Addressing America’s Energy Challenges

Steven E. Koonin
EWNP Symposium
Duke University
March 8, 2012
Report on the First Quadrennial Technology Review
Report DOE/S-0001

September, 2011
TODAY’S ENERGY LANDSCAPE
U.S. Energy Flows in 2009

Total energy input is approximately 95 Quads

Source: Lawrence Livermore National Laboratory
Energy supply has changed on decadal scales

U.S. Energy Supply Since 1850

Source: EIA
U.S. Energy Challenges

Energy Security

Monthly Spot Price OK WTI

$/bbl

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
<td>150</td>
<td>160</td>
<td>170</td>
<td>180</td>
<td>190</td>
<td>200</td>
<td>210</td>
<td>220</td>
<td>230</td>
<td>240</td>
<td>250</td>
<td>260</td>
<td>270</td>
</tr>
</tbody>
</table>

Competitiveness

Global Lithium-ion Battery Manufacturing (2009)

Other 2%
U.S. 1%
South Korea 27%
Japan 46%
China 25%

Environmental Impacts

CO2 Emissions in OECD vs non-OECD Countries

Worldwide Shipments of Solar Photovoltaics (MW)

Water Withdrawals in % By Category (2005)

Thermoelectric Power

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Public supply</td>
<td>11</td>
<td>1</td>
<td>31</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquaculture</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
U.S. Energy Flows in 2009

Total energy input is approximately 95 Quads

Source: Lawrence Livermore National Laboratory
Six Strategies

ENERGY SUPPLY
- Deploy Clean Electricity
- Modernize the Grid

ENERGY DEMAND
- Increase Building and Industrial Efficiency

STATIONARY
- Deploy Alternative Hydrocarbon Fuels
- Electrify the Vehicle Fleet

TRANSPORT
- Increase Vehicle Efficiency
The Transport Logic

We are coupled to a global oil market

- Balance of payments, high and volatile prices, insecurity, GHGs
- Demand is growing, easy resource is concentrating
Trends in U.S. Consumption, Production, and Net Imports of Petroleum and Other Liquid Fuels, 1949-2010

Source: EIA
The United States gets close to 50% of its petroleum imports from the Western Hemisphere and less than 20% from the Persian Gulf.

Global Liquids Production, 1990-2035

(Total includes crude oil, natural gas liquids, and biofuels). Constant U.S. conventional production is projected. (EIA, Annual Energy Outlook 2011). For reference, both Gulf of Mexico crude and corn ethanol productions increased by 0.8 million barrels per day over a decade.

Source: EIA
US liquid fuel use

U.S. liquid fuels consumption
million barrels per day


History

2009

Projections

Biofuels including imports

Natural gas plant liquids

Liquids from coal

Petroleum supply

Net petroleum imports

17% 13% 12% 31% 42%

February 2011
Light Duty Vehicle Miles Traveled
Billions

15 BGY Cap
Conventional Renewable Fuel
(Corn Ethanol)

Advanced Biofuels
(include cellulosic biofuels & other than starch-based ethanol)

Production Targets (Billions of Gallons)

2012
2015
2022

Renewable Fuel
Standard (RFS2)

Conventional (Starch) Biofuels
Cellulosic Biofuels
Biomass-based diesel
Other Advanced Biofuels
The Transport Logic

We are coupled to a **global** oil market

- Balance of payments, high and volatile prices, insecurity, GHGs
- Demand is growing, easy resource is concentrating

**Increased domestic production fixes jobs, balance of payments; not price**

- We cannot produce enough fast enough to affect the global market; OPEC distorts
- Conventional and unconventional crude, biofuels, CTL/CTL/CBTL/... sold at oil price
- Go beyond “energy independence” to “price independence” *(cf UK fuel riots of 2000)*
Saudi, GOM, and U.S. ethanol production

Source: EIA
I'm thinking about buying a more fuel efficient car.

Why?

It's my patriotic duty to reduce this country's dependence on foreign sources of oil.

Why?

Because then the countries that hate us will have less money to fund terrorists.

Actually, developing countries would buy the oil you saved, thus adequately funding those same terrorists.

At least I wouldn't be funding them myself.

Oil is a fungible commodity. The capitalist system virtually guarantees that you'll end up buying the lowest cost oil from sources unknown to you.

Well, maybe, but I want my car to make a statement.

