NREL
NATIONAL RENEWABLE ENERGY LABORATORY

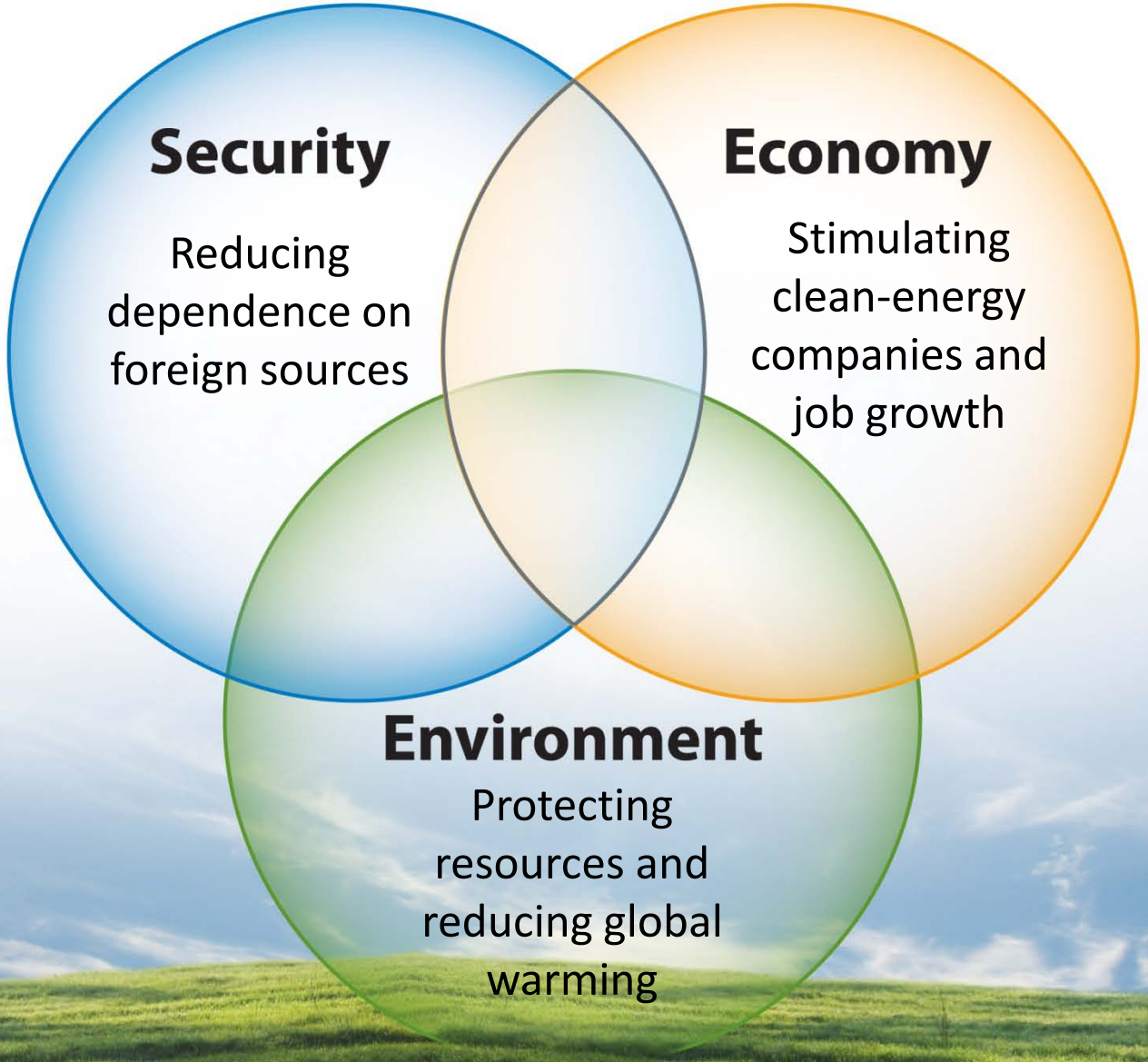
Clean Energy Innovation Through Deliberate Science

European Energy Conference
Maastricht, Netherlands

April 18, 2012

Dr. Dan E. Arvizu
Laboratory Director

National Energy Imperatives



A Profound Transformation is Required

Today's U.S. Energy System

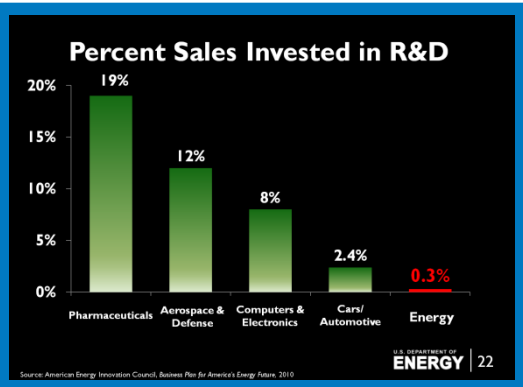
- Dependent on foreign sources
- Subject to price volatility
- Increasingly vulnerable energy delivery systems
- 2/3 of source energy is wasted
- Produces 25% of the world's carbon emissions
- Role of electricity increasing

TRANSFORMATION

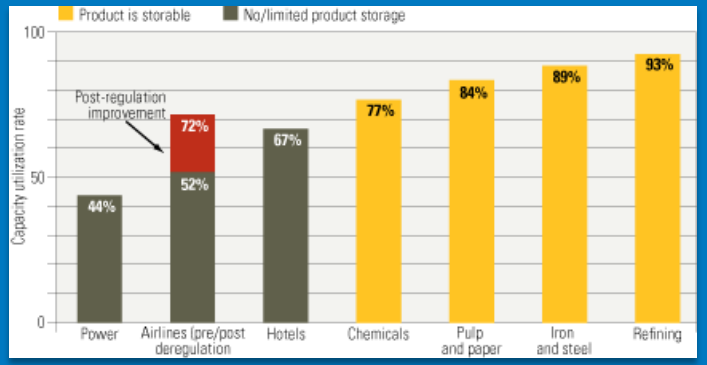
Sustainable Energy System

- Carbon neutral
- Efficient
- Diverse supply options
- Sustainable use of natural resources
- Creates American jobs
- Accessible, affordable and secure

