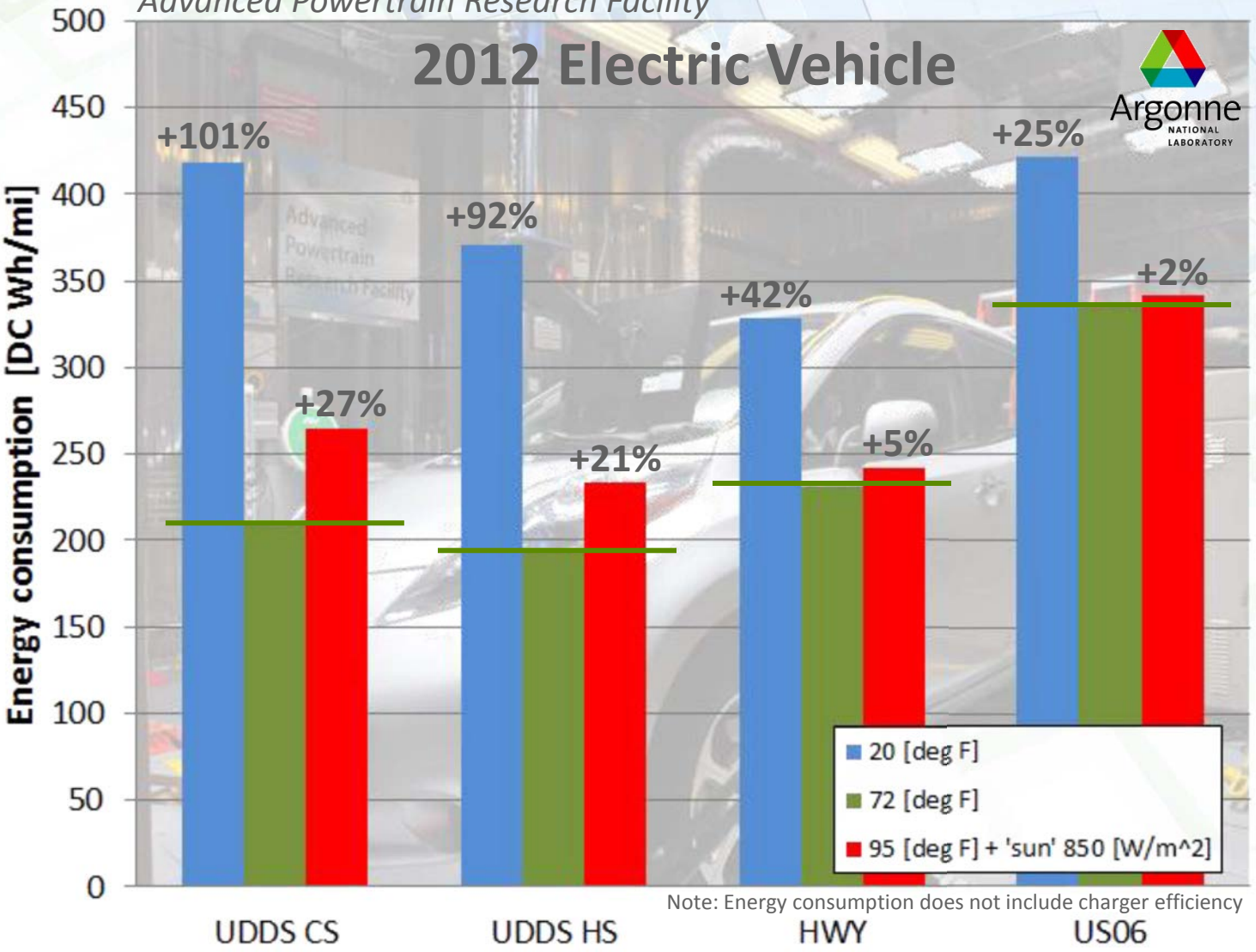
Jetta TDI (bio-fuels)

