Strengthening America's Infrastructure Security in Energy and Climate

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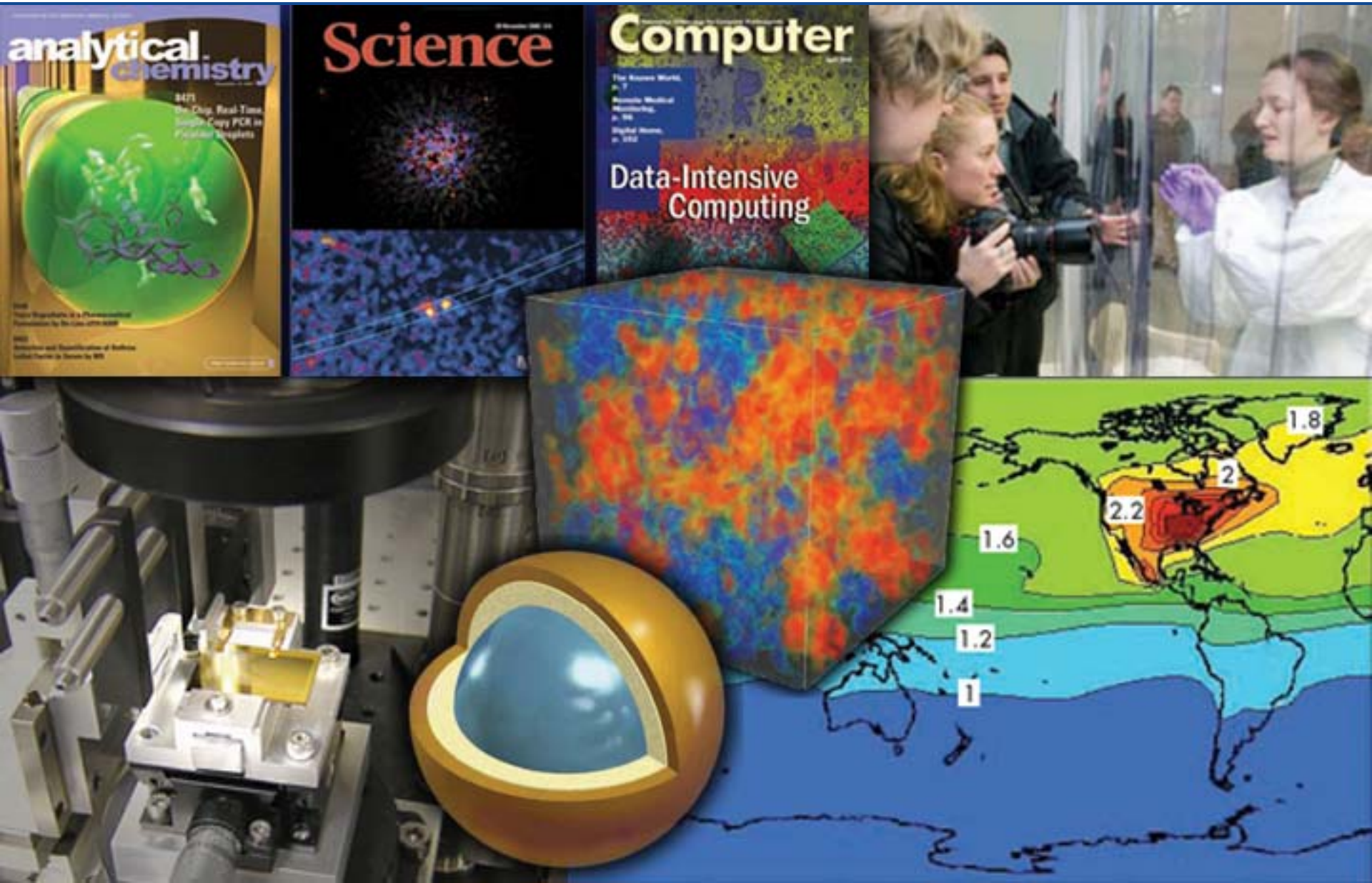
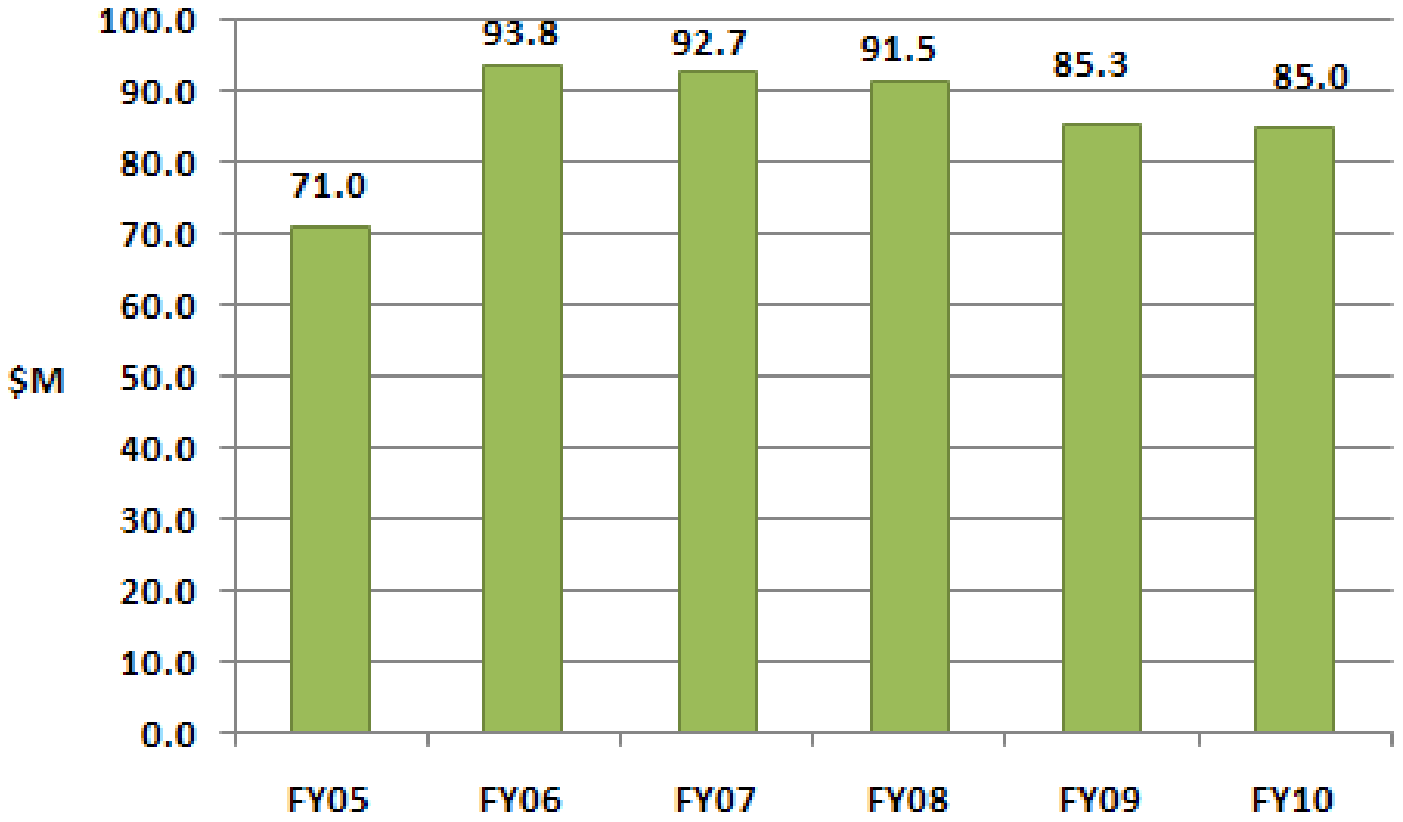
Science and Technology