Energy Sector Challenges



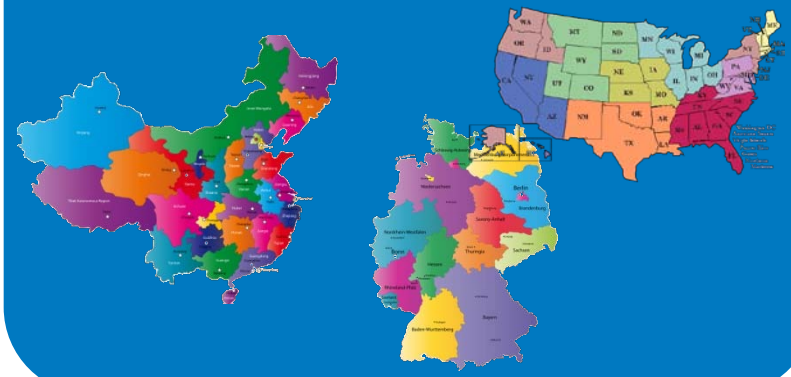
R&D Investment Drives Innovation



Asset Utilization

Capital Intensive with Long Life Cycles

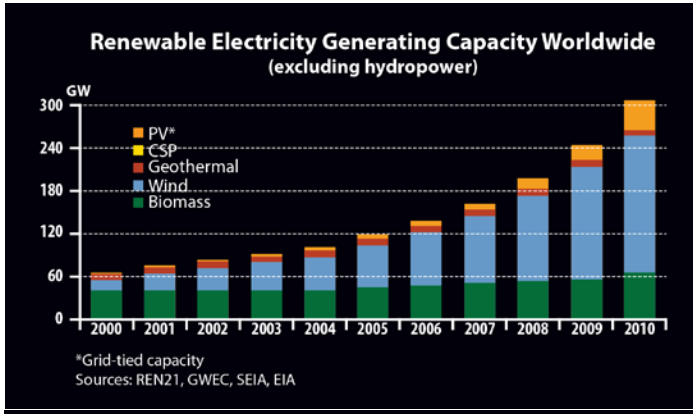
National Strategies Driving Energy Market