Fuel cell

Hydrogen internal combustion engine

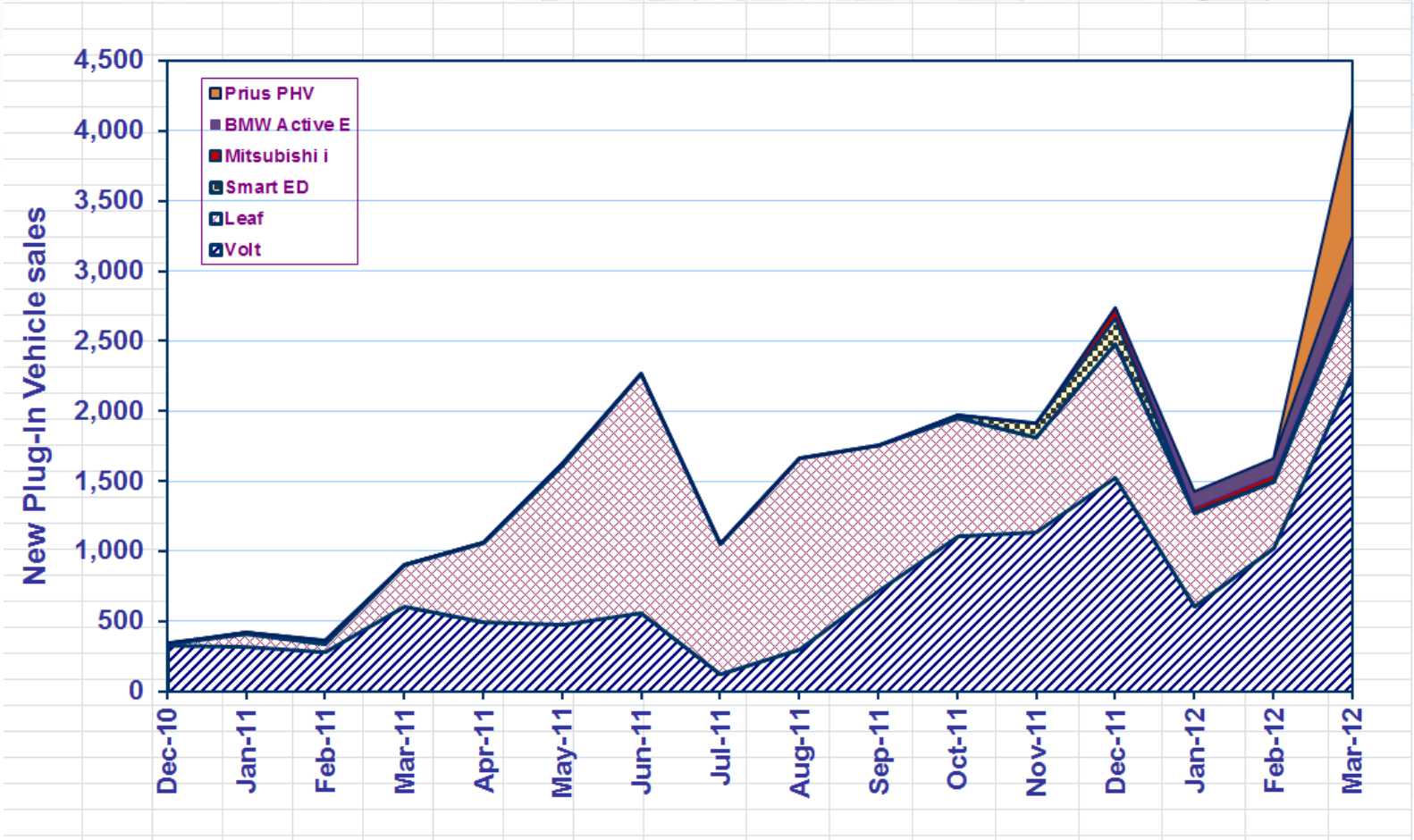
# Impact of Temperature on Energy Consumption

*Advanced Powertrain Research Facility*




Note: Energy consumption does not include charger efficiency

# SALES: Battery Electric Vehicles are Struggling, PHEVs look very promising



# Transformer Sizing – BEVs are huge

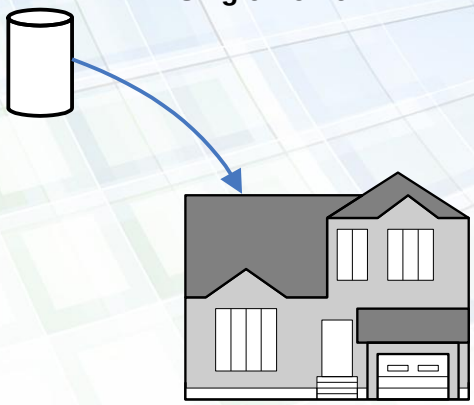
## Typical home loads and service
(sized for average, not peak demands)

| | Totals | Watts AC | Heat |
|---|---|---|---|
| Sink Disposal | 1,000.00 | 1,000.00 | 1,000.00 |
| Water Heater | 2,400.00 | 2,400.00 | 2,400.00 |
| Garage Door | 1,500.00 | 1,500.00 | 1,500.00 |
| Dish Washer | 1,600.00 | 1,600.00 | 1,600.00 |
| Clothes Dryers | 5,000.00 | 5,000.00 | 5,000.00 |
| Oven | 1,500.00 | 1,500.00 | 1,500.00 |
| Range | 1,500.00 | 1,500.00 | 1,500.00 |
| AC compressor | 4,000.00 | | |
| condenser fan | 240.00 | | |
| air handler | 345.00 | 4,585.00 | |
| heat coils | 15,000.00 | | 18,845.00 |
| space heater | 3,500.00 | | |
| Pool pump | | | |
| Lighting | 1,200.00 | 1,200.00 | 1,200.00 |
| Plazma TV | | | |
| Other | | | |
| | 38,785.00 | 20,285.00 | 34,545.00 |
| Less heat and AC | | 15,700.00 | 15,700.00 |
| BEV | 19,200.00 | 19,200.00 | 19,200.00 |
| PHEV | 3,300.00 | 3,300.00 | 3,300.00 |

| Peak Values | | | | |
|---|---|---|---|---|
| | BEV added | 57,985.00 | 39,485.00 | 53,745.00 |
| | PHEV added | 42,085.00 | 23,585.00 | 37,845.00 |
| | Both | 61,285.00 | 58,485.00 | 72,745.00 |

