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Transformational Science for Energy and the Environment

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A Common Sense of National Purpose

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"We must also change how we power our automobiles. We will increase our research in better batteries for **hybrid and electric cars**, and in pollution-free cars that run on **hydrogen**. We'll also fund additional research in cutting-edge methods of producing **ethanol**, not just from corn, but **from wood chips and stalks, or switch grass**. Our goal is to make this new kind of ethanol practical and competitive within six years."

--President George W. Bush announces the **Advanced Energy Initiative** in his State of the Union Address, January 31,2006

"America is on the verge of technological breakthroughs that will enable us to live our lives less dependent on oil. **And these technologies will help us be better stewards of the environment, and they will help us to confront the serious challenge of global climate change.**"

--President George W. Bush, State of the Union Address, January 23, 2007

For America and the Globe: "A Whole New World"

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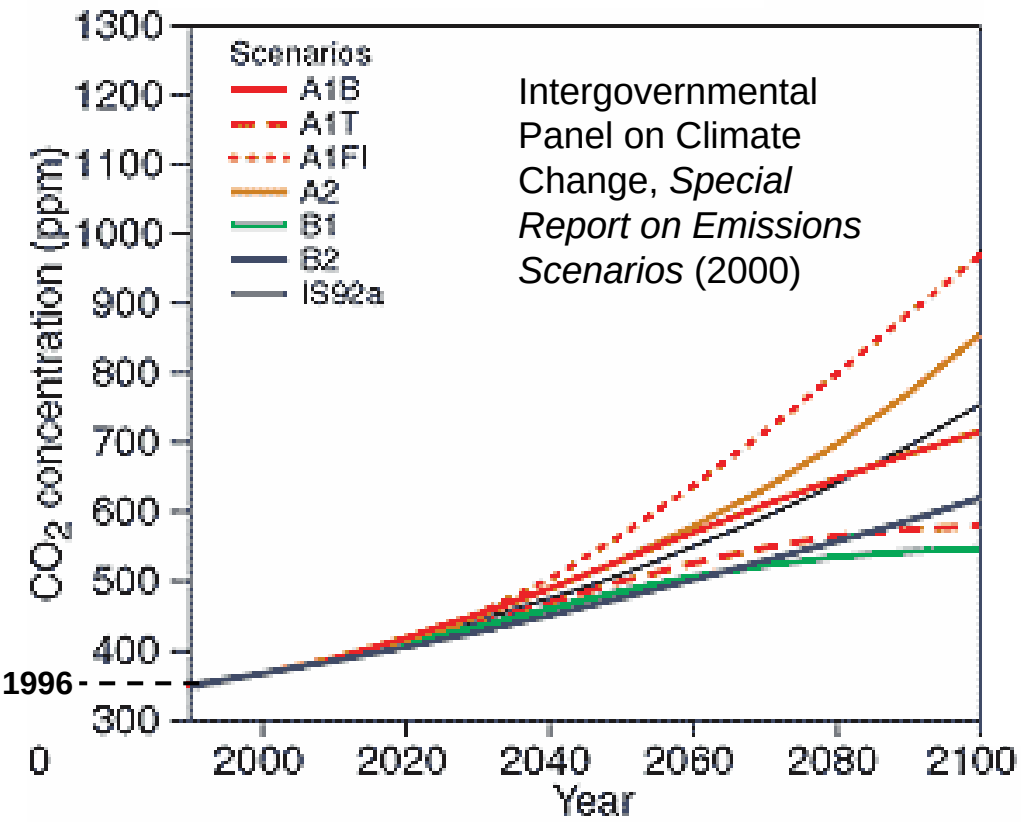
- Energy once thought to be cheap, unlimited, freely available – no longer
- Dependence on fossil fuels and imported oil poses growing risk to economy, environment, and national security
- Global energy consumption set to double (at least) by end of century



The historical, pre-industrial average CO_2 concentration = **280ppm**

The Challenge

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- We must meet the increasing demand for energy without adding catastrophically to atmospheric carbon dioxide
- Current fossil energy sources, current energy production methods, and current technology cannot meet the challenge
- Incremental changes in technology will not suffice
- We need **transformational discoveries** and truly **disruptive technologies**

Examples of Transformational Pathways

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- Efficiency } Solid State Lighting
- Wind & Solar } Electrical Energy Storage
- Bioenergy } Mimicking Nature
- Nuclear } Spent Fuel
- Fusion } A Star on Earth