LDRD research benefits both NNSA mission challenges and broader national needs



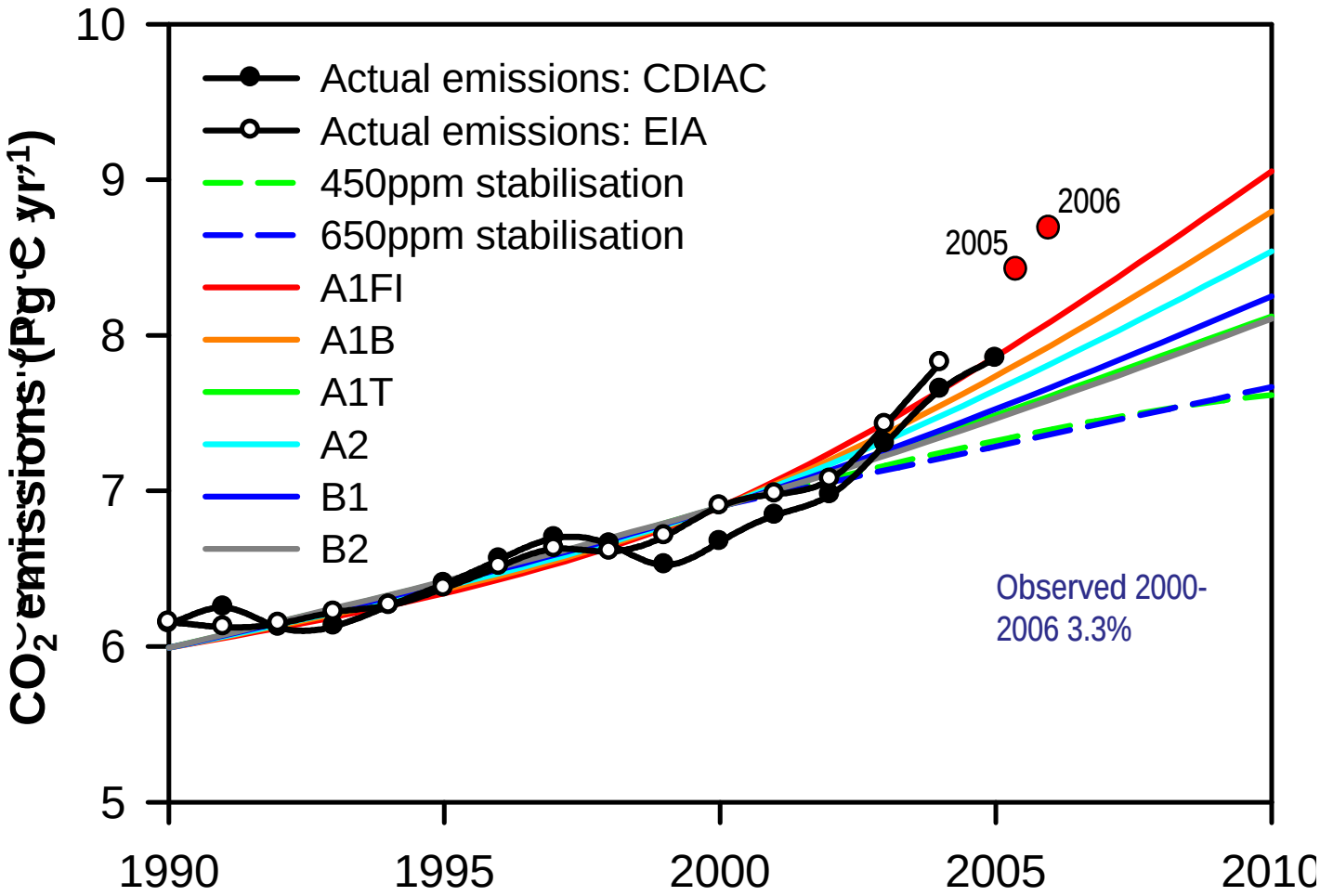

Emerging 21st-Century Societal Drivers and National Priorities
Enduring and evolving 20th-Century mission
Stockpile Stewardship Science
LIFE
Nuclear Threat Elimination
ST&E Foundations
Climate and Energy Challenges
Bio Security
Advanced Lasers and Applications
Cyber, Space, Intelligence

LLNL Annual LDRD investments represent 8% of the total Lab budget and are a substantial investment in core R&D



LDRD helps the Labs and LLNL prepare for the future S&T challenges facing the nation

Annual worldwide CO_2 emissions have grown faster than under any of the IPCC 2001 projected scenarios



Raupach et al. 2007, PNAS

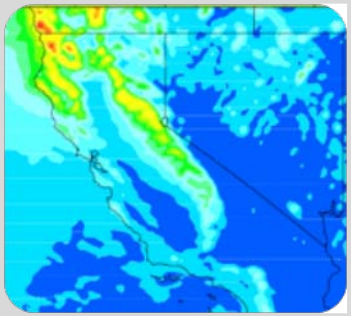
This set of strategic program elements reflects the highest priorities in terms of national need & the nature of the market

Breakthrough science to predict, analyze &, monitor	Innovative solutions to reduce atmospheric GHG and deliver clean power	
▪ Uncertainty quantification for regional climate prediction	▪ Wind Energy Prediction	Critical New Role
▪ Greenhouse Gas Emission Verification ▪ Energy System Analysis	▪ Underground Coal Gasification and Carbon Sequestration ▪ Air Capture of CO_2	Critical New Arena

LLNL is developing multifaceted capabilities to assess regional climate change and its impacts

Regional climate prediction

- Identify key processes and parameters driving uncertainty in climate predictions
- Demonstrate UQ capabilities on regional predictions of climate impacts critical to national security



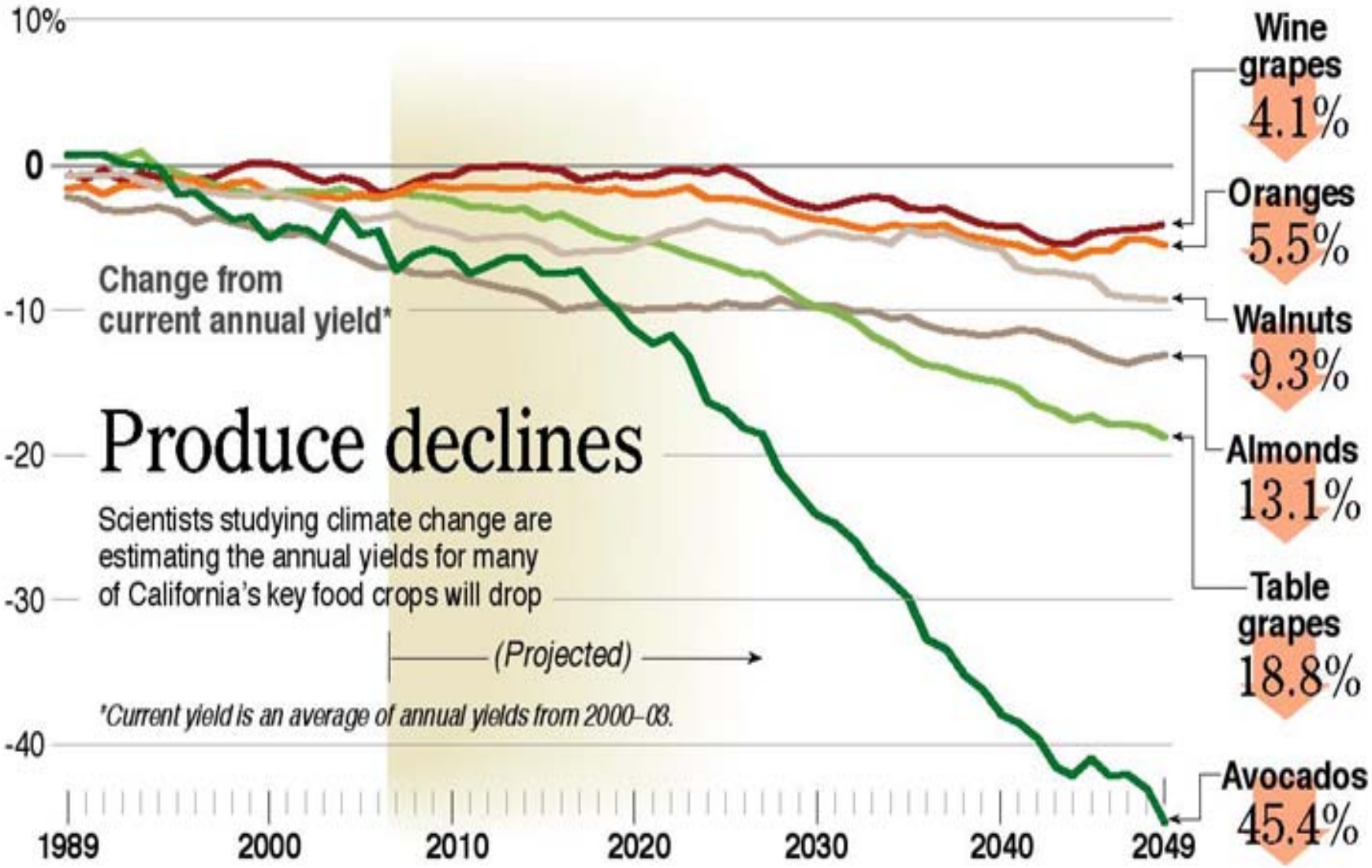
Greenhouse gas emission verification

- Data inversion determines regional carbon emissions for treaty verification
- Unique capabilities: radiocarbon measurement (CAMS) and atmospheric inversion (NARAC)

Regional energy system analysis

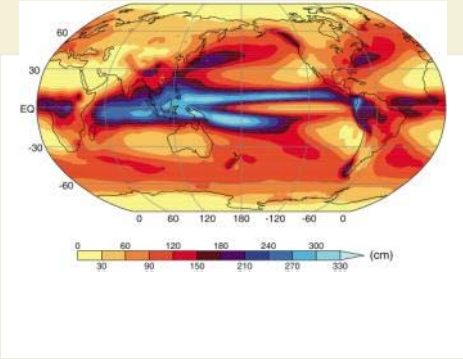
- Deliver integrated analysis of regional energy systems including demand, production, and transmission infrastructures
- Complex systems models and analysis

Water availability, food productivity, extreme weather are all critical factors to ensuring our national security



An end-to-end modeling capability will improve our ability to provide actionable data to address climate impact