**Single Transformer Single Home**

10kVA

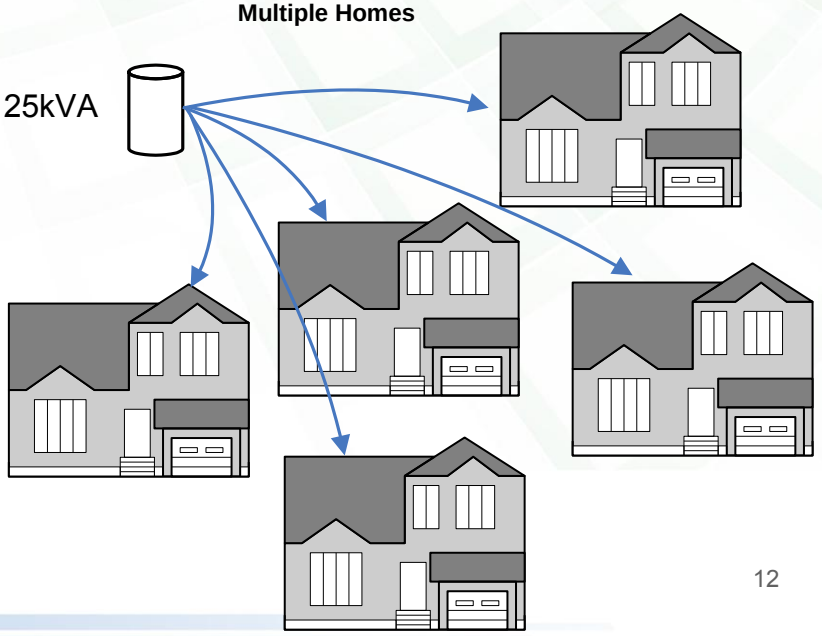


**Overloads - 140% for brief periods of time, 3-4 hours**

**2007 heat-storm data, at 1 am the average home load was still 5.5 kw**

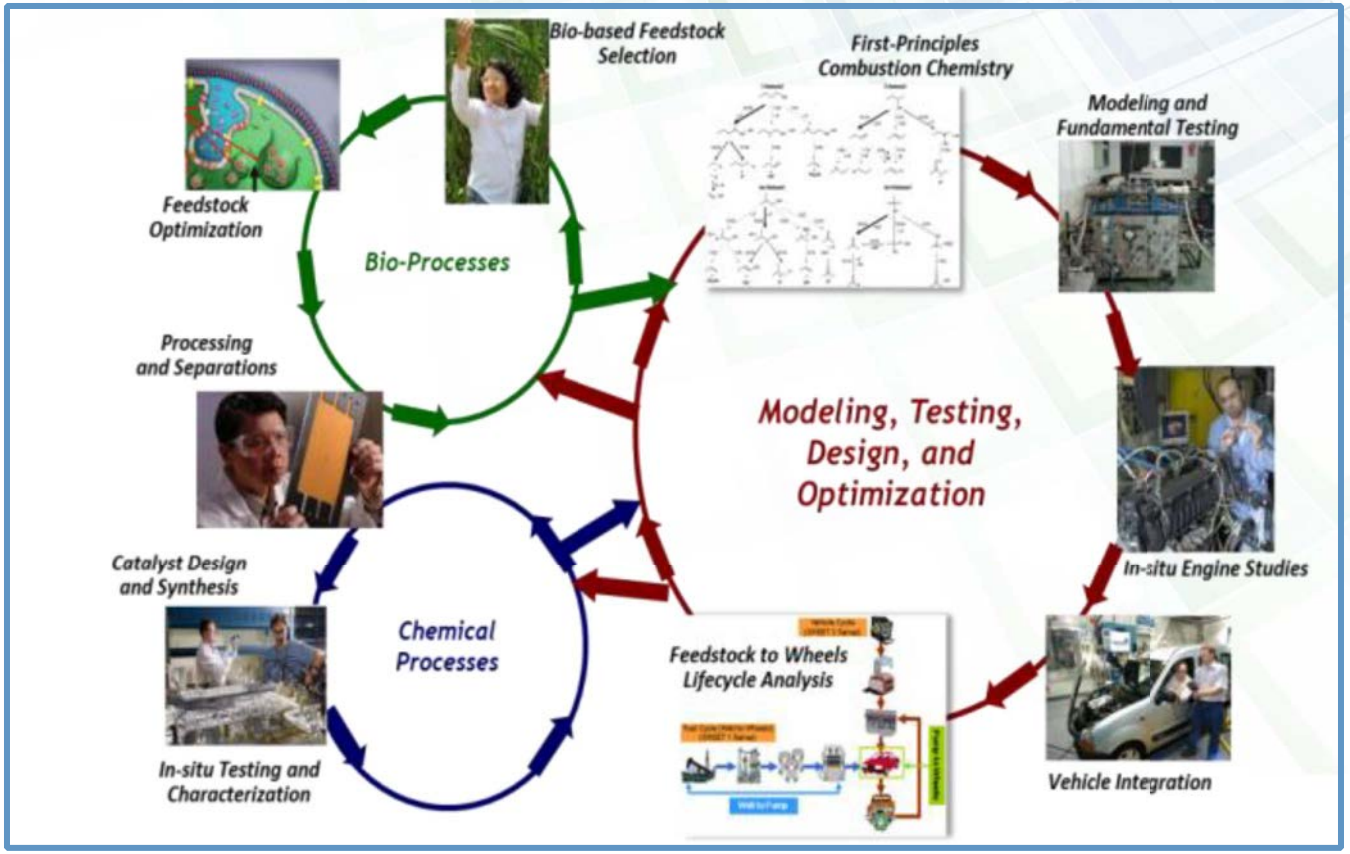
**Single Transformer Multiple Homes**

25kVA



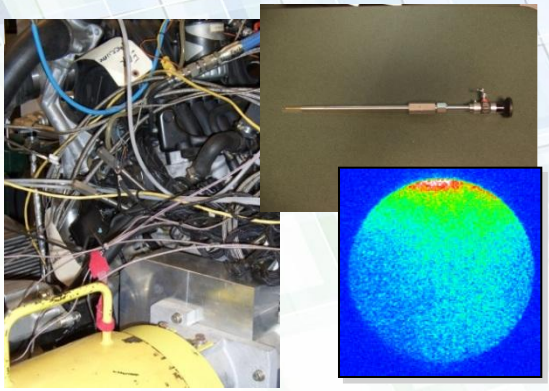
# Argonne Combustion Research

- *Integrated Basic/Applied Development combustion science*
- *Advanced Photon Source (APS) for injector spray research and nozzle design*
- *Applied combustion research*
- *Computational Facilities*