And the statement would be "Hey, everyone, I don't understand what fungible means!"
The Transport Logic

We are coupled to a global oil market
- Balance of payments, high and volatile prices, insecurity, GHGs
- Demand is growing, easy resource is concentrating

Increased domestic production fixes jobs, balance of payments; not price
- We cannot produce enough fast enough to affect the global market; OPEC distorts
- Conventional and unconventional crude, biofuels, CTL/CTL/CBTL/… sold at oil price
- Go beyond “energy independence” to “price independence” (cf UK fuel riots of 2000)

Must decouple from the global oil market
- Reduce oil demand materially through efficiency
- Shift LDVs to a non-fungible fuel (Grid? Hydrogen? Natural Gas?)
- Advanced biofuels for the remaining HDV demand

Strategies (ordered by cost-effectiveness and time-to-impact)
- Increasing vehicle efficiency - nearest-term impact with existing technology.
- Electrifying the light duty fleet - a graceful transition: HEVs to PHEVs to BEVs
- Deploying alternative hydrocarbon fuels - biased toward fuels for HDVs
Total Vehicle Fuel Use and Total U.S. Road Vehicles in 2009

- 1.8 Million Barrels per day (14%)
- 3.0 Million Barrels per day (22%)
- 4.0 Million Barrels per day (30%)
- 4.7 Million Barrels per day (34%)

- 10 Million Vehicles
  - 4% (Light Trucks and SUVs)
  - 55% (Passenger Car)
  - 41% (Total Vehicles)
  - 55% (135 Million Vehicles)

Six Strategies

- **ENERGY SUPPLY**
  - Stationary: Deploy Clean Electricity
  - Transport: Deploy Alternative Hydrocarbon Fuels

- **ENERGY DEMAND**
  - Modernize the Grid
  - Electrify the Vehicle Fleet
  - Increase Building and Industrial Efficiency
  - Increase Vehicle Efficiency

www.energy.gov/QTR

Source: EPA
Projected Reductions in the Fuel Consumption of Large Cars and Small Trucks through Technology

Source: National Research Council with data adapted by a National Petroleum Council study committee; joint study by the Environmental Protection Agency and National Highway Traffic Safety Administration (EPA/NHTSA).
New vehicle technology takes time

Comparison of 2015–2020 New-Vehicle Potential Fuel-Saving Technologies for Seven Heavy-Duty Vehicle Types

Adapted from Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles (NAS 2009)
Turbulence Modeling on Heavy Duty Trucks

Simulated air flow around a heavy-duty vehicle. The turbulent flow between the tractor and the trailer and the vortex underneath the tractor increases drag and fuel consumption.

SmartTruck UnderTray add-on accessories predict 12% drag reduction and 6.9% increase in EPA-certified fuel efficiency.
Six Strategies

ENERGY SUPPLY
- Deploy Clean Electricity
- Modernize the Grid

ENERGY DEMAND
- Increase Building and Industrial Efficiency
- Increase Vehicle Efficiency

STATIONARY
- Deploy Alternative Hydrocarbon Fuels

TRANSPORT
- Electrify the Vehicle Fleet
Relation of Fuel Prices to Crude Oil Price, 2000–2011

Data from EIA and Nebraska Energy Office
Progressive Electrification of the Light-Duty Fleet

Challenges with Batteries and Motors

**Batteries**
- Cost
- Performance
- Physical Characteristics

**Adequate supply chain**
- Rare-earth elements in permanent magnet motors
- Lithium in batteries
- OEM & component manufacturing capacity

**Charging**
- Infrastructure
- Standardization of chargers and grid interface
- Charging times
- Consumer behavior
Impacts of Plug-In Electric Range and Charging Infrastructure

Current Fueling Stations in the United States

Source: DOE EERE (for alternative fueling stations) and EIA (for gasoline stations)
Estimated Supply Impacts of Meeting 50% of Today’s LDV Demand by Various Alternative Fuels
Six Strategies

- **ENERGY SUPPLY**
  - Deploy Clean Electricity
  - Modernize the Grid

- **ENERGY DEMAND**
  - Increase Building and Industrial Efficiency

- **STATIONARY**
  - Deploy Alternative Hydrocarbon Fuels

- **TRANSPORT**
  - Electrify the Vehicle Fleet
  - Increase Vehicle Efficiency
Life-Cycle Carbon Emissions for Various Transportation Fuels

CTL = coal to liquids, CCS = carbon capture and storage, BTL = biomass to liquids, CBTL = coal and biomass to liquids

Source: America's Energy Future Panel on Alternative Liquid Transportation Fuels (2009)
Biomass can provide significant carbon

15% of Transportation Fuels

Annual US Carbon (Mt C)
Platforms / Pathways

Cellulosic Sugar Platform
- Enzymatic Hydrolysis → Sugars → Fermentation

Pyrolysis Oil Platform
- Fast Pyrolysis → Liquid Bio-oil → Upgrading

Syngas Platform
- Gasification → Raw syngas → Filtration & Clean-up

Lipid (Oil) Platform
- Algal and other Bio-Oils → Transesterification → Catalytic Upgrading