Global climate models



- Higher-spatial resolution
- Shorter time steps

Regional climate models

- Validated regional data
- Downscaled from global models

Coupled hydrological models

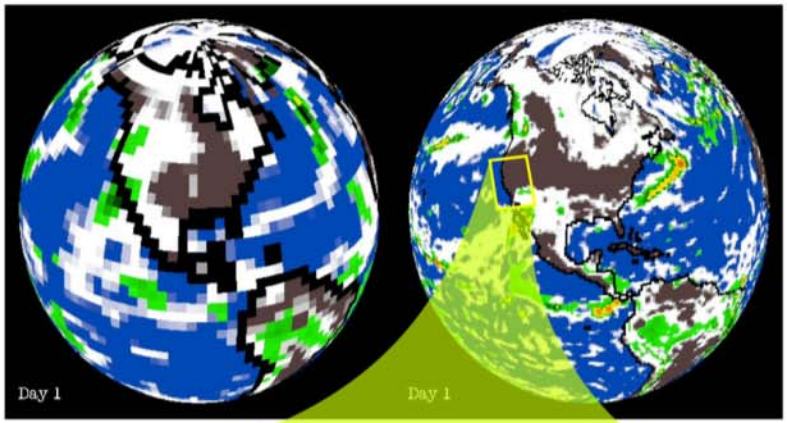
- California and international sites
- From regional meteorological data

Actionable data

- Policy decision
- Adaptation
- Mitigation

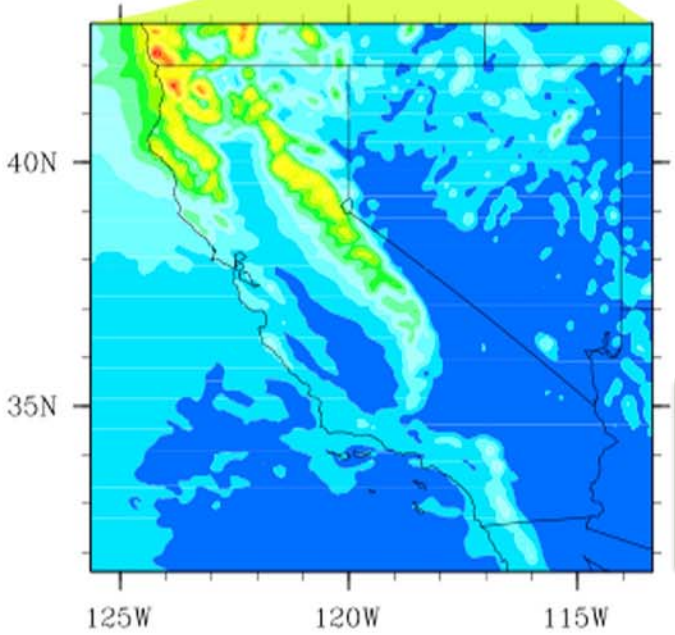
LLNL's supercomputers are providing unprecedented insight into regional impact of global climate change

Resolution of a typical climate simulation



Enhanced resolution of LLNL's climate simulation

Our climate simulations allow detailed predictions of regional precipitation answering critical questions of California's future water resources, as well as air quality and ecosystems



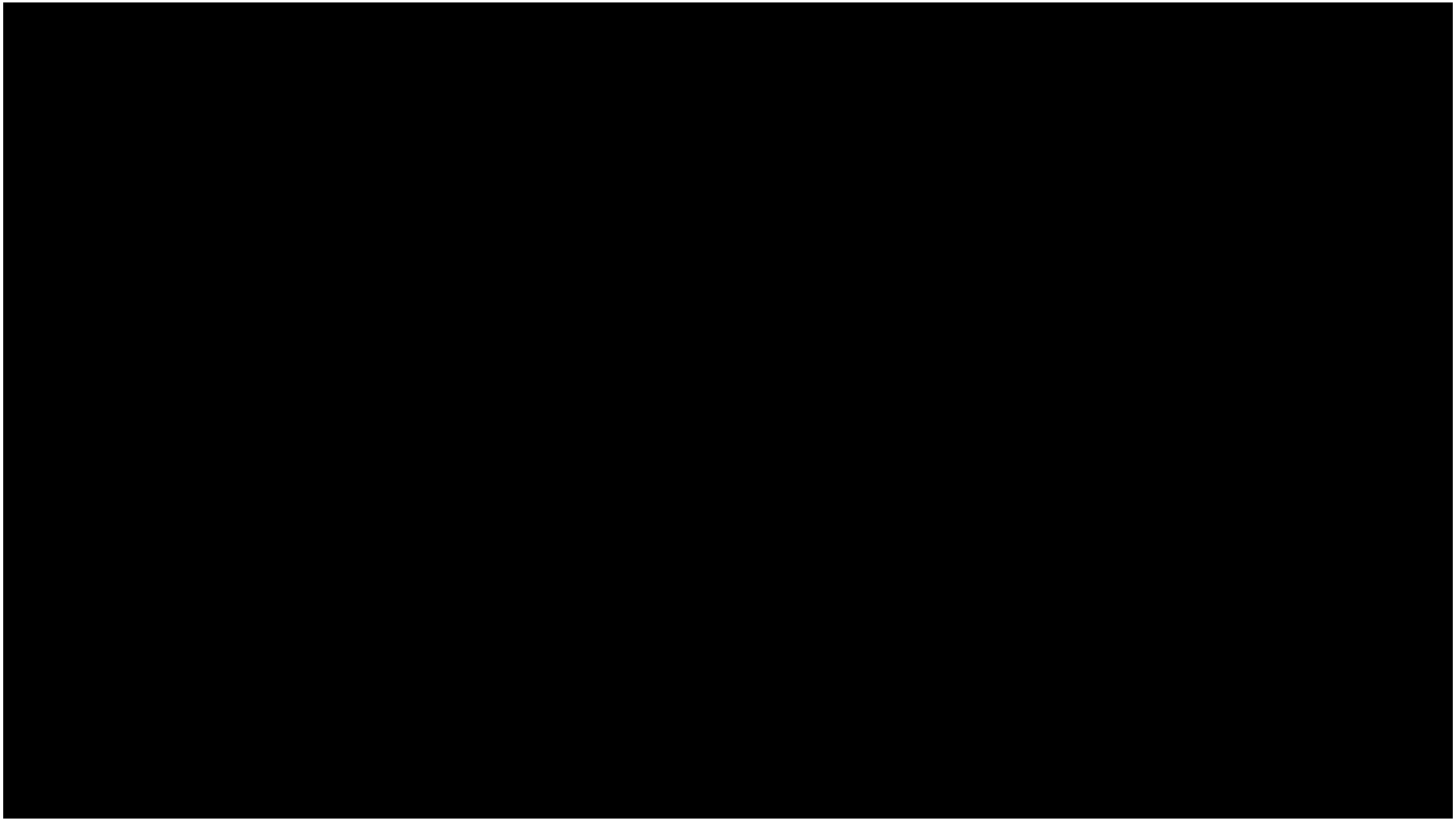
Precipitation over California

Target Resolutions
Global: 15 km
Regional: 1 km

Need 09 update

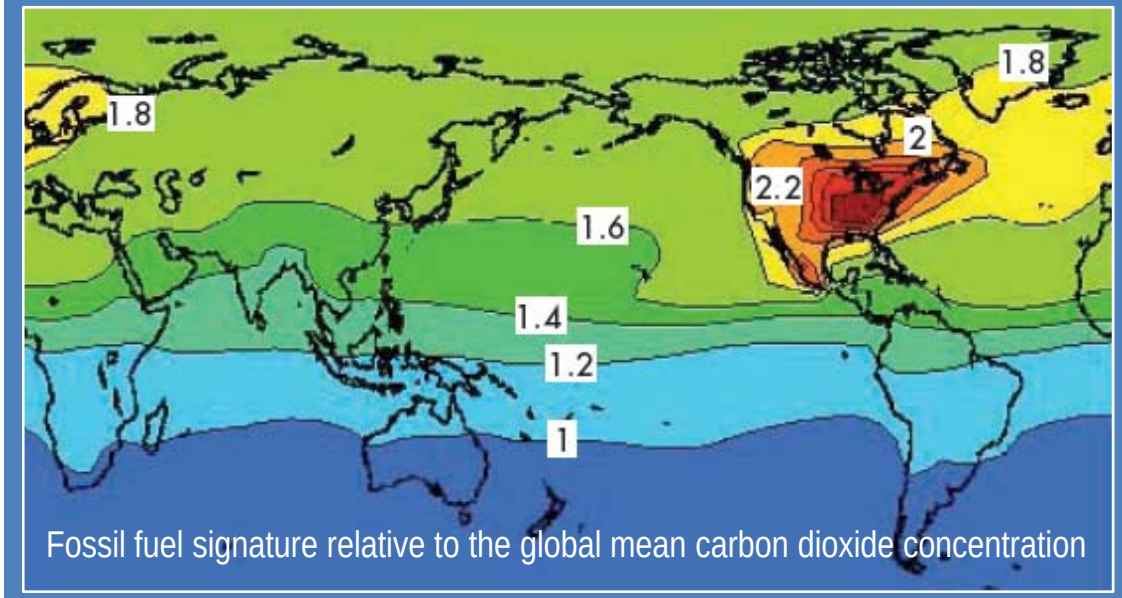
06-ERD-066

Advancing understanding of climate processes are critical to assessing potential impacts