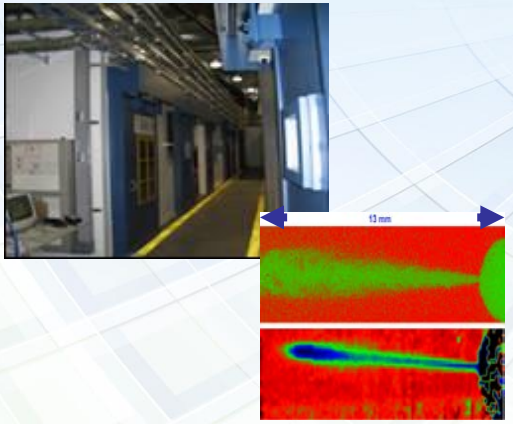


# The Vision: A Center of Competence for Combustion Modeling and Simulation

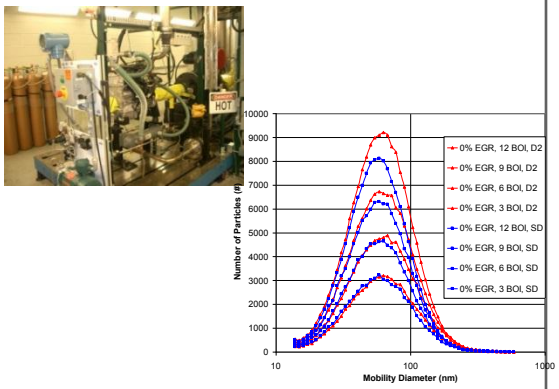
**Basic and Applied Combustion Research**
- Computational Expertise
- Engine Development



**Advanced Combustion Testing**
- Endoscope
- Advanced Gasoline
- Rapid Compression Machine

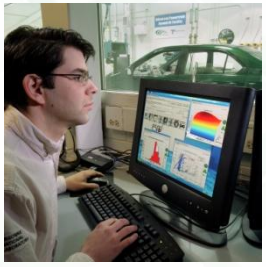



**Advanced Photon Source**
X-rays for fuel spray and combustion research




**Alternate Fuels Development**
- Ethanol, Biodiesel,
- Hydrogen and Natural Gas

**International Collaborations**
- Industry
- Universities
- Government Agencies



High Performance Computing

# High-Performance Computing Initiative

## External Collaborations: Caterpillar , Cummins, Chrysler and Convergent Science

**Objective** of this project is to identify the fundamental benefits of massive parallel computing capability on engine simulation. Specifically, we will answer the question of "*what are we able to learn through taking advantage of massive parallel hardware, that we could not have learned with our current hardware limitations*".

1) Can engine models run massively parallel?

Yes, it has been run on 1000 processors with 30 million cells at Argonne clusters!

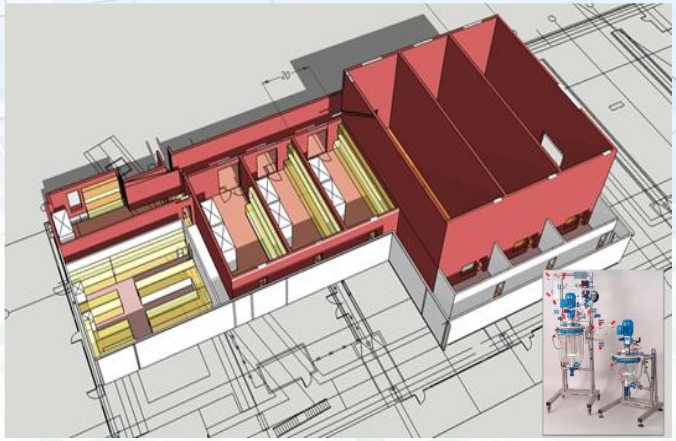
Current industry state-of-the-art is 25-50 processors with 2-3 million cells.

2) How is the scalability and efficiency?

Scalability is poor due to load-balancing issues during piston motion leading to communication time > computational time

# Advanced Battery Materials Manufacturing R&D

- *Advanced Battery Materials Synthesis and Manufacturing R&D capability provides unique resource to support domestic manufacturing---facility endorsed by A123, BASF, EnerDel, Johnson Controls, SiLyte*
- *Leverages Argonne's capabilities in battery chemistry development:*
  - *Experimental materials---10-100g batches*
  - *Material validation---~10kg*
  - *Process validation---~100kg*
- *Argonne funding provided by Division (royalty), LDRD, DOE and DoD/Tardec*



*Concept drawing of Argonne's Materials Engineering Facility. The facility is rated for high-hazard materials. The 13,000 sq.ft. facility will be operational in 2012. Interim facilities are operational.*

# The Materials Engineering Research Facility (MERF)

- 10,000 sq. ft. facility consists of “Group-H occupancy” pilot labs and high bay spaces.
- All interim labs will be relocated to the MERF, starting in April.
- 50% DOE – 50% DoD funded