Efficiency: Enormous Potential for Energy Savings

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- U.S. electricity production uses 40% of primary energy
- Overall, about 60% of U.S. primary energy is lost in waste or rejected heat
- Efficiency
  - Behavioral
  - Technological
- Technological path offers greatest potential for energy savings while supporting economic growth and rising standard of living

Solid State Lighting

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- 20% of the Nation's electricity is used for artificial lighting
- Solid state lighting – direct conversion of electricity to visible white light using semiconductor materials – has the potential to significantly reduce energy consumption
- There is no fundamental physical barrier to achieving efficiencies approaching 100% for visible white light
- Office of Science Workshop: "Basic Research Needs for Solid State Lighting," May 22-24, 2006
  - Priority research directions identified include the science of inorganic and organic thin films for light-emitting diodes, novel materials science, and optical physics
  - Understand materials and nanostructures at a fundamental level to enable rational design

Wind & Solar Energy

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- "If the technology is developed further . . . it's possible we could generate up to 20% of our electricity needs through wind."—President George W. Bush
- Top wind turbine now rated at 6 MW (1 MW powers over 250 homes)
- Wind now produces 9,149 MW, enough to power 2.3 million homes

- More energy from sunlight strikes the Earth in one hour than consumed on the planet in a year
- ~2,000 MW of solar energy was produced in 2006 in the US, enough to power 500,000 homes
- Demand for PV and Concentrated Solar Power saw record growth in 2006 – move towards utility market

DOE Transformational Research on Electrical Storage

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- Many renewable energy sources such as wind and solar are *intermittent*
- To make these energy sources base load competitive, we need significant breakthroughs in electrical *storage* technologies
- Improving storage will require transformational science
- Office of Science Workshop: "Basic Research for Electrical Energy Storage," April 2-4, 2007
  - Priority research directions identified include retrosynthesis of high performance new materials capable of multi-electron storage per redox center, tailoring nanoscale electrode architectures for optimal transport, new approaches to electrolyte design.
  - Understand and control interfacial charge transfer and the dynamics of phase transition, novel chemistries for scavenging impurities and self-healing, probing energy storage physics and chemistry at all time and length scales.

Bioenergy: Major Promise for Energy and the Environment

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- The U.S. is capable of producing 1 billion dry tons of biomass annually (agricultural and forestry wastes, grains, and 55 million acres of perennial bioenergy crops) – enough for 60 billion gallons of ethanol per year, or ~30% of today's transportation fuel usage – and continue to meet food, feed, and export demands
- Includes specialized perennial feedstock crops: e.g., switchgrass, miscanthus, willows, hybrid poplar
- Biofuels are essentially **carbon-neutral** or even carbon-negative – as plant feedstocks grow, they reabsorb the carbon dioxide emitted when biofuels are burned, and they can store carbon dioxide in their roots
- Many scientists believe we are within reach of major breakthroughs in developing cost-effective methods of producing **cellulosic ethanol** in the near to medium term

How Nature Does It: Powerful Capabilities of Microbes

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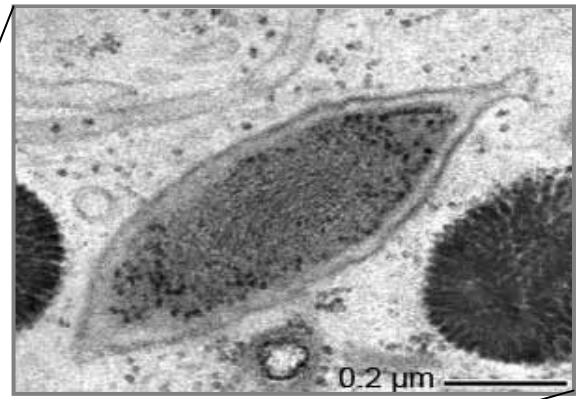
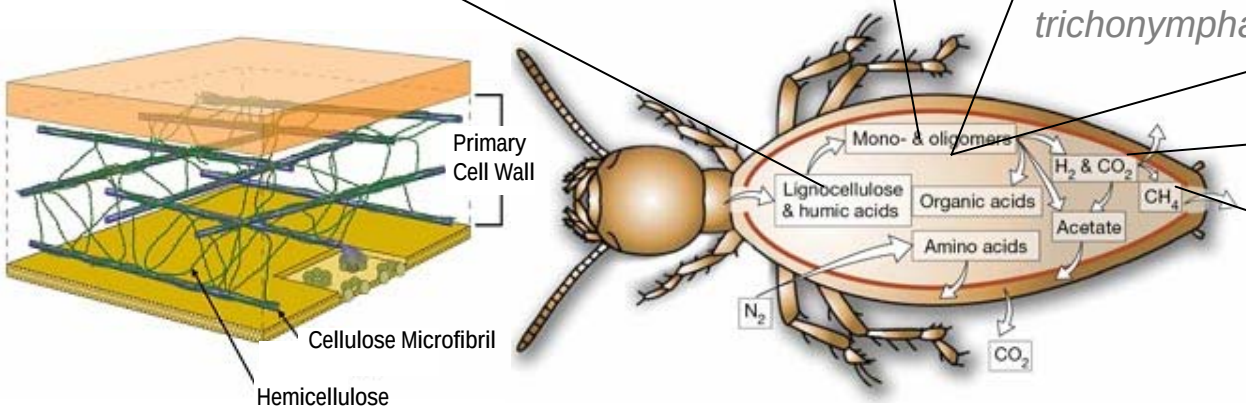
The termite's gut contains about 200 different species of bacteria, some of which are "experts" at breaking down cellulose and helping transform it into fuel in the form of hydrogen and methane.