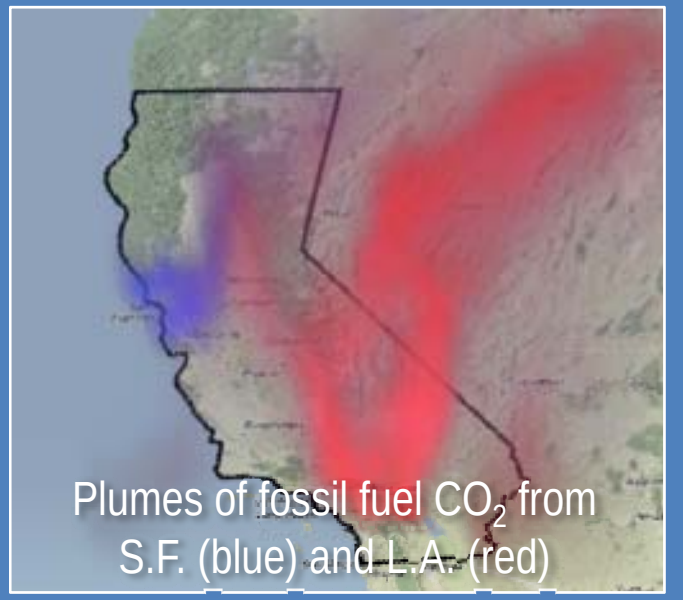


Our unique expertise in carbon isotope analysis allows us to provide independent verification of CO_2 emissions

- Carbon cycle research at the Center for Accelerator Mass Spectrometry utilizes the dual nature of ^{14}C as a tracer of carbon
- The singular (fossil fuel) source of ^{14}C-free CO_2 allows us to discriminate CO_2 to better than 1%



Fossil fuel signature relative to the global mean carbon dioxide concentration

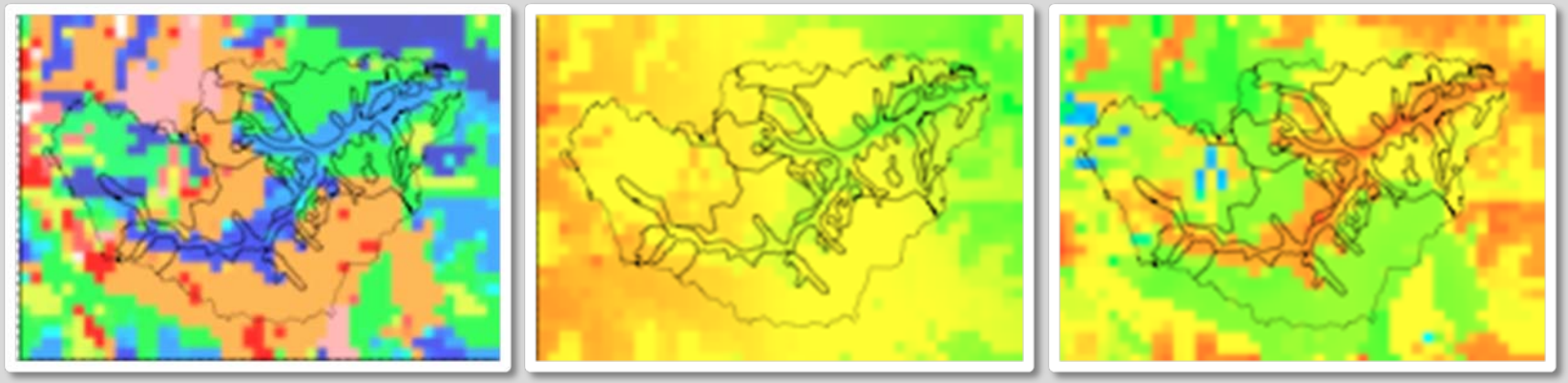

Plumes of fossil fuel CO_2 from S.F. (blue) and L.A. (red)

07-ERD-064

LLNL has developed a unique capability for simulating coupled subsurface, surface, and atmosphere processes

- PF.WRF couples NCAR's Weather Research Forecasting system (WRF) with LLNL's saturated flow model Parflow
- More accurate prediction of regional climate and hydrologic impact for wind power and water resources
- Captures the effects of deep or lateral groundwater motion on surface water balances and thus low-level winds

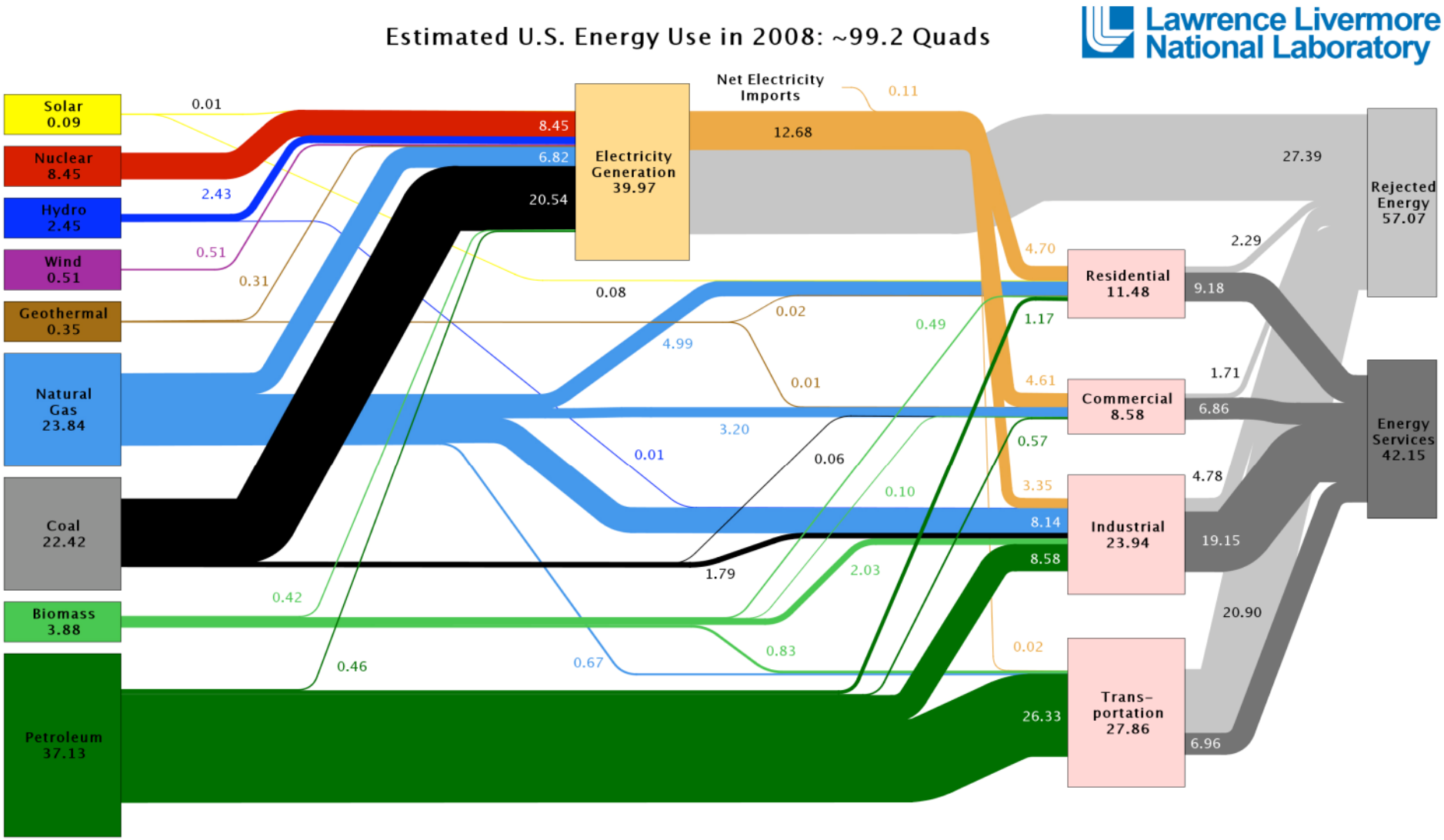
Land Surface Saturation | Land Surface Temperature | Latent Heat Flux