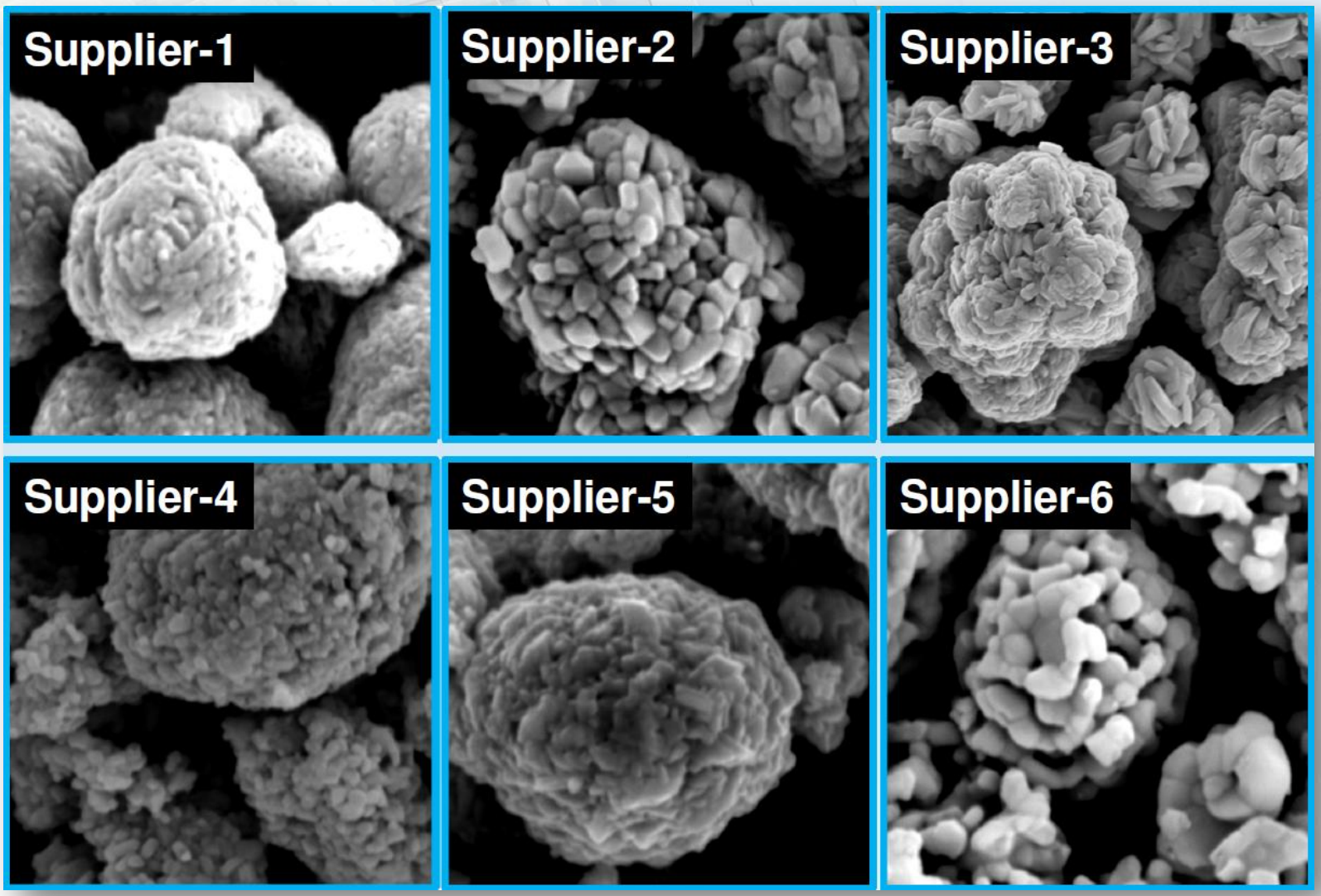
Analytical Lab

Pilot Labs (benchtop)

Pilot Labs (walk-in)

High Bay Spaces

# $LiNi_{1/3}Co_{1/3}Mn_{1/3}$ From 6 Suppliers



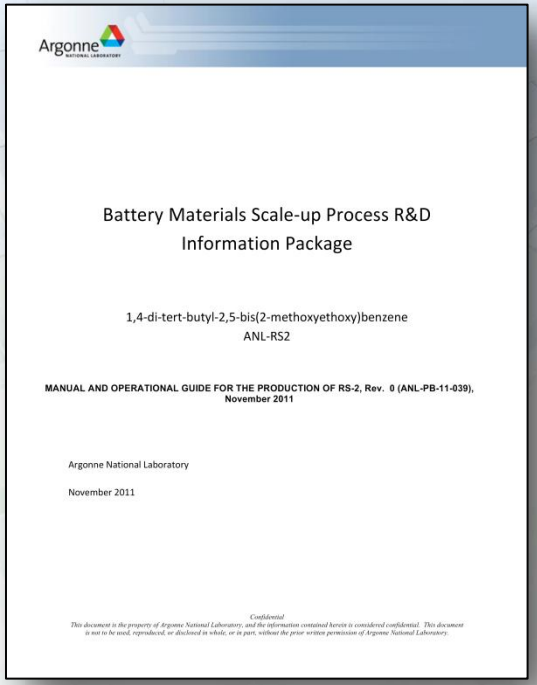

The same chemical composition does not mean the same performance!

# Electrolyte Materials Scale-up R&D Progress

| Material | Status |
|---|---|
| ANL-RS2 | Scale-up R&D complete – Kilogram quantities available |
| 1NM3 | Scale-up R&D complete – Kilogram quantities available |
| 2SM3 | Scale-up R&D complete – Kilogram quantities available |
| ANL-RS6 | Scale-up R&D complete – Kilogram quantities available |
| LiDFOB | In progress |
| 1S1M3 | In progress |

# Technical Accomplishments and Progress
# Redox Shuttle ANL-RS2

- Technology Transfer Package was created.
- Process technology patent filing is in progress.
- Samples of the material were supplied for evaluation to researchers and industry - and license signed.