Other enzymatic/biochemical methods

Feedstocks
- Energy crops
- Agricultural byproducts
- Waste Streams
- Algae
- Coal
- Natural Gas

Products
- Co or By Products
- Power
  - Ethanol
  - Methanol
  - Butanol
  - Olefins
  - Aromatics
  - Gasoline
  - Diesel
  - Jet
  - Dimethyl Ether
  - Heat and Power
The Stationary Logic

Generation, transmission, and demand are interdependent
  - More complicated than transport

The U.S. is energy independent here
  - Competitiveness and environmental impacts come to the fore.
  - Strengthening domestic innovation and manufacturing capabilities
  - Keep energy affordable while keeping it clean

Strategies (ordered by cost-effectiveness and time-to-impact)

- **Increasing energy efficiency in buildings and industry** - most immediate route to increasing energy productivity.
- **Modernizing the grid** will not only increase reliability and security, but also give greater control to meet clean energy aspirations in other strategies.
- **Deploying clean electricity** - accommodates retirement of existing generators and reduces environmental impacts (greenhouse gas emissions, water, ...).
Six Strategies

**ENERGY SUPPLY**
- Deploy Clean Electricity
- Modernize the Grid

**ENERGY DEMAND**
- Increase Building and Industrial Efficiency

**STATIONARY**
- Deploy Clean Electricity
- Modernize the Grid

**TRANSPORT**
- Deploy Alternative Hydrocarbon Fuels
- Electrify the Vehicle Fleet
- Increase Vehicle Efficiency

- **22% Residential**
  - Space Heating: 28.1%
  - Space Cooling: 14.3%
  - Water Heating: 14.1%
  - Lighting: 10.9%
  - Electronics: 7.9%
  - Refrigeration: 6.7%
  - Wet Clean: 4.8%
  - Cooking: 4.5%
  - Computers: 2.5%
  - Other: 3.5%
  - Adjust to SEDS*: 2.8%

- **18% Commercial**
  - Lighting: 21.7%
  - Space Heating: 15.5%
  - Space Cooling: 13.4%
  - Ventilation: 9.1%
  - Refrigeration: 6.9%
  - Water Heating: 4.2%
  - Electronics: 4.1%
  - Computers: 3.8%
  - Cooking: 1.3%
  - Other: 12.8%
  - Adjust to SEDS*: 7.3%

* Energy adjustment EIA uses to relieve discrepancies between data sources. Energy attributes to the commercial buildings sector, but not directly to specific end-users.

Source: DOE Buildings Energy Data Book
An understanding of the interfaces between all building sub-systems is needed for maximum energy efficiency.

Building SPICE program:
Tools to Design New Buildings With Embedded Energy Analysis

Building Operating Platform (BOP):
Sensors, Communication, Controls, Real-Time Optimization
Six Strategies

**STATIONARY**
- Deploy Clean Electricity
- Modernize the Grid

**ENERGY SUPPLY**

**ENERGY DEMAND**
- Increase Building and Industrial Efficiency

**TRANSPORT**
- Deploy Alternative Hydrocarbon Fuels
- Electrify the Vehicle Fleet
- Increase Vehicle Efficiency
GRID MODERNIZATION
The U.S. Grid

- **The numbers**
  - > 200,000 miles of transmission lines distribute approx. 1 TW of power
  - Over 3,500 utility organizations

- **Desiderata**
  - Reliability
  - Efficiency
  - Security
  - Flexibility to integrate intermittent renewables
  - Two-way flow of information and power
  - Growth to handle growing demand

- **Challenges**
  - Active management is required to balance generation, transmission, and demand at all times
  - Excursion from ideal operation can be catastrophic
High Quality Data Recorded Prior to 2003 Blackout

Illustration of the Grid’s Complex Interactions Between Governance and Operations
Six Strategies

**STATIONARY**
- **ENERGY SUPPLY**
  - Deploy Clean Electricity
- **ENERGY DEMAND**
  - Modernize the Grid
  - Increase Building and Industrial Efficiency

**TRANSPORT**
- **ENERGY SUPPLY**
  - Deploy Alternative Hydrocarbon Fuels
- **ENERGY DEMAND**
  - Electrify the Vehicle Fleet
  - Increase Vehicle Efficiency
Deploy Clean Electricity

Solar Photovoltaic (PV)

Wind

Nuclear Energy

Concentrating Solar Power

Carbon Capture and Storage

Other technologies
- Natural gas
- Hydro
- Solar thermal (parabolic troughs)
- Geothermal
Additions to U.S. Electricity Generation Capacity, 1985–2035