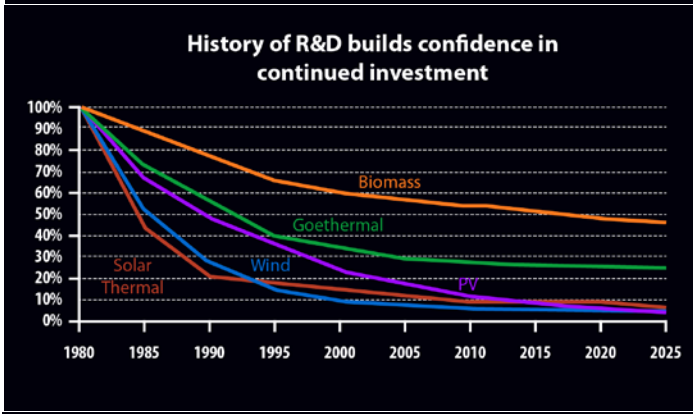


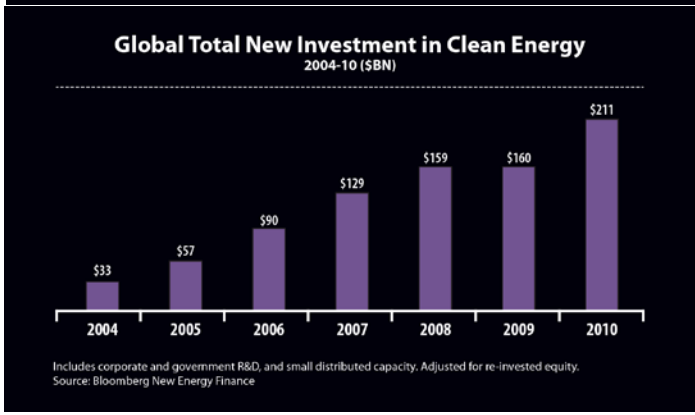
Decade of Global Progress

Increasing Capacity, Improving Efficiency, Reducing Costs, Expanding Investment

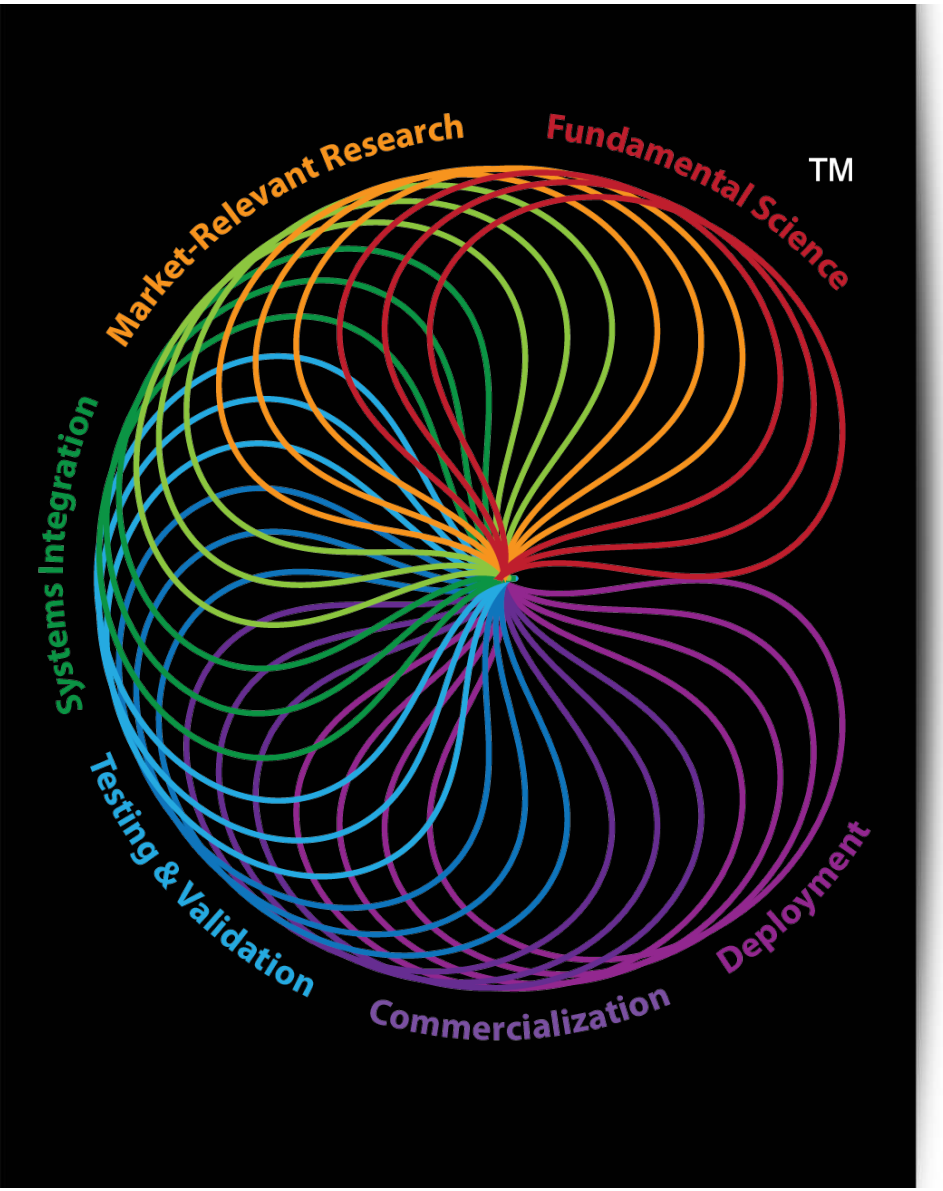
- Wind power capacity increased by a factor of 10 – to more than 200 gigawatts
- Solar PV capacity grew by factor of 30 – to approximately 35 gigawatts
- Biofuels emerged as a major industry – producing approximately 28 billion gallons annually
- LEED-certified commercial buildings increased to more than 10,000
- Costs reduced significantly – approaching grid parity
- Clean energy investment grew from $33B in 2004 – to $211B in 2010







innovation Through *Deliberate Science*



Spectrum of Energy Innovation

From Science through Deployment

- Comprehensive approach to innovation
- Collaboration with private industry
- Connects science to the marketplace
- Delivers market-relevant technologies and competitive clean-energy products

innovation Impact


Natural Gas—In the News

THE WALL STREET JOURNAL. | MARKETS

MARKETS | December 31, 2011

Natural Gas Ends 2011 at 27-Month Low

Can Natural Gas Break Our Oil Habit?

It is cleaner and more abundant, but it won't free America from foreign energy

By THOMAS K. GROSE

March 5, 2009 | RSS Feed | Print

denverpost.com

US natural gas supplies grew last week

PRINT EMAIL 0 COMMENTS

The Associated Press

POSTED: 04/12/2012 09:15:10 AM MDT
UPDATED: 04/12/2012 09:17:50 AM MDT

THE ASSOCIATED PRESS April 11, 2012, 3:52PM ET text size: T

US natural gas boom leads to decade-low price

The New York Times

Business Day
Economy

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH

OFF THE CHARTS

Why One Gas Is Cheap and One Isn't

By FLOYD NORRIS
Published: March 30, 2012

The New York Times

Business Day
Energy & Environment

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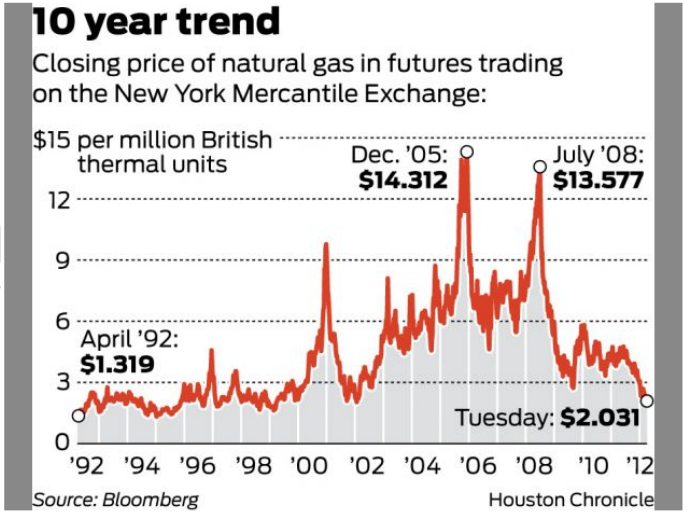
Natural Gas Signals a 'Manufacturing Renaissance'

Michael F. McElroy for The New York Times.

Clean Energy in partnership with Pilot Travel Centers opened up a liquid natural gas truck filling station in Seville, Ohio.