"Candidatus Endomicrobium trichonymphae"

Enzymes that break down cellulose and hemicellulose

Fermentation pathways



Hydrogen production

Methane production

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How DOE Does It: Bioenergy Research Centers

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- Funding: **$375 million** to be provided **over five years** to establish and operate **three** new **Bioenergy Research Centers**
- Goals: **transformational discoveries** in basic science to make production of **cellulosic ethanol**, sunlight-to-fuels, and other biofuels truly cost-effective and economically viable
- Method: advanced systems biology research on **microbes** and **plants** - to learn to exploit nature's own conversion methods, plus develop a new generation of optimized bioenergy crops
  - Understand metabolic pathways in microbial bioconversion processes
  - Analyze plant cell wall structure and assembly
  - Fine-tune microorganisms and plants to each other
  - Pursue both microbial and bio-mimetic conversion methods
- Innovative multidisciplinary approach: **no construction, rapid start-up** – utilizing **latest biotechnology advances** plus **world-class instruments in DOE complex** (high-intensity light sources, etc.)
- **Open competition**: universities, national labs, nonprofits, private firms, and **partnerships** of such entities invited to compete to establish a Center – set-up in FY 2007 and operational in FY 2008.

Nuclear Energy: Fossil-Free Power with Zero Greenhouse Gas Emissions

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- Currently provides 20% of nation's electricity, could provide much more
- Good for both energy security and the environment
  - Reduces nation's dependence on fossil fuels and imports
  - **No toxic or carbon emissions**: **nuclear energy use currently eliminates 700 million tons of carbon dioxide**, the equivalent of **58 million passenger cars**
- Key challenge is handling spent fuel – and related problem of proliferation
- Advances in science and engineering can provide major reduction in spent fuel by "closing" fuel cycle:
  - Recycling spent fuel and burning it in new fast reactors
  - Potentially reducing storage requirements by up to 90%
  - Taking advantage of advances in materials science, computation
- "Our Atomic Future," by William Tucker, The Wall Street Journal, March 28, 2007

DOE Transformational Research on the Advanced Fuel Cycle

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- Basic Energy Sciences
  - Workshop, July 31-August 2, 2006: Materials under extreme conditions; chemistry under extreme conditions; chemistry in high-radiation environments, corrosive environments, at interfaces, and in complex solutions; separations science; advanced actinide fuels; actinide containing waste forms; predictive modeling and simulation
- Nuclear Physics
  - Workshop, August 10-11, 2006: Nuclear measurements (nuclear reactions, accelerator facilities, and instrumentation), nuclear data, nuclear theory/computations
- Advanced Scientific Computing Research
  - Workshop, August 15-17, 2006: Reactor core simulation, materials and fuels, separations chemistry, repository modeling, seismic/structural/balance of plant, validation