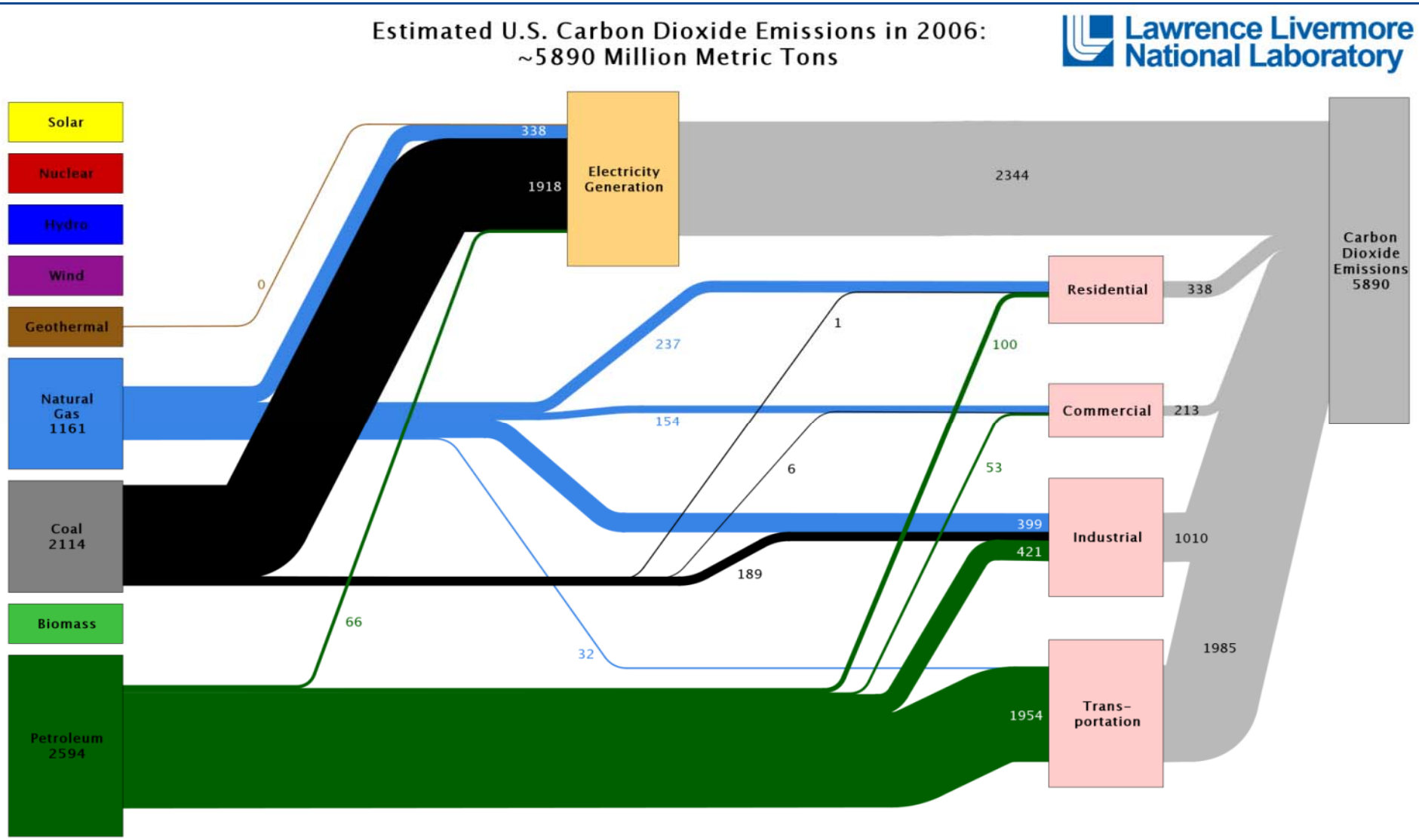
Little Washita, OK, watershed simulation, at 36 hr

Creating secure, safe, and affordable energy systems requires understanding the entire system

Lawrence Livermore National Laboratory



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527


Estimated U.S. Carbon Dioxide Emissions in 2006:
~5890 Million Metric Tons
Lawrence Livermore National Laboratory
Solar
Nuclear
Hydro
Wind
Geothermal
Natural Gas 1161
Coal 2114
Biomass
Petroleum 2594
Electricity Generation
Residential
Commercial
Industrial
Trans-portation
Carbon Dioxide Emissions 5890
0
338
1918
2344
237
154
1
6
100
53
66
32
189
399
421
1954
338
213
1010
1985

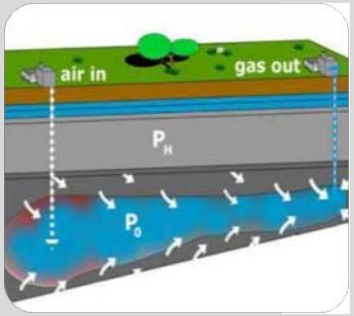
LLNL is providing low-carbon energy solutions to reducing greenhouse gas emissions

Wind energy prediction

- Highly resolved models of wind flows over complex terrain
- Improve operation of existing wind farms and turbine design

Underground coal gasification, carbon sequestration

- Process simulation and geophysical monitoring tools and integration
- Quantum chemical simulation, synthesis, computational fluid dynamics of air flow
- Geomechanical and geochemical modeling

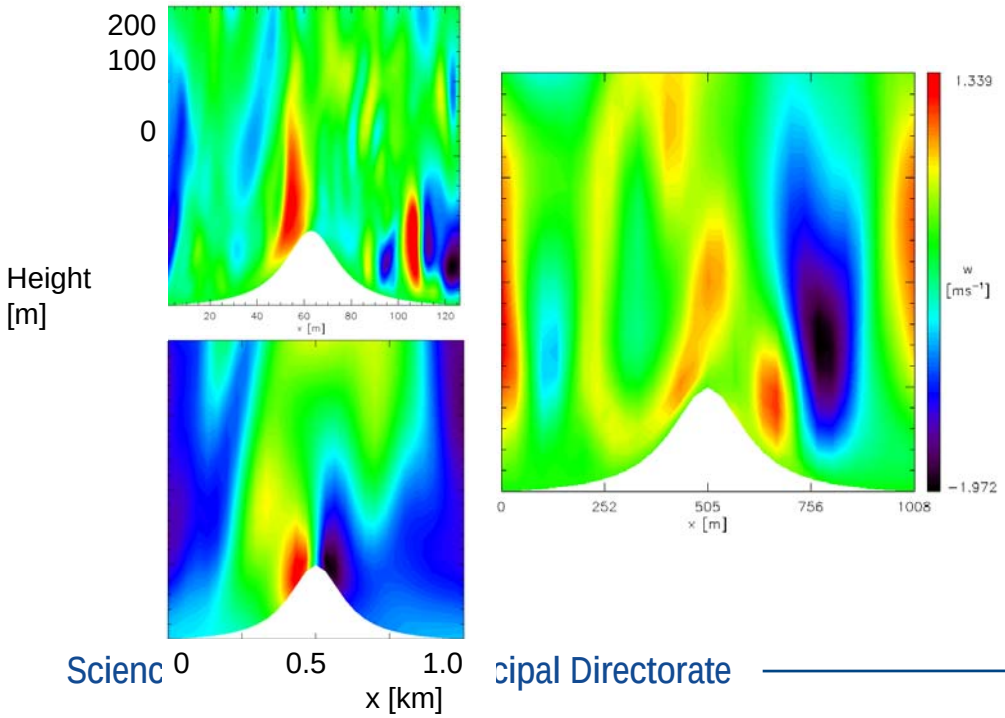


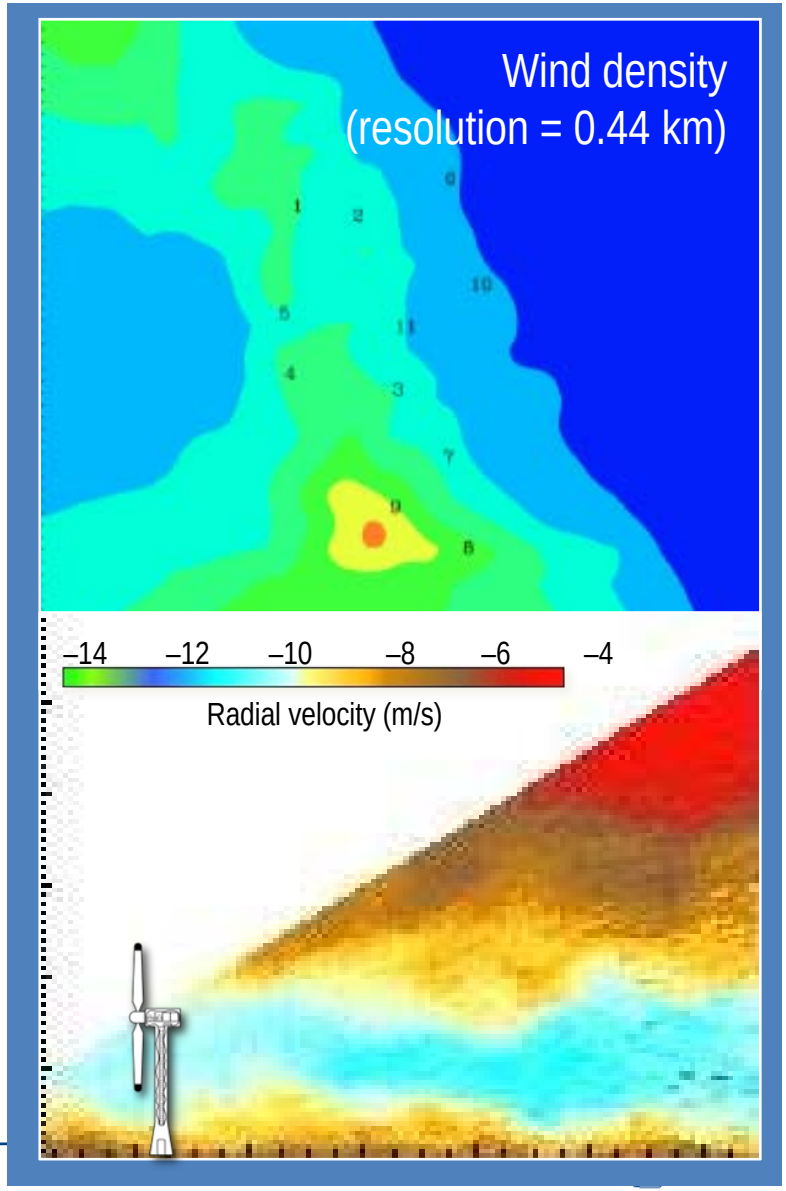
Modeling and Simulation for Extreme Materials

