Energy Efficiency: Progress and Opportunities

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The Good News: U.S. Energy Productivity is Improving

Source: Based on data from EIA
Annual Energy Review 2004
For 30 years, energy efficiency has been the largest U.S. energy resource

Energy efficiency and conservation improvements since 1973 have reduced annual energy consumption by 40+ quads.

Roughly $400 billion energy savings per year.
Projected Cost of New Generation vs. Energy Efficiency Improvement—the Fastest, Cheapest, Cleanest Energy Resource

Sources: Annual Energy Outlook 2007 (EIA), Figure 56, and “Five Years In: An Examination of the First Half-Decade of Public Benefits Energy Efficiency Policies” (ACEEE, 2004), Table 5.
Global supply curves for CO₂ reductions highlight low- and no-cost efficiency options

U.S. energy productivity is outperformed by many countries

Source: Council on Competitiveness. 2007. Competitiveness Index: Where America Stands. Figure 4.32, p. 103.
Energy efficiency must help the U.S. and Georgia meet its future needs

Continuing to grow our energy use by 1.1% annually would require:

~31% increase by 2030
~183% increase by 2100 (850 more 300 MW plants...)

Cutting the growth rate in half (0.55%) would result in a more viable pace of resource expansion:

~15% increase by 2030
~68% increase by 2100
How Much More Energy Efficiency is Available and Worth Buying?

A lot, based on 3 assessments.
(1) Scenarios for a Clean Energy Future

- Advanced policies implemented in 2000 could cut U.S. electricity consumption in 2020 by 24%, with no net cost to the economy.
  - Funded by DOE and EPA
  - Undertaken by researchers at 5 DOE national laboratories with input from experts groups
  - Published in November 2000

http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm
(2) Meta-Analysis of Recent Studies

- 10 - 33% reductions in electricity use are "achievable," depending on timeframe and state/region
  - Conducted by the American Council for an Energy Efficient Economy in 2004
  - Update: FL, GA, & NC estimates range from 9 to 14% (2017 vs 2023)

(3) National Action Plan for Energy Efficiency

• More than half of expected growth in demand for electricity and natural gas can be avoided over the next 15 years

  – This can be done by extending energy efficiency “Best Practice” programs to the entire country
  – Save nearly $20 billion annually on energy bills
  – Avoid 30,000 MW -- 60 new 500 MW power plants
  – Avoid more than 400 million tons of CO₂ annually
  – NAPEE Leadership Group included 27 electric and gas utilities, 16 state agencies, and 13 other organizations (+ EPA and DOE)

Layers of Inefficiency Exist

3% efficient!

New “Systems” are Needed: Distributed Generation

Today’s Central Generation

Tomorrow’s System with Distributed Generation
Another Promising New System: Plug-in Hybrid Electric Vehicles

The direction of power flows with plug-in hybrid electric vehicles


Idle capacity of today’s grid could support 73% of light duty fleet


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“Smart growth” could benefit from “systems” engineering
Nano-info-bio discoveries will lead to highly efficient technologies

• Illustrative Opportunities:
  - Integrated heat pump technologies
  - Phase change materials in insulation
  - Self-optimizing sensor systems
  - Pulse thermal processing
  - Super-durable materials for aggressive environments
  - Energy-efficient distillation through supercomputing
  - Novel energy-efficient separations

New technologies could have broad impact in daily life.
Buildings Use 72% or U.S. Electricity & 54% of Natural Gas

Industry 33%
Transportation 28%
Buildings 39%

Residential (21%)
- Heating 32%
- Water Heat 13%
- Lights 28%
- Cooling 13%
- Other 10%
- Refrigeration 9%
- Cooking 5%
- Electronics 5%
- Computers 1%
- Other 4%

Commercial (18%)
- Heating 16%
- Cooling 10%
- Lights 12%
- Water Heat 7%
- Office Equip 7%
- Ventilation 7%
- Cooking 2%
- Computers 3%
- Refrigeration 4%
- Other 10%
DOE Goal: Cost-Competitive Net-Zero Energy Home (ZEH)

Typical 2200 sq. ft. home – $1600/yr.

2002 Energy Star at 15% savings

Building America goal: 60-70% energy savings

Net-Zero Energy Use

2020 Energy Production
ZEH-0 supplies the remaining 30-40% of energy needs from solar electricity and heat

Progression to Full ZEH
Near Zero-Net Energy Homes are Being Built

- Advanced energy technologies being researched with Habitat for Humanity
  - Integrated heat pump water heaters
  - High velocity ducts
  - Structural insulated panels
  - Photovoltaics
  - Geothermal heat pumps

- Annual heating cost = $92, cooling cost = $74 with air-source heat pump, and hot water cost = $90

- 82 cents per day for total energy including plug loads
Several Heat Pump Technologies are Emerging as 50% Energy Savers

Heat Pump Water Heater

50% saver for the electric water heating mass market

Air-Source        Integrated Heat Pump (IHP)        Ground-Source

H, C, WH, V & demand dehumidification in all-electric homes.
Phase Change Materials in Insulation

- PCM microcapsules could enable a new generation of building insulation
- First dynamic hotbox test of a wood-framed wall containing PCM-enhanced cellulose insulation – showed 40% reduction of cooling load