The Promise of Fusion – A Star on Earth

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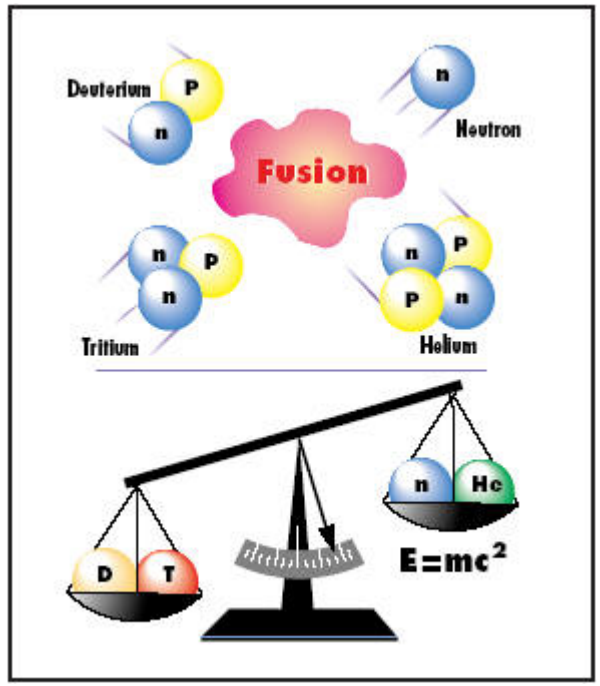
- Fusion = harnessing the sun's and stars' own method of energy production
- Uses abundant fuel, available to all nations - deuterium and lithium are easily available for millions of years
- No carbon emissions, short-lived radioactivity
- Low risk of nuclear materials proliferation
- No fissile or fertile materials required
- Cost of power estimated similar to coal, fission
- Can produce electricity and hydrogen for fuel



ITER – Unprecedented International Cooperation on Fusion

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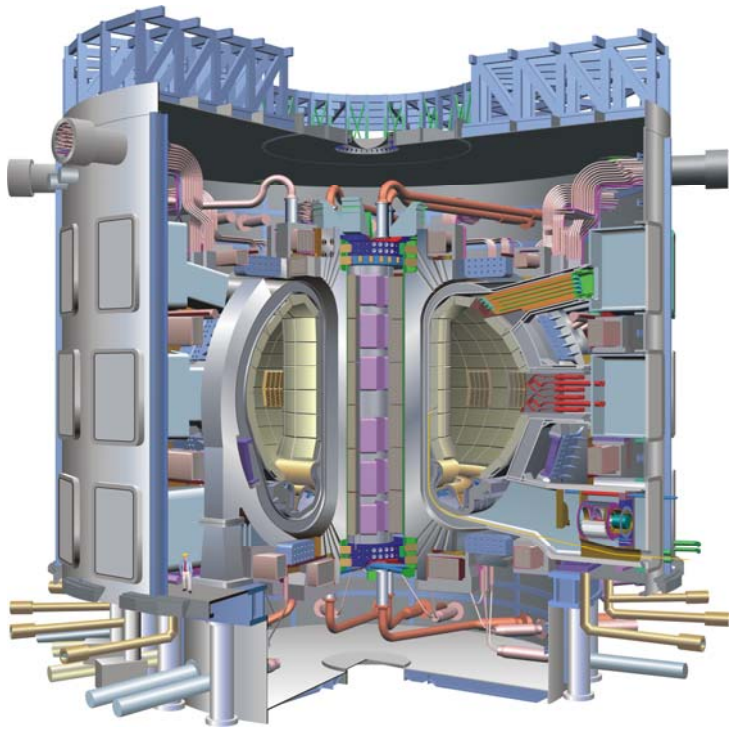
- ITER: Experimental fusion reactor designed to be the penultimate step to development of commercial fusion energy
- Major cooperative project of EU, Japan, Russia, China, Republic of Korea, India, and the United States
- Historic international agreement signed on November 21, 2006. Site preparation underway; Interim ITER Council in operation.



Beyond the Zero-Sum Game

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"What I'm talking about is a comprehensive approach to solving a national issue, which is dependence on oil, and how best to protect this environment. . . . It's time to get rid of the old, stale debates on the environment and recognize new technologies are going to enable us to achieve a lot of objectives at the same time.

"Technology will enable us to be able to say we can grow our economy and protect our environment at the same time. It's not a zero-sum game anymore. These technological breakthroughs are going to say to our farmers, you're energy producers. And that's good for America. It's going to say to those entrepreneurs that are risk-takers, this is a good place to try to make a good return on capital."

--President George W. Bush,
Remarks at Joint DOE/USDA Conference, "Advancing Renewable Energy," St. Louis, MO, October 12, 2006