- Structural materials in extreme radiation environments for fusion and fission
- Actinides and materials for ultra deep burn fuels
- Peta to Exa scale simulation and V&V for accelerated development

Application of LLNL simulation tools will increase the efficient deployment of zero-carbon wind energy

- Massively parallel computing can be used to model wind turbines and to design wind farms
  - Optimize new designs
  - Estimate and maximize energy production
  - Analyze power grid data to effectively deploy resources





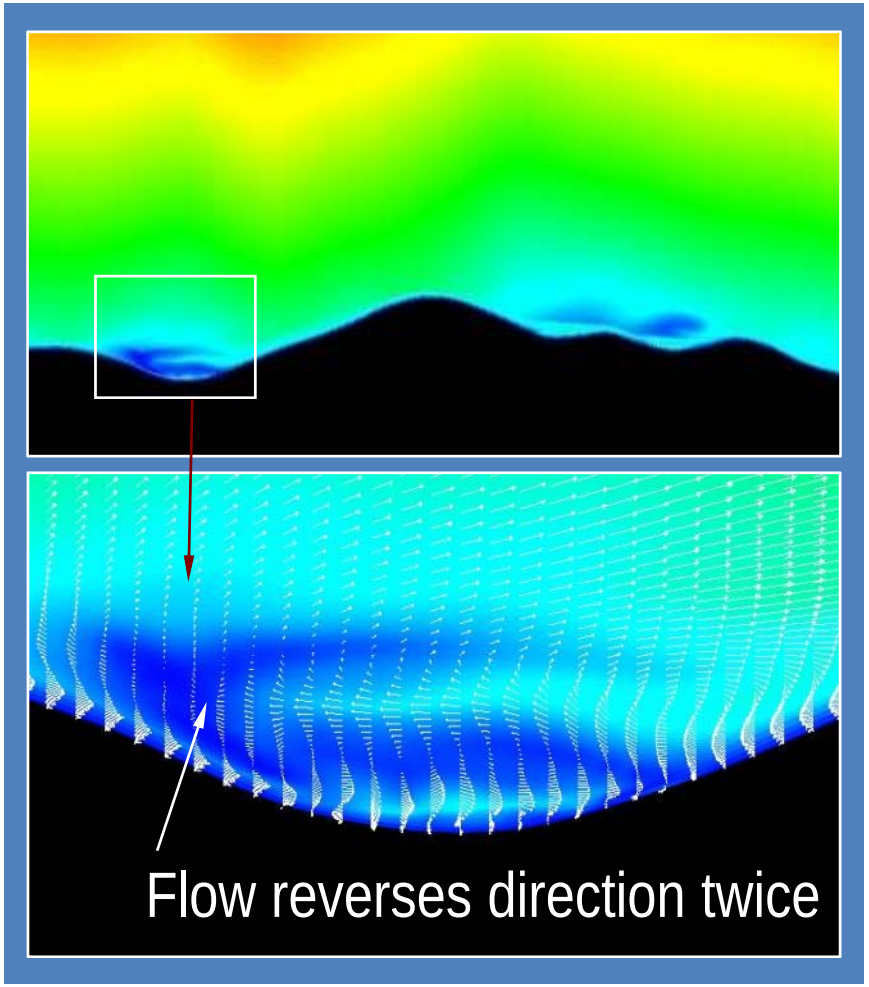
LDRD investment at LLNL enables the development of high-quality and high-efficiency wind flow models

Predictions of wind characteristics

- Optimize wind farm siting
  (+10-20% above base case)
- Improve efficiency of operations
  (+10-20% output & profit)
- Reduce damage to turbines
  (>4X longevity)

February 2009: LLNL signs agreement with Siemens to improve wind energy generation

SIEMENS

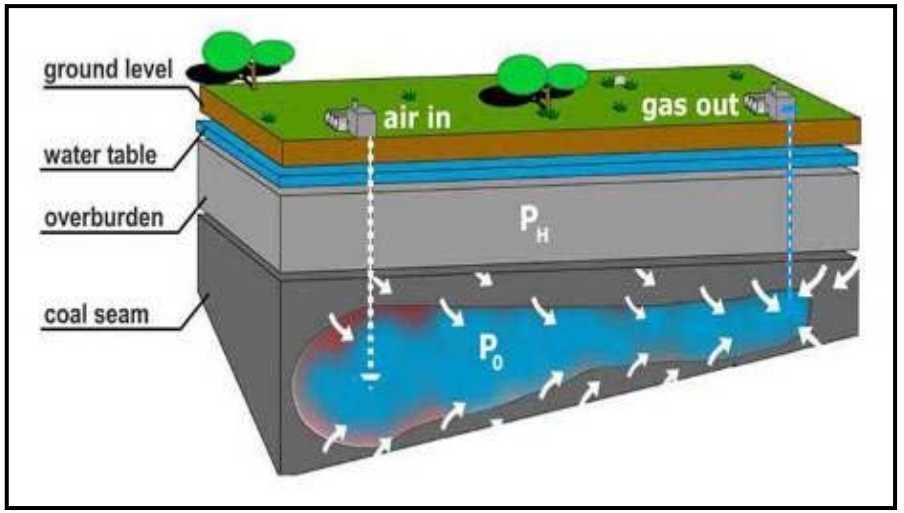


Underground coal gasification: promise of reduced carbon management costs and increases energy security

Courtesy ENN, Lang Fang China

Underground coal gasification (UCG) could change the game for energy and environmental security

- **Secure domestic supply**
  - **3–4 times increase in coal reserves**
  - **Low-cost synthetic natural gas**
- **Economics and energy supply**
  - **Appears substantially cheaper (>30%) that conventional PC power**
  - **Lower CAPEX and OPEX**
- **Greenhouse gas emission reduction**
  - **30–50% reduction in carbon capture and sequestration (CCS) deployment costs**
  - **Cheap hydrogen production; more H_2/ton that surface equiv. pre-shift**
- **Environmental quality gains**
  - **No mining required (acid drainage, mountain top removal)**
  - **Criteria pollutant emission management (SO_x, NO_x, Hg, ash)**
  - **Much less water consumption**



Courtesy ErgoExergy, CA

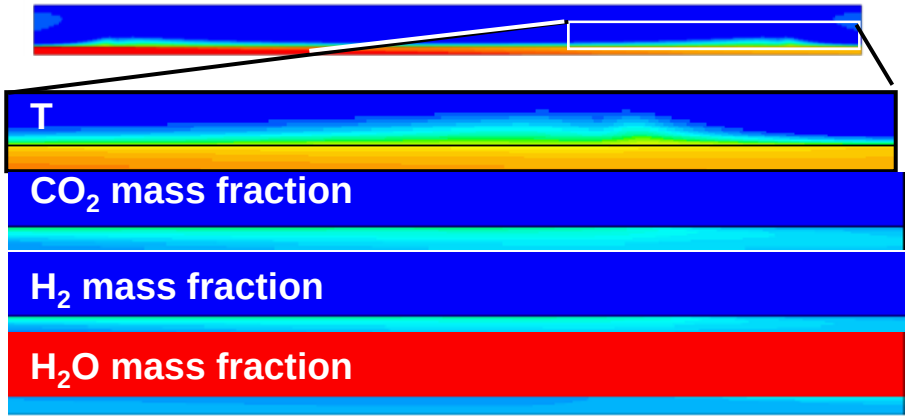
Economic and environmental aspects have increased interest in N. America and key developing countries (India, China, S. Africa)

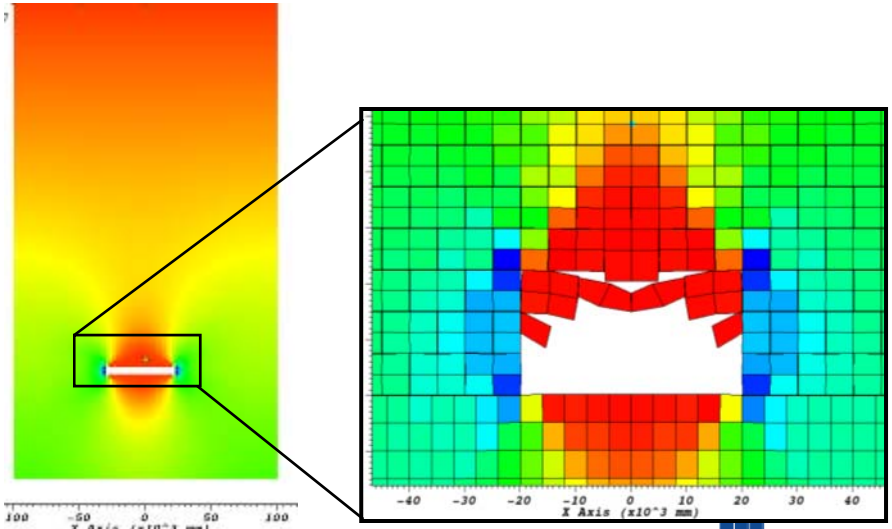
LLNL continues to show leadership and LDRD investment in UCG technology development