Source: EIA
Age and Capacity of Generators by Fuel Type

Source: EIA
U.S. Natural Gas Supply, 1990-2035

The chart illustrates the historical and projected U.S. dry gas supply from 1990 to 2035. The supply is categorized into several types: Net imports, shale gas, tight gas, non-associated onshore, non-associated offshore, and coalbed methane. The chart shows a steady increase in total gas supply, with significant contributions from shale gas and net imports. The projections indicate continued growth, particularly in shale gas and net imports, with some decline in other categories. Notable is the increase in supply from 2009 onwards, driven by technological advancements and increased exploration. The data highlight the evolution of U.S. gas supply strategies over the years.
U.S. Natural Gas Wellhead Price, 1976-2011

Source: EIA
Estimated Greenhouse Gas Emissions From Generation

CCS = Carbon Capture and Storage; CSP = Concentrating Solar Power; NGCC = Natural Gas Combined Cycle; PV = Photovoltaic
Annual Grid-Connected Generation Deployment

Source: EIA

Source: EIA
Water Consumption for Various Power Generation Technologies

Source: NREL
## Projected 2030 Population Growth and Corresponding State Rainfall

<table>
<thead>
<tr>
<th>State</th>
<th>Projected Population, % Change from 2000</th>
<th>Average Annual Precipitation Compared to U.S. Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nevada</td>
<td>-70</td>
<td>114</td>
</tr>
<tr>
<td>Arizona</td>
<td>-57</td>
<td>109</td>
</tr>
<tr>
<td>Florida</td>
<td>-4</td>
<td>85</td>
</tr>
<tr>
<td>Texas</td>
<td>-61</td>
<td>80</td>
</tr>
<tr>
<td>Utah</td>
<td>-36</td>
<td>60</td>
</tr>
<tr>
<td>Idaho</td>
<td>-36</td>
<td>56</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>New York</td>
<td>3</td>
<td>38</td>
</tr>
<tr>
<td>Ohio</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Iowa</td>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>West Virginia</td>
<td>-5</td>
<td>52</td>
</tr>
<tr>
<td>South Dakota</td>
<td>-6</td>
<td>52</td>
</tr>
</tbody>
</table>

Sources: NOAA and U.S. Census Bureau
# DOE’s Priority Basic Energy Research Areas

<table>
<thead>
<tr>
<th>Materials</th>
<th>Non-Medical Biology</th>
<th>Informatics/Computing</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Materials theory</td>
<td>• Biofuels</td>
<td>• Computational fluid dynamics</td>
</tr>
<tr>
<td>• Nanoscience</td>
<td>• Bio-remediation</td>
<td>• Turbulence</td>
</tr>
<tr>
<td>• Nanoelectronics</td>
<td>• Carbon sequestration</td>
<td>• Energy Storage</td>
</tr>
<tr>
<td>• Superconductivity</td>
<td>• Coal bed methane</td>
<td>• Geotechnics</td>
</tr>
<tr>
<td>• Synthesis science</td>
<td>• De-sulphurization</td>
<td>• Nano science</td>
</tr>
<tr>
<td>• Structural and materials</td>
<td>• Enhanced oil recovery</td>
<td>• Nuclear energy</td>
</tr>
<tr>
<td>• Tools and techniques</td>
<td>• Genetically engineered feedstocks</td>
<td>• Predictive simulation</td>
</tr>
</tbody>
</table>

- Materials theory
- Nanoscience
- Nanoelectronics
- Superconductivity
- Synthesis science
- Structural and materials
- Tools and techniques
- Biofuels
- Bio-remediation
- Carbon sequestration
- Coal bed methane
- De-sulphurization
- Enhanced oil recovery
- Genetically engineered feedstocks
- Computational fluid dynamics
- Turbulence
- Energy Storage
- Geotechnics
- Nano science
- Nuclear energy
- Predictive simulation
The Department’s Fiscal Year 2011 Energy Technology Budget, Categorized by Strategy

Total = $3.0B

- Transport = 26%
- Stationary = 74%

- Vehicle Efficiency: 51%
- Clean Electricity: 19%
- Modern Grid: 5%
- Building and Industrial Efficiency: 13%
- Alternative Hydrocarbons Fuels: 9%
- Electrification: 4%
Key Takeaways

- There are “stories” for Transport and Stationary
  - Sensible futures, DOE’s role, technology programs
- DOE’s energy portfolio is unbalanced
  - Stationary much larger than Transport
  - Clean Power dominates Stationary (~50% of total)
- DOE needs integrated analytic capability (technology, business, market, policy, and social science)
- DOE’s informational and convening roles are highly valued by stakeholders, but under-valued within the Department (as compared to its technical capabilities)
- DOE needs to be more selective in its technology initiatives
- QTR establishes a framework for QER and future QTRs