By JIM MOTAVALLI
Published: April 10, 2012

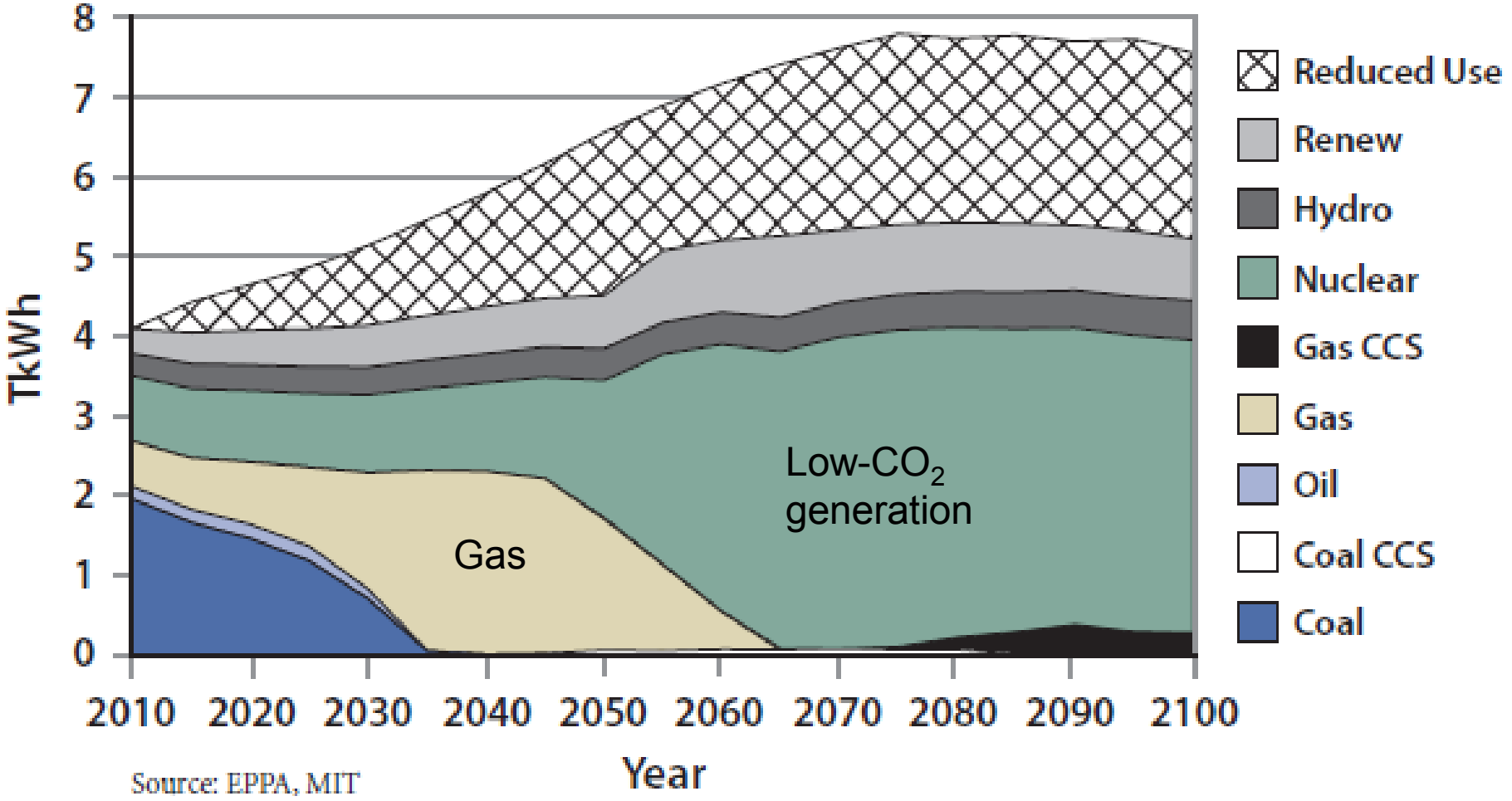


The Washington Post with Bloomberg

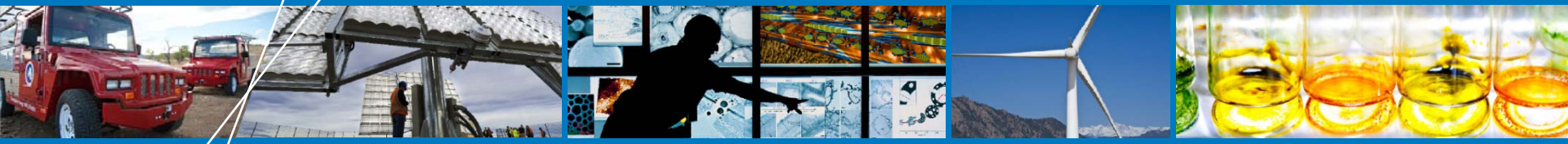
BUSINESS *Where Washington and Business Intersect*

New drilling technique leads to vast supplies and cheaper energy bills for homes, businesses

MIT Future of Natural Gas Study



Source: EPPA, MIT



Status of the Technologies

Innovation for the Future

Integration:

- Integrating renewable energy at all scales

Solar:

- Lowering cost of solar energy systems by 75% by 2020

Biofuels:

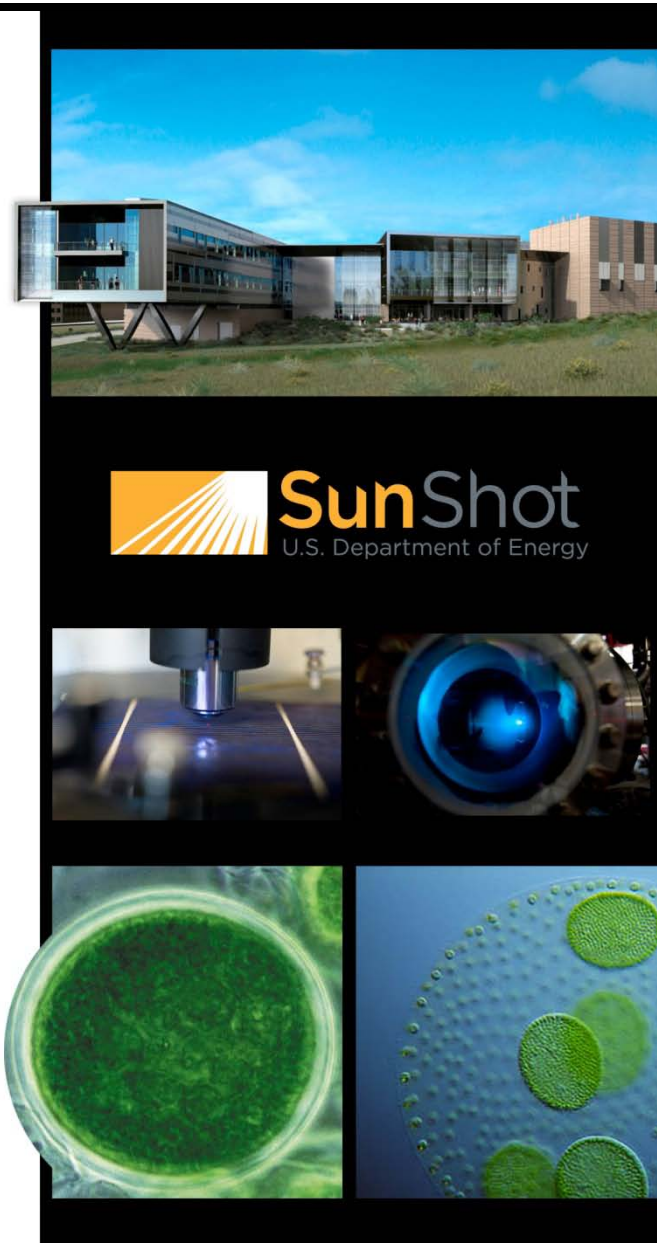
- Advanced biofuels – enabling cost-effective refining into transportation fuels