Major current accomplishments

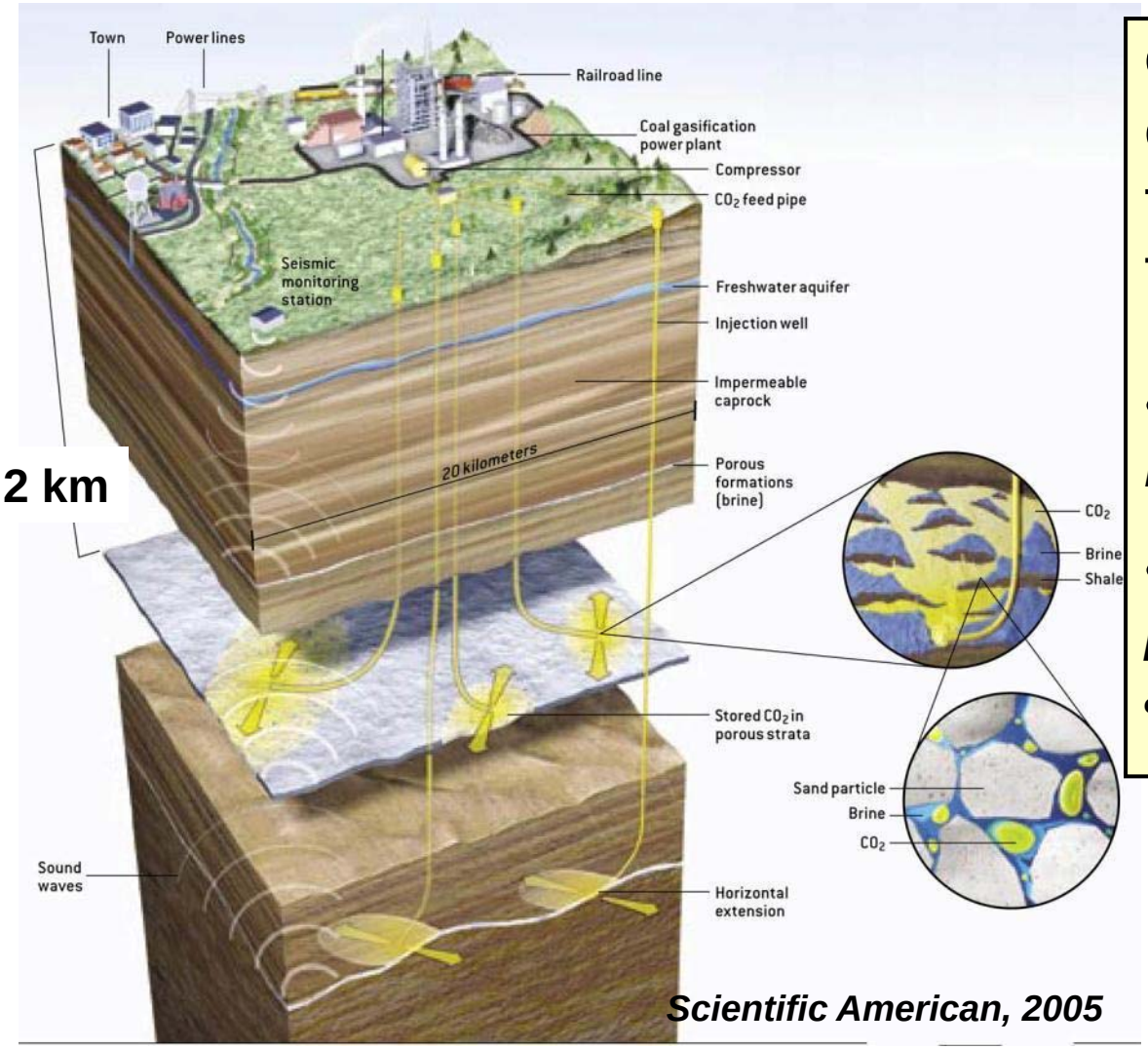
- Partnered with several US and international projects and companies
- Developed a set of tools for environmental assessment
- Developed methodologies for process control monitoring
- Developed “best in class” gasification, thermo-hydrological, and geomechanical simulation tools for UCG
- Developed engineering and economic models for UCG
- Developed and tested resource assessment tols for UCG
- Beginning work on monitoring suites (assessment, simulation, design)

LDRD vitally important to many efforts





Geological carbon sequestration is the deep injection of CO_2 to avoid atmospheric release



Scientific American, 2005

CO_2 can be stored in deep geological formations as a pore-filling fluid:

- **Saline Formations:** ***largest capacity (>2200 Gt)***
- **Depleted Oil & Gas** ***potential for enhanced oil and natural gas recovery***

LLNL LDRD investments have provided new S&T and tools for deployment

Primary sequestration focus areas

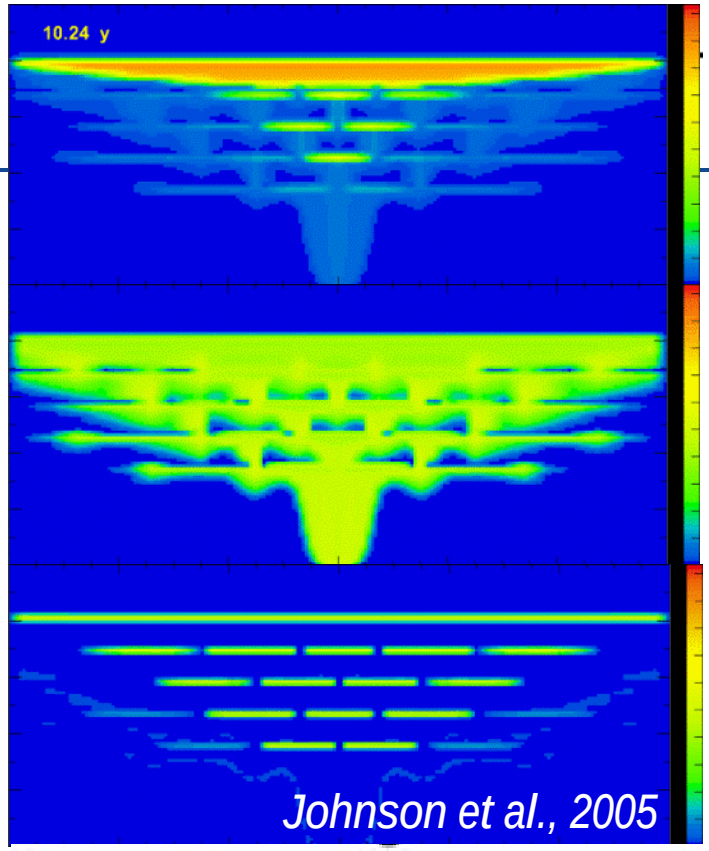
- Advanced process simulation (including laboratory work)
- Tools and methods to monitor and verify CO_2 underground, including monitoring integration
- Site characterization and risk assessment

Other efforts

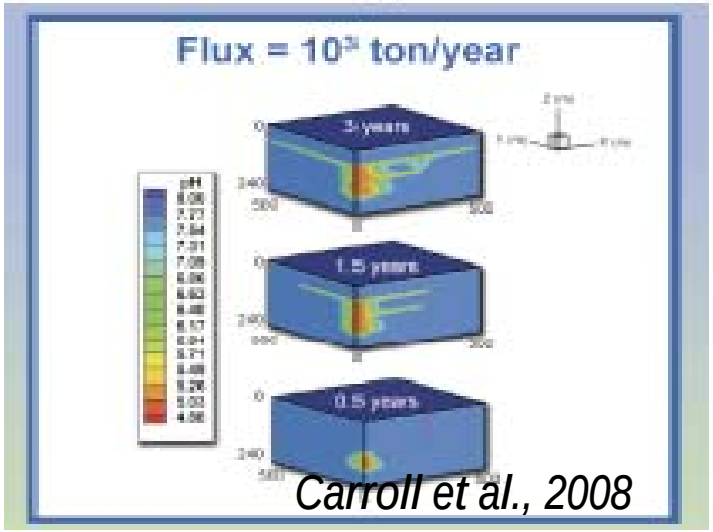
- Wellbore integrity
- Atmospheric leakage
- Carbon capture technologies
- CCS and water co-production

LLNL works closely with the DOE, industry, and other key stakeholders

- Active in 4DOE regional partnerships
- All four commercial international projects
- Partnered with power generators, oil & gas companies, NGOs
- Developing guidelines; practices' protocols