Installation of PCM-enhanced cellulose insulation in a test wall

Polymer coating

Paraffin
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Roof Heat Flux
[Btu/(hr · ft\(^2\))]

Control - Asphalt Shingle (SR093E89)
PVDF Metal _ PCM

ORNL PCM attic

90% reduction of peak load
Reduction of night sub-cooling

ORNL control attic

ORNL PCM attic
Self-optimizing sensor systems

- Low-cost ubiquitously distributed micro-sensors that are self-calibrating and self-diagnosing
- Intelligence distributed to the sensor with wireless telemetry
- Anticipatory prognostics to allow continuous optimization
- Ultra-low power electronics operated from power scavenging

Potential Opportunities and Annual Energy Savings:
- Small motors: ~0.3 quads
- Industrial buildings EMS: ~0.75 quads
- Industrial energy systems:
  - Petroleum refining ~0.1 quad
  - Chemicals ~0.13 quad
  - Forest products ~0.15 quad
  - Food & beverage ~0.05 quad
- Manufacturing: ~0.65 quad
Pulse Thermal Processing (PTP) - An Enabling Tool for Broad Area Nanoscale Processing

- PTP allows high temperature processing (3.5 - 20 kW/cm²) to achieve functionalization of nanomaterials on polymer substrates
- Uses a high density infrared radiant arc lamp (1 millisecond pulse capacity of 0.7 - 12 MW)
- Approaching power densities of a laser with processing area of 300 cm²

Flexible solar module

TiO₂ nanoparticles (approx. 35 nm) sintered on a polymer substrate for a photovoltaic application. (ORNL data with 0.7 seconds of processing)
Industry: Critical to National Energy Picture

*Industry is the largest energy using sector*

- 37% of U.S. natural gas demand
- 29% of U.S. electricity demand
- 30% of U.S. greenhouse gas emissions
- Uses more energy than any one of the other G8 nations

**2004 Energy Use***

- **100.3 Quads**
  - **Industry**: 33%
  - **Transportation**: 28%
  - **Commercial**: 18%
  - **Residential**: 21%

*Includes electricity losses

### Energy Use (Quadrillion Btu)

- **Chemicals**: 7.8
- **Aluminum**: 0.9
- **Petroleum Refining**: 7.3
- **Fabricated Metals**: 3.3
- **Forest Products**: 0.7
- **Plastic & Rubber**: 1.9
- **Iron & Steel**: 1.6
- **Food Processing**: 1.4
- **Non-Metallic Minerals**: 4.1
- **Non-Mfg**: 3.8
- **Other Mfg**:

Source: DOE/EIA Monthly Energy Review 2004 (preliminary) and estimates extrapolated from MECS

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Super-durable materials for aggressive environments

- Nano structures and phases enable new properties at the macroscale:
  - Enhanced mechanical strength
  - Improved high temperature tolerance
- Uses computational microstructure design methodology
- Result: higher temperature, stronger and more degradation resistant materials for industrial processes
- Potential Opportunities and Annual Energy Savings:
  - A 10% impact on industrial boilers, chemical reaction vessels, and furnaces can lead to energy savings of ~1.5 quad.

Process heating uses over 15 Quadrillion Btu/yr in the US (~15% of annual U.S. energy use)

New alloys possess stable nanostructures of ~10nm

Atom Probe Analyses

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Enhanced nickel aluminide (Ni$_3$AL) for rolls in steel reheat furnaces

- Development of new alloys and manufacturing procedures enabled production of 115 rolls for installation and testing.
- Materials successfully reached 32 month milestone – over 300,000 tons of steel processed (~4.3X steel in Empire State Building).
- Eliminated over 85 furnace shut downs (~260 days; over 25% increase in up-time).
- Higher yield, no rework and increased product quality due to no roll-related downgrading of steel.
- 35% increase in furnace energy efficiency (natural gas).

ORNL R&D on new Ni$_3$AL alloys is successfully applied in industry.
Energy-efficient distillation through supercomputing

- Advanced modeling and simulation of complex industrial processes can lead to significantly improved design and operation.

- Modeling of counterflows through structured packings can improve distillation hydrodynamics:
  - Empirically characterizing the hydrodynamics of a packing element requires a high-end supercomputing cluster capability.
  - Terascale computers will be needed to perform an integrated hydrodynamic calculation for an entire distillation column.

- Potential Opportunities and Annual Energy Savings:
  - Distillation accounts for ~3 quads of energy usage annually, about half in petroleum refineries.
  - 10-20% reductions are possible with improved geometries of packing elements.
  - Comparable savings possible through steam system engineering.

Source: http://distillation.ornl.gov
The Future for Energy Efficiency Is Bright

Comparative Cost of 2010 Generating Options (and Energy Efficiency) under Different Carbon Prices

![Graph showing levelized cost of electricity vs. cost of CO2](https://example.com/graph.png)

- **EE added at $0.03/kWh per “Five Years in: An Examination of the First-Half Decade of Public Benefits Energy Efficiency Policies” (ACEEE, 2004)**

*Coal @ $1.50/MMBtu  **Nat Gas @ $6/MMBtu
***29% Capacity Factor  ****$1700/kW Capital Cost
Concluding Remarks

- Targeting energy efficiency is a no regrets strategy for mitigating climate change
- Technology advances are needed to sustain the pipeline of new options
- New and reformed policies are needed to overcome market and government failures*

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