Argonne NATIONAL LABORATORY

Battery Materials Scale-up Process R&D
Information Package

1,4-di-tert-butyl-2,5-bis(2-methoxyethoxy)benzene
ANL-RS2

MANUAL AND OPERATIONAL GUIDE FOR THE PRODUCTION OF RS-2, Rev. 0 (ANL-PB-11-039), November 2011

Argonne National Laboratory

November 2011

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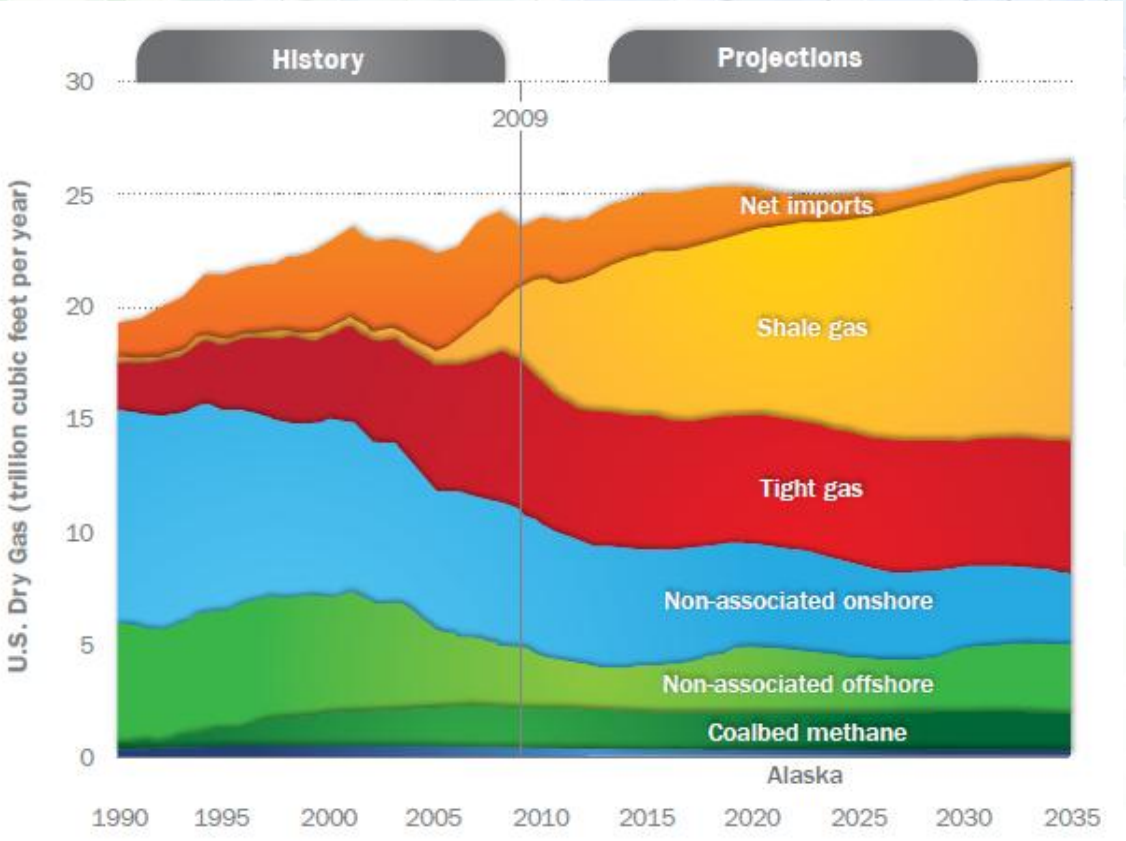
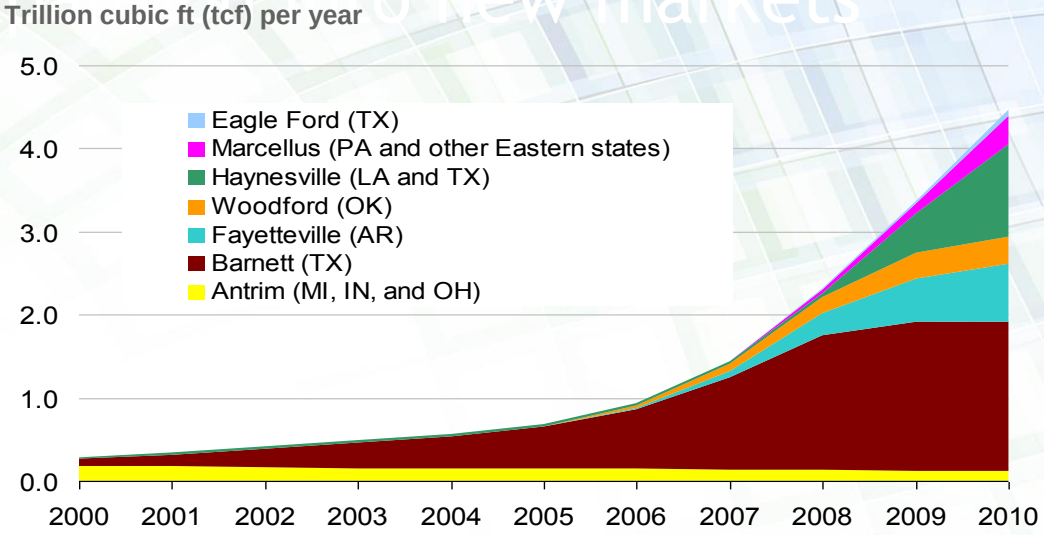
# *The US is awash in natural gas* gas


- Over 40 states have natural gas resources
- Reserves and production forecasts have doubled
- Reserve-to-production ratios have climbed from ~10 to >100 years