Johnson et al., 2005

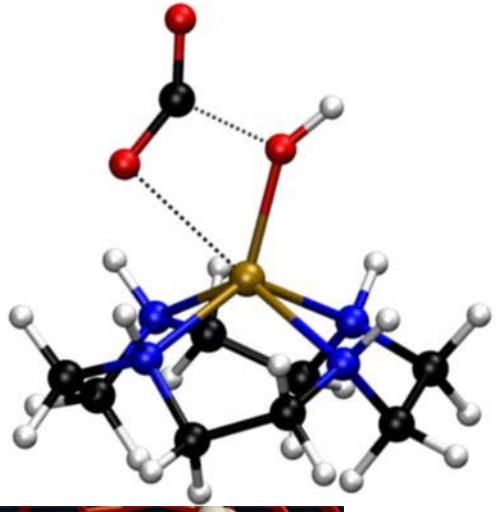


Carroll et al., 2008

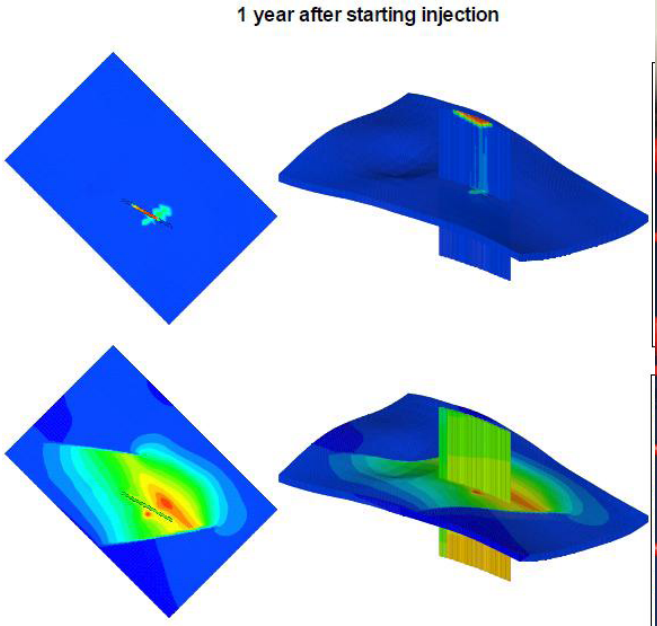
New LDRD investments will lead to lower costs for capture and safer, more effective sequestration

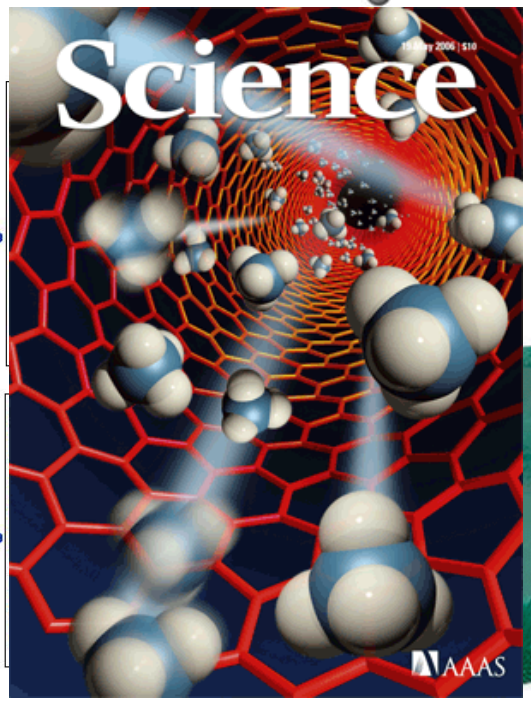
Continued thrust areas

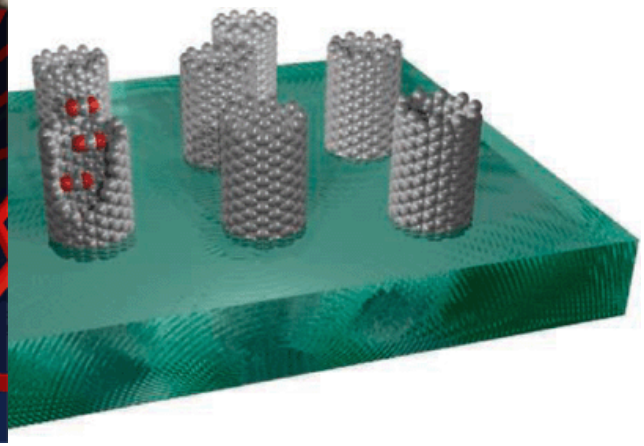
- Low-cost capture technologies (nanotube membranes, catalysts)
- Improved monitoring approaches and integration/data fusion
- Reduced and quantified potential risks (air, groundwater, seismicity)



1906 S.F. Quake







LDRD has allowed LLNL to contribute to the US economic competitiveness in energy and environment

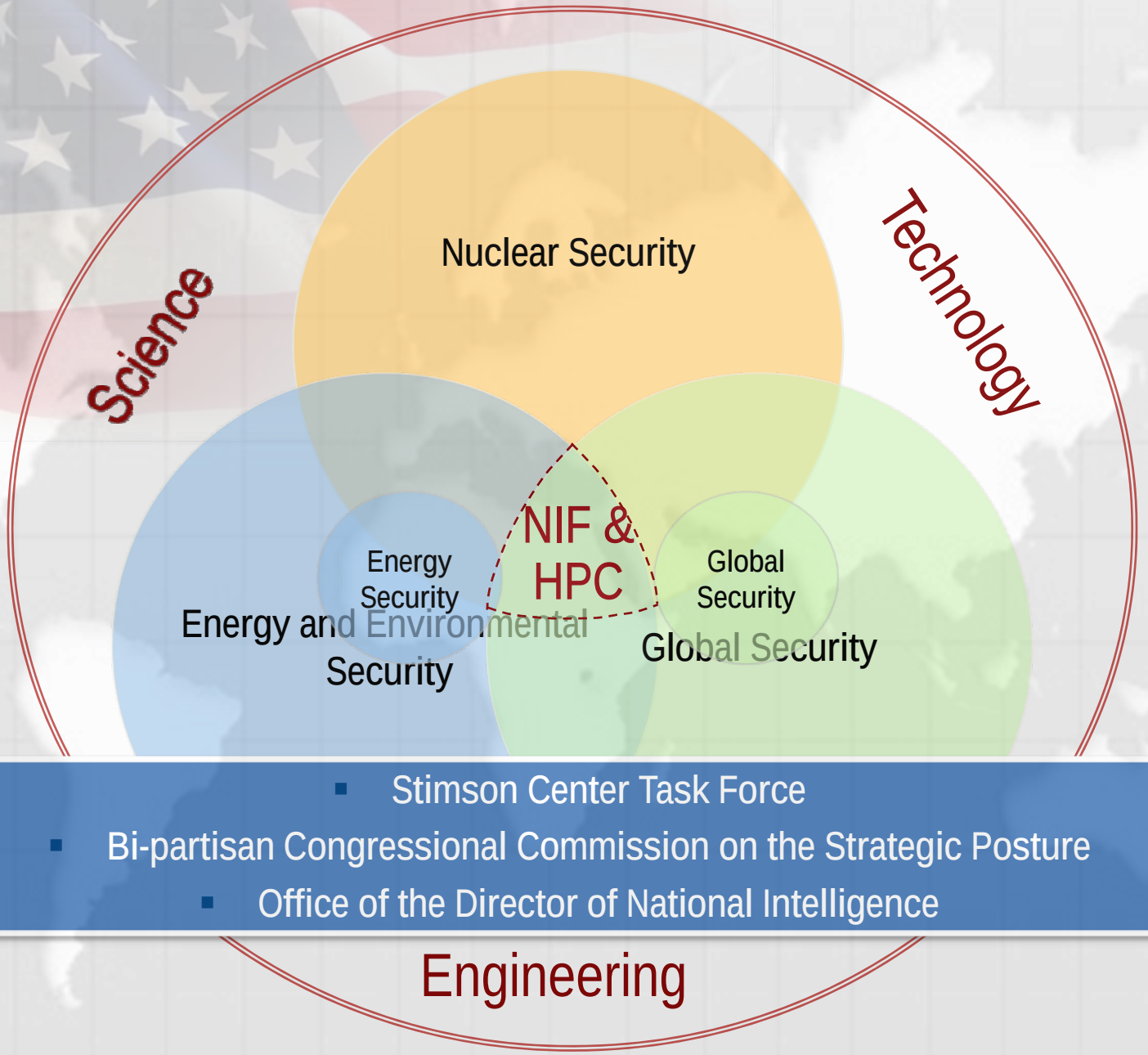
- **Modular electromechanical batteries**
- **Advanced lithium batteries**
- **The *Inductrack* system (MagLev)**
- **Corrosion-resistant materials**
- **Simulations for advanced engine design**
- **Light-weight (carbon fiber) materials**
- **Heavy truck vehicle efficiency**
- **The Hyperion High-Performance Computing Consortium**
- Carbon nanotube membranes
- Underground coal gasification
- **Geothermal innovations**
- Wind power predictions
- Carbon capture and sequestration innovations
- Air capture of CO_2

LDRD investment is a key to staff retention, recruitment, and training

- LDRD is the most significant avenue for recruitment of new scientific personnel to the Laboratories
- More than 50% of postdoctoral employees receive LDRD support
- LDRD is the gateway for converting ~70% of postdocs to staff positions

LDRD helps the Labs and LLNL prepare for the future S&T challenges facing the nation

LLNL Vision: National Security in a Global Context



- Stimson Center Task Force
- Bi-partisan Congressional Commission on the Strategic Posture
- Office of the Director of National Intelligence