Wind:

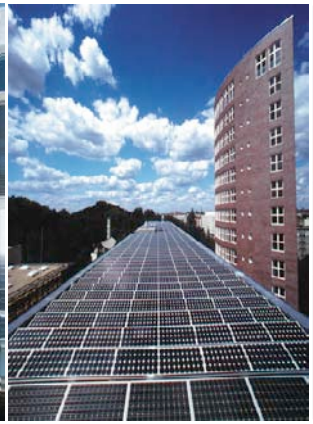
- System and component reliability, resource modeling and forecasting

Efficiency:

- Whole building systems integration
- Battery performance



Solar Electricity: *State of the Technology*

Photovoltaics (PV)

- Market: Residential; Commercial, Utility
- Geographically diverse
- kWs to MWs to GWs
- U.S. Capacity: 4.0 GW
- U.S. Forecast: 22+ GWs in pipeline
- Costs. $3 to $7/W: *LCOE 7 to 16¢/kWr
- Technologies: Conversion; thin-films, crystalline silicon. Storage; battery

Solar Thermal Electric (CSP)

- Market: Commercial; Utility
- Geographically confined to “sun bowls”
- MWs to GWs
- U.S Capacity: 0.5 GW
- U.S. Forecast: ~6 GWs in pipeline
- Costs. $4 to $8/W: *LCOE 12 to 20 ¢/kWr
- Technologies: Conversion; parabolic troughs, central receivers, dish. Storage; thermal, up to 15 hours.

*With federal incentives; e.g. the FTC.

Updated: April 2012
Source: GTM/SEIA : U.S. Solar Market Insight Q4 2011 & 2011 Year-in-Review

Market Relevant Process Innovation

"Black Silicon" Nanocatalytic Wet-Chemical Etch

natcoretechnology
advancing solar science

2010 R&D 100

Flash Quantum Efficiency System

2011 R&D 100

FlashQE

HelioVolt

COMPANY PRODUCTS TECHNOLOGY PARTNERS CAREERS CONTACT

ANNOUNCEMENTS

HELIOVOLT IN THE NEWS

PV-Tech.org
Lone Star CIGS: HelioVolt comes back out into the light, re-enters thin-film PV fray »

GIGAOM
HelioVolt Raises $8.5M in Debt, Close to Prime Time? »

Revolutionary CIGS thin-film manufacturing process using inket printing

HelioVolt

R&D 100
2008

DUPONT innovaLIGHT

English | 中文

COMPANY TECHNOLOGY NEWS CONTACT

THE WORLD'S BEST SOLAR CELLS JUST GOT BETTER
with Innovalight solar technology.

Raise Efficiency and Lower Cost Per Watt in Under 90 days

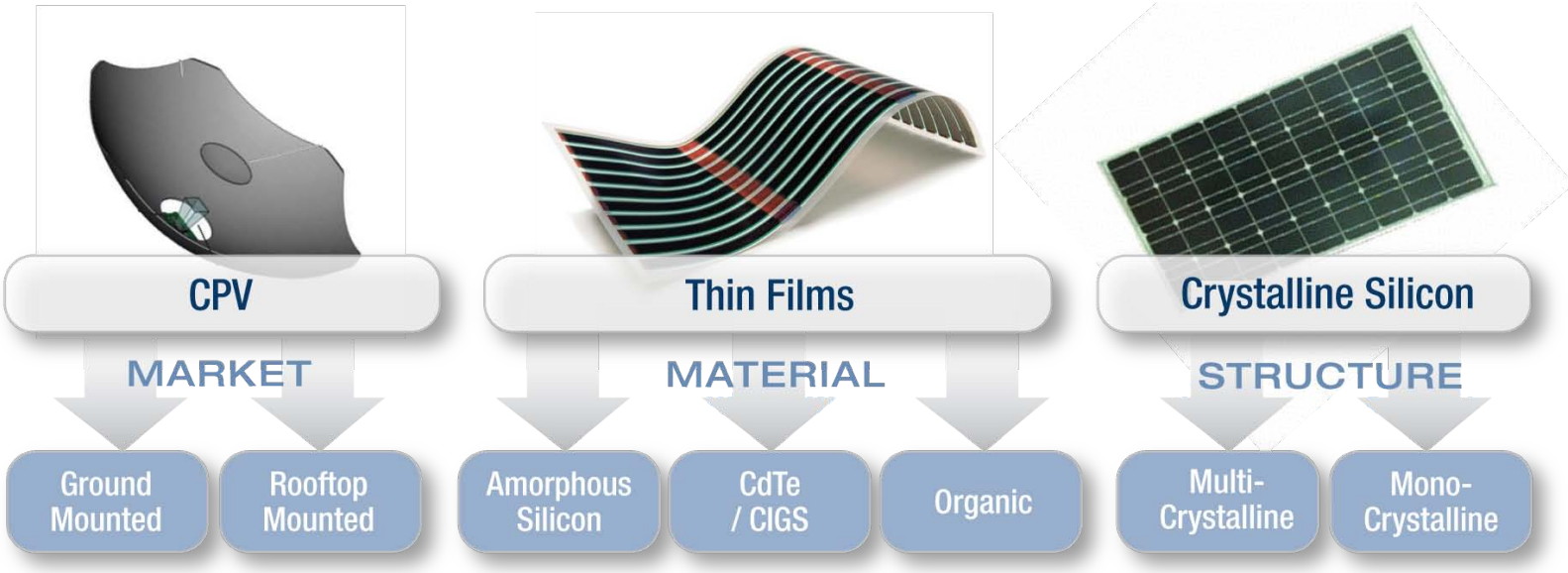
Innovalight's patented technologies cost effectively increase the conversion efficiency of crystalline silicon solar cells. The easy-to-implement technologies improve cell manufacturers' existing factory output and reduce production costs.