# Shale gas production is and will continue to grow rapidly expansion into new markets

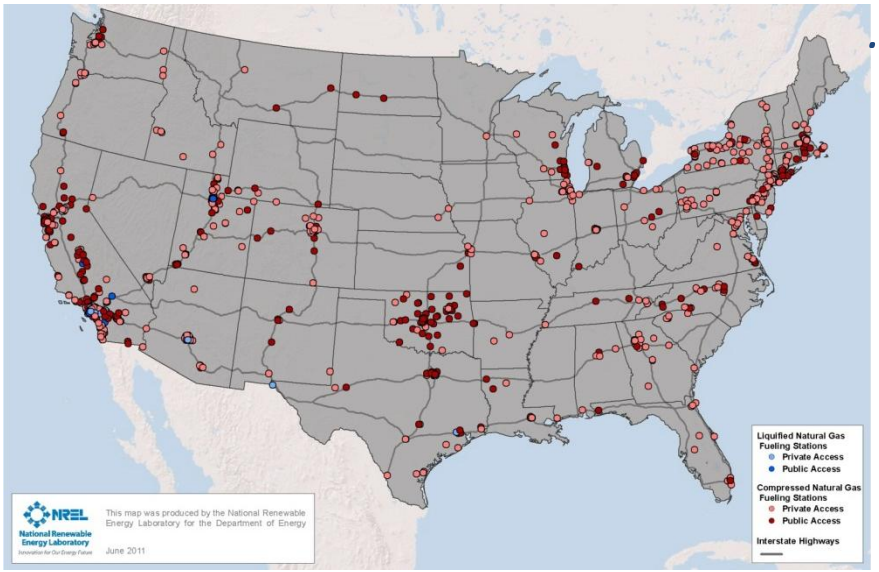



R. Newell, Dec. 16, 2010.

Photo courtesy of American Clean Skies Foundation

- Gas production grew 17%/year from 2000 to 2006; 48%/year from 2006 to 2010
- Total production expected to triple from 2009 to 2035 in EIA's Reference forecast, but there is uncertainty about the size of the technically recoverable resource base.
- Of 22 shale basins in the US only 7 are now producing significant oil or NG
- New technologies have uncertain energy and environmental implications

# Fueling infrastructure, particularly for LNG, is a major challenge



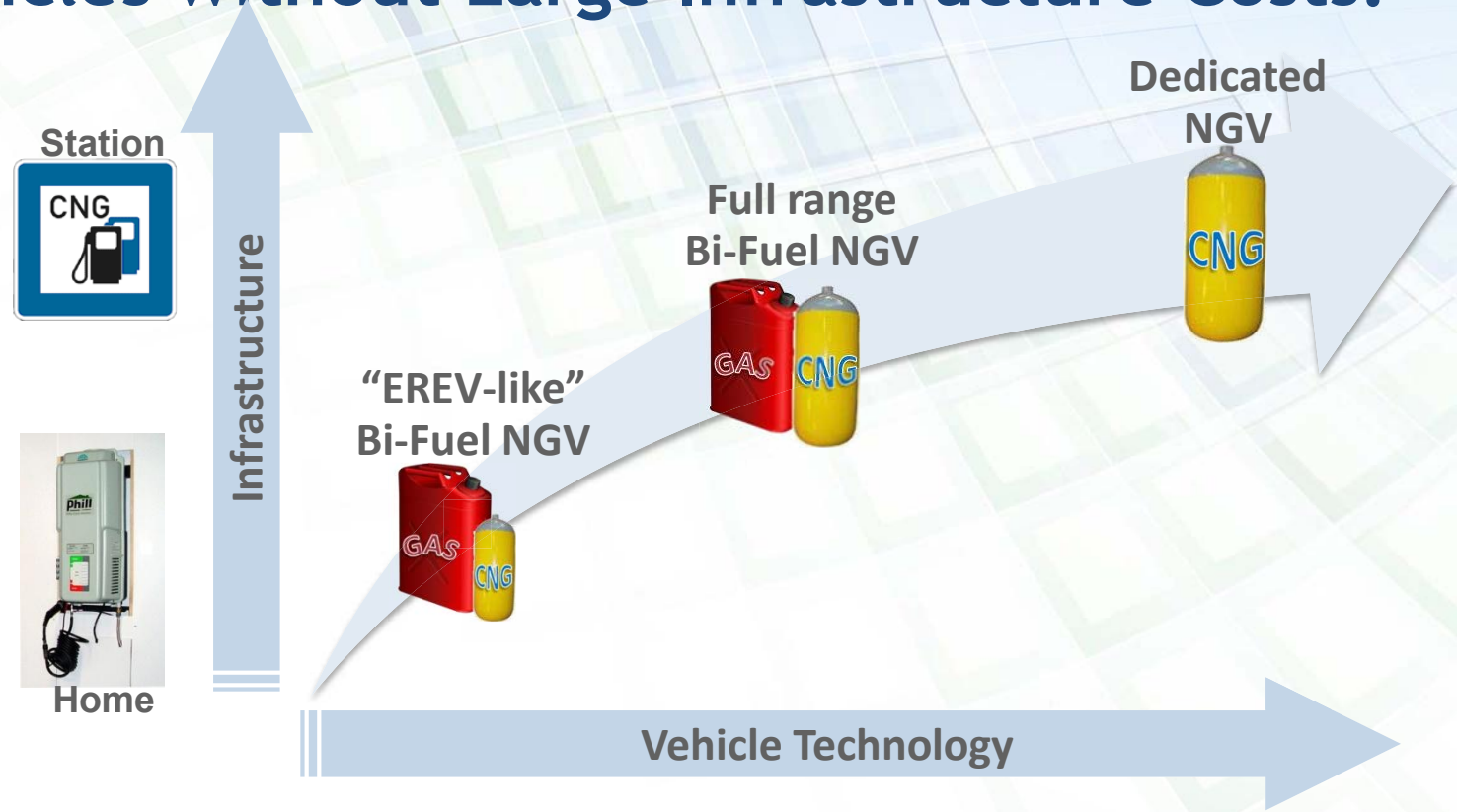

Melendez, M. and M. Mintz, *Natural Gas Alley*, Clean Cities Stakeholder Summit, Indianapolis, June 28, 2011.