LEARN MORE

Silicon Ink NREL Incubator Project

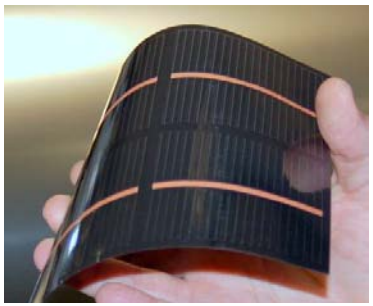
2011 R&D 100

Pursuing a Range of Promising PV Technologies

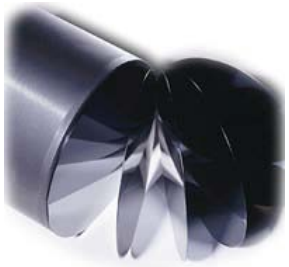


20x-100x

500x

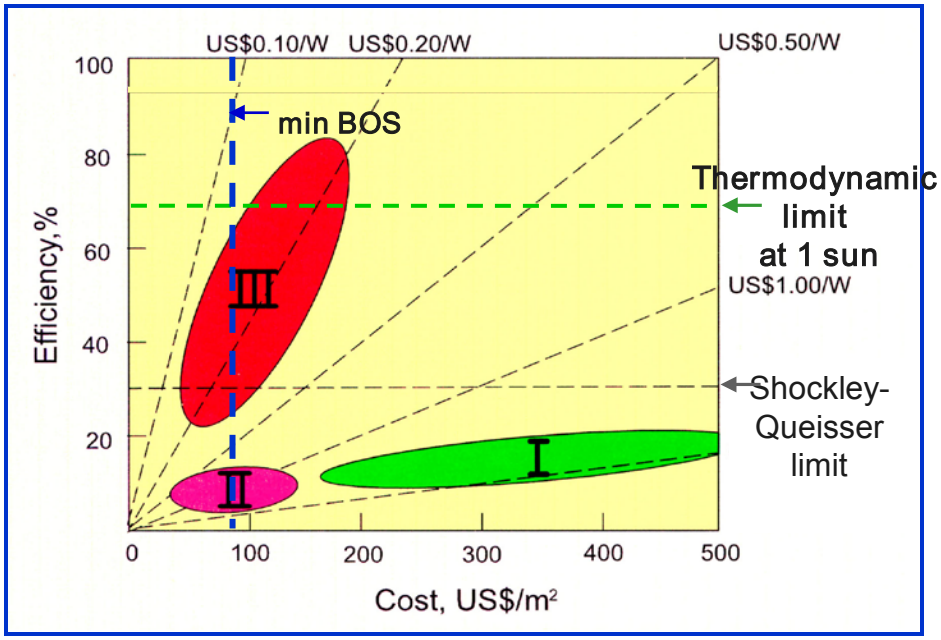


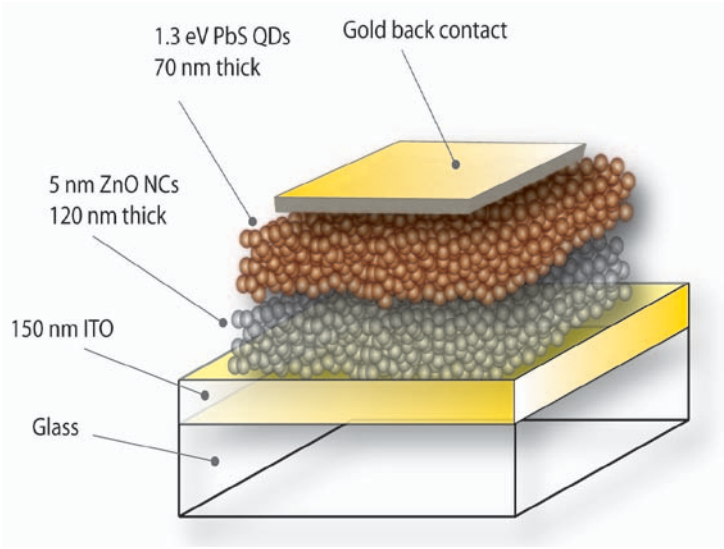
Cu(In,Ga)Se_2 ~ 1-2 um

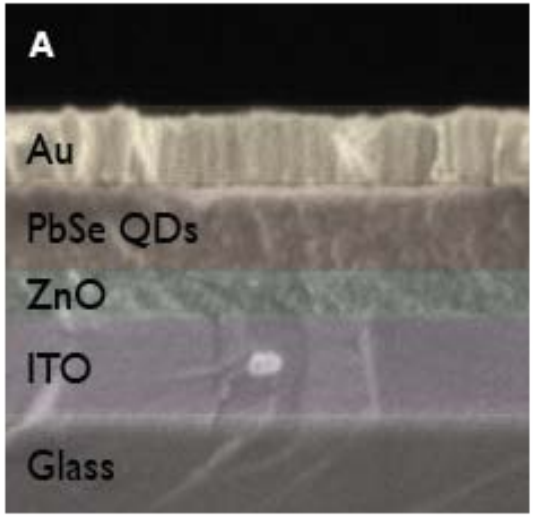


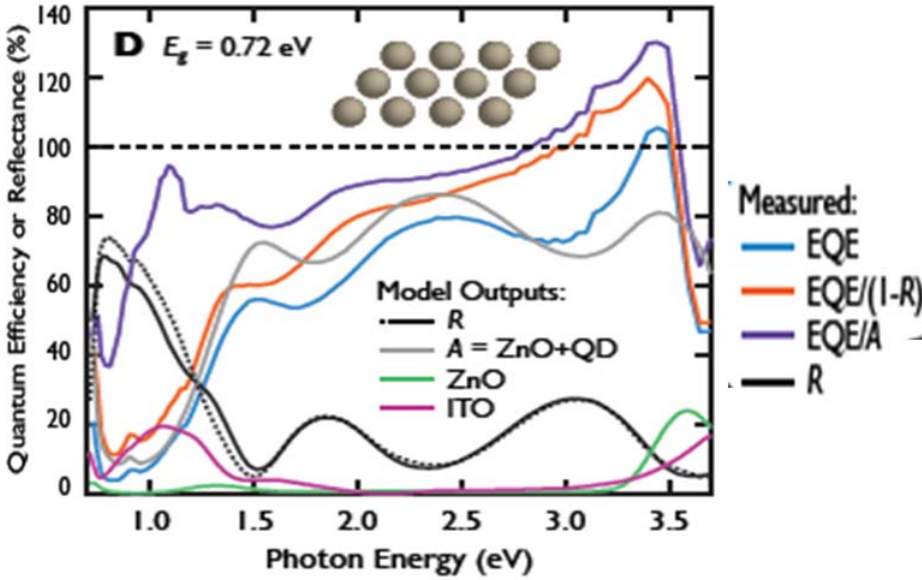
c-Si ~ 180 um

Solar Science Innovation

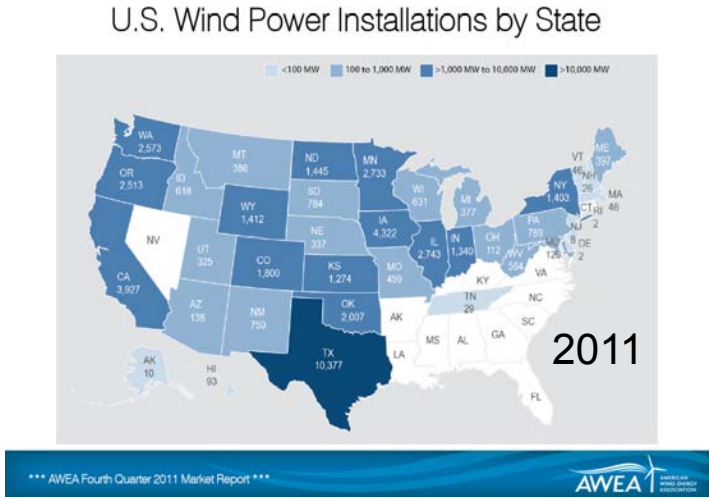








Wind energy: *State of the Technology*



- Costs: 7-10 cents/kWh LCOE*
- Installed wind project cost = $2,155/kW
- 1.5-3.0 MW commercial turbines are typical
- 10 MW prototype machines in development
- Direct drive generators more common
- Variable speed and grid-friendly operation
- Technologies targeting offshore wind markets

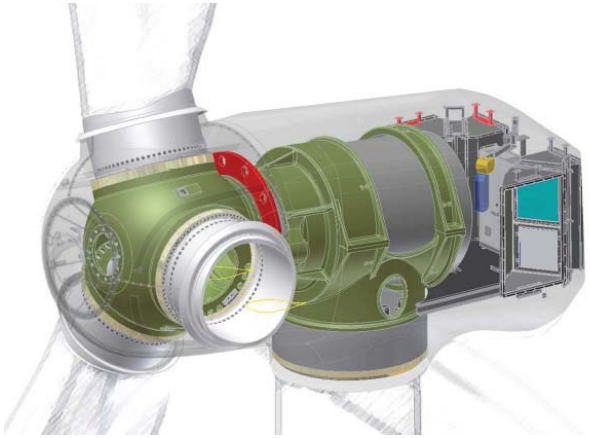
- U.S. installed capacity = 46.9 GW (12/2011)
- 38 of 50 states have utility-scale wind with 14 states > 1,000 MW installed
- Over 8.3 GW currently under construction
- U.S. wind capacity represents more than 20% of the world's installed wind power
- U.S. wind percentage of electricity is over 2.3%
- Over 400 manufacturing facilities across the U.S. make components for wind turbines

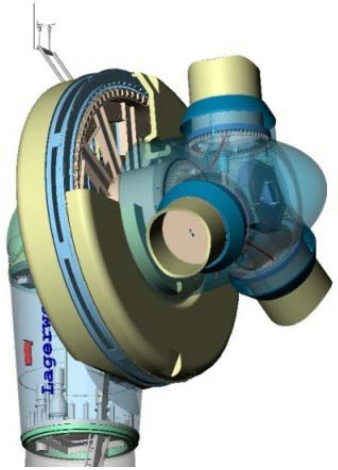
Updated: April 2012

* Estimate for utility-scale wind, class 4 wind sites, no subsidies

Wind Technology Innovation

- Modular large components – blades, drivetrains, and tall towers
- Advanced drivetrain power conversion systems – superconducting direct drive generators
- Flexible, ultra-large rotors and systems
- Active controls for structural load reduction, improved wind plant performance, and grid-friendly operation
- Floating offshore wind turbines
- Airborne wind power systems





Biofuels: *State of the Technology*

Current Status:

U.S. produced 13.5 billion gallons of ethanol and 1.1 billion gallons of biodiesel (2011)

Biorefineries:

- 219 commercial corn ethanol plants
- 180 biodiesel refineries
- 28 cellulosic ethan