Grace, P. *America's Natural Gas Fueling The Future of Transportation*, Sept. 22, 2011

## …but a step change may be underway

- As of May 2011, 885 CNG and 44 LNG stations were in operation in the US
- Less than half (386 CNG and 17 LNG) were open to the public
- In July 2011, Clean Energy announced plans for "America's Natural Gas Highway", with 150 LNG stations at Pilot Flying J Travel Centers within 2 years
- CNG stations are also coming on line with assistance from DOE's Clean Cities, ARRA (~130 alone) and other government sources. Some (Fair Oaks, ……) will sell CRNG

# A Strategy to use U.S. Natural Gas Scenario for LD Vehicles without Large Infrastructure Costs.




**Vehicle System** (Architecture, sizing, integration)

| Add-on CNG | Integrated system | Optimized platforms |
|---|---|---|

**Combustion System**

| Bi-Fuel (low tech) | Bi-Fuel (high tech) | Single fuel (high tech) |
|---|---|---|

# Consider The Following Comparison

## EREV PHEV

- Alternative fuel for **35 miles**
- Domestic and clean alternative fuel
- High battery costs (~$10-15k)
- 177 kg for 35 miles
- Charger costs
- High cost hybrid drive system with high-power electric motors
- Fast charging challenges
  - Battery management, infrastructure costs per vehicle

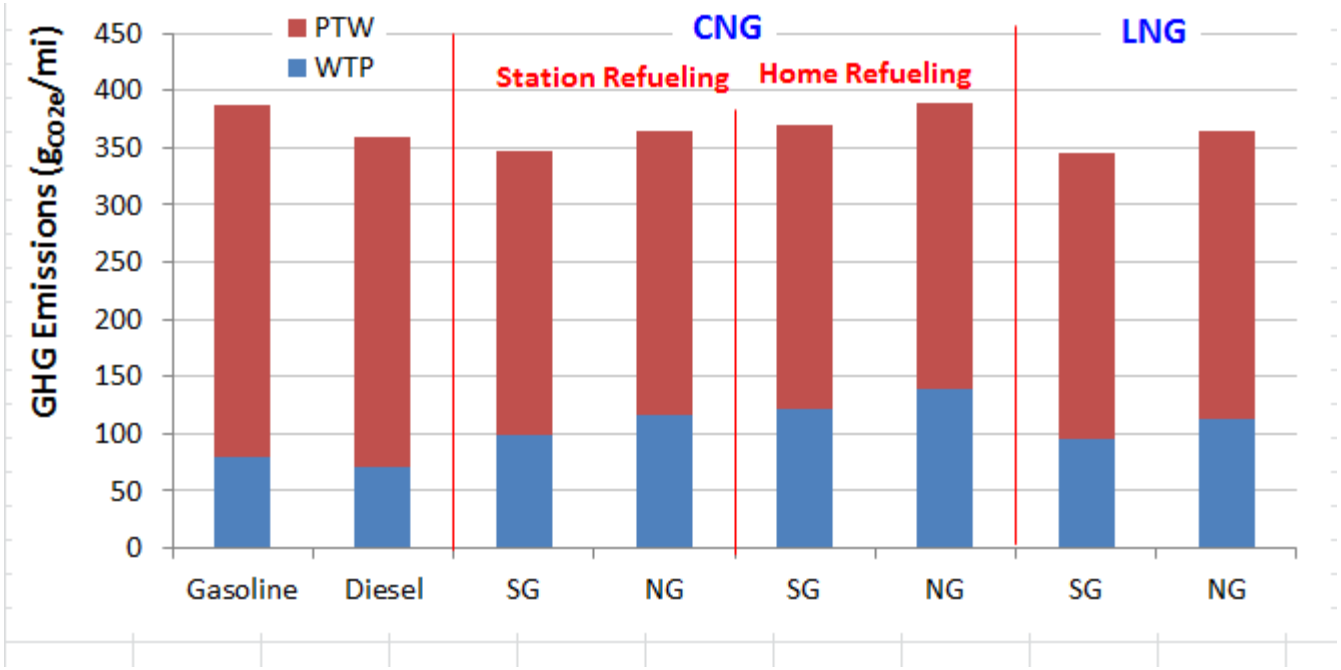
## Bi Fuel CNG

- Alternative fuel for **50-100 miles**
- Domestic and clean alternative fuel
- Moderate CNG tank costs (<$1k)
- 50 kg for 100 miles (est)
- Compressor costs similar to charger costs
- No HEV needed, less sensitive to ambient temperatures
- Fast refill – CNG stations
  - Refueling infrastructure more expensive than gasoline, but much less than fast charge

**AT HOME "PLUG IN" ALT FUEL CARS**

# But the carbon emission benefits are minor

- CNG vehicles may have reductions in WTW GHG emissions relative to gasoline vehicles.
- LNG vehicles may have a little higher GHG reductions.
- CNG vehicles with shale gas (SG) has a small incremental GHG reduction benefit relative to those with conventional natural gas (NG).
- Home CNG refueling has WTW GHG penalty of 6 percentage points relative to CNG station refueling because of high electricity consumption for the former.



# Conclusion: Coming Trends in Vehicle Research

- The ICE is not dead and will continue to dominate
- Oil price remains the driver.
- Battery Electric Vehicles are going to have a hard time making it – PHEV's not so hard.
- Natural gas may be a game changer – but is the atmosphere big enough for all that carbon?
- New Energy Policies will shift toward cost and carbon