Cost goal:

Cellulosic ethanol—cost parity with gasoline by 2012

Major Technology Directions:

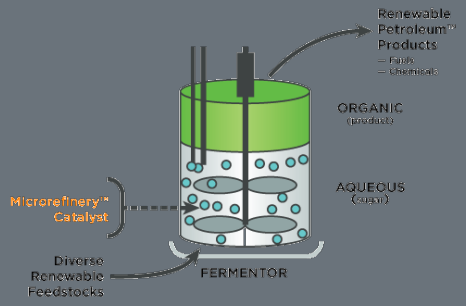
- Foundational Science: Enzymes, fermentation, understanding biomass and cell composition
- Feedstocks: Sustainable feedstock production systems
- Pretreatment & Conversion R&D: Biochemical and thermochemical conversion processes
- Advanced Biofuels and Algae: Broadening RD&D beyond cellulosic ethanol to address “drop in’ and high-energy content fuels from algae and other biomass resources

Updated: 4/2012

Biofuels Innovation

New conversion technologies are being developed, offering the possibility of revolutionary, high volume methods for producing biofuel hydrocarbon fuels for our trucks, trains, ships, and aircraft . . .

Biological Conversion



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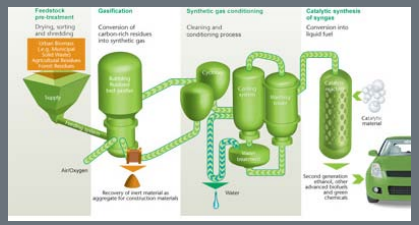
AMYRIS

Chemical Catalytic Conversion



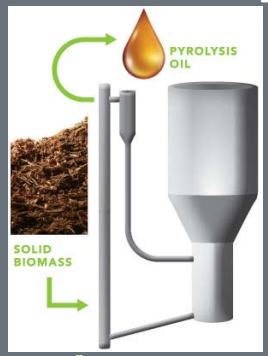
VIRENT
IT'S ABOUT TIME

RENTECH®

ClearFuels®
TECHNOLOGY, INC.

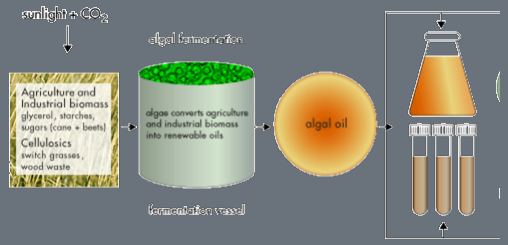
Enerkem

Pyrolysis/Bio-Oil Pathways



Envergent
TECHNOLOGIES
A Honeywell Company

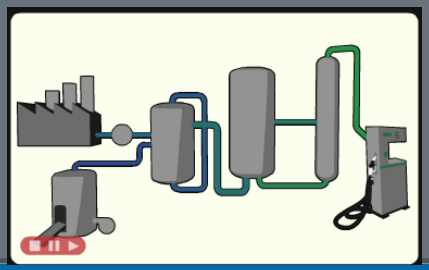
Heterotrophic Algae Conversion



solazyme®

MARTEK
life enriched™

Hybrid Conversion Technologies



LanzaTech

coskata

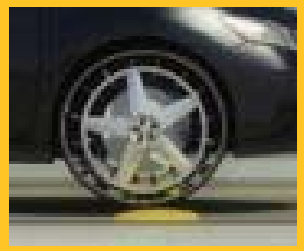
Transportation Innovation

Portfolio of technologies leading to 54.5 mpg

Degree of electrification (power electronics & energy storage)

Start/stop

Regenerative braking



Low rolling resistance tires

Electric infrastructure

Electric powered steering

Light weighting

8 speed transmissions

Turbocharging, direct fuel injection, advanced combustion

Variable cylinder mgmt

Improved aerodynamics

Diesel powered & or Alternative Fuels, H2

Buildings Innovation

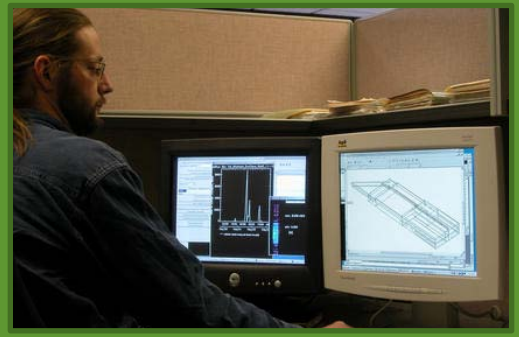
High Performance Buildings

BIPV Products & PV-T Array

Compressorless Cooling

Electrochromic Windows

Polymer Solar Water Heaters



Computerized optimization & simulation Tools

Research Support Facility

Efficiency/Integration Innovation

- **Buildings**
- **Whole building systems integration**
- Computerized building energy optimization tools
- Advanced HVAC (Heating Ventilating and air conditioning)
- Cost effective ultra energy efficient retrofits

Grid Integration

Interconnection Standards

- IEEE Standards Development
- Standards Testing and Validation

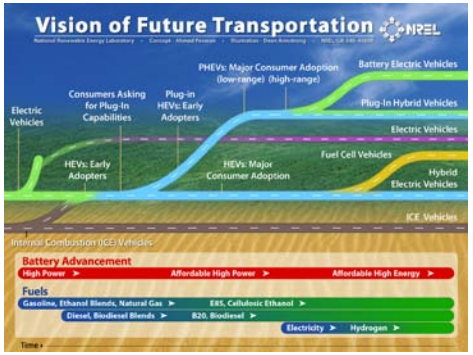
Smart-Grid Data Hub

RE Grid Integration

- Power Electronics for Interconnection monitoring and control
- Grid-to-vehicle interface

Advanced Vehicles

- Fuels utilization
- Component technologies
- Electric vehicle-to-grid interface



To achieve a clean energy vision, we must…

- Invest in innovation
- Invent the future we desire
- Improve access to capital
- Partner on a global scale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May 2011