Carbon Dioxide Sequestration: State of the Science

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California Energy Commission

Carbon Management: An Approach for Integrated Energy Systems Management

Efficiency $< \frac{\text{Btu}}{\text{GSP}}$

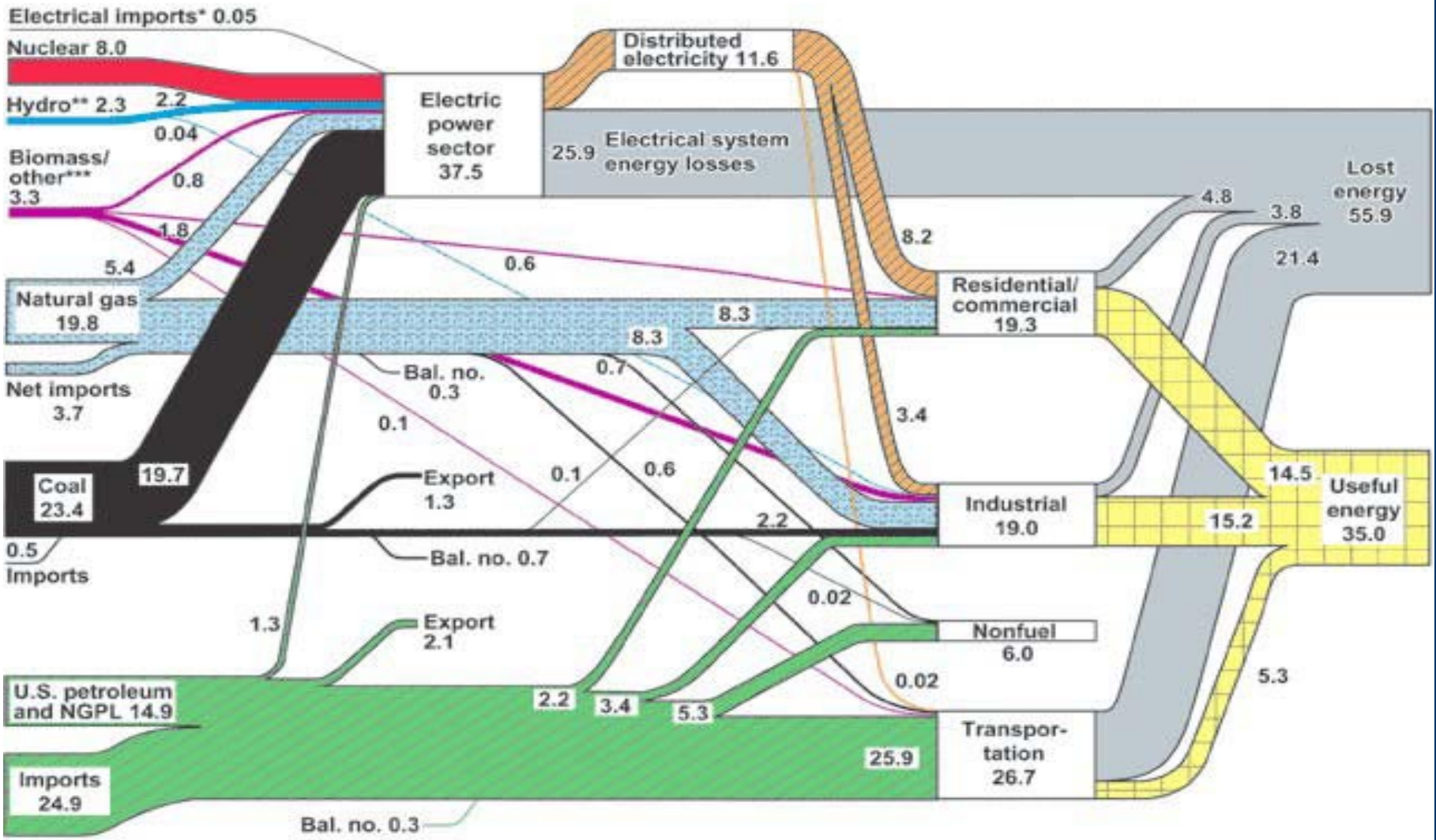
Decarbonization $< \frac{CO_2}{\text{Btu}}$

Sequestration $< \frac{CO_2 \text{ atm}}{CO_2 \text{ produced}}$

The Challenge We Face is Daunting as We Enter Another "Fossil Fuel Economy"

- 7.4 GtC/year in 1997
  - 3.5 GtC to the atmosphere
  - 85% of U. S. energy
- 10 GtC/year in 2020
  - Relative abundance and low costs of fossil fuels
- Sequestration limitations
  - Raw materials and financial commitments
  - Limited collateral benefits
  - Uncertain impacts

U.S. Energy Flow Trends – 2001
Net Primary Resource Consumption ~97 Quads



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2001*
*Net fossil-fuel electrical imports
**Includes 0.2 quads of imported hydro
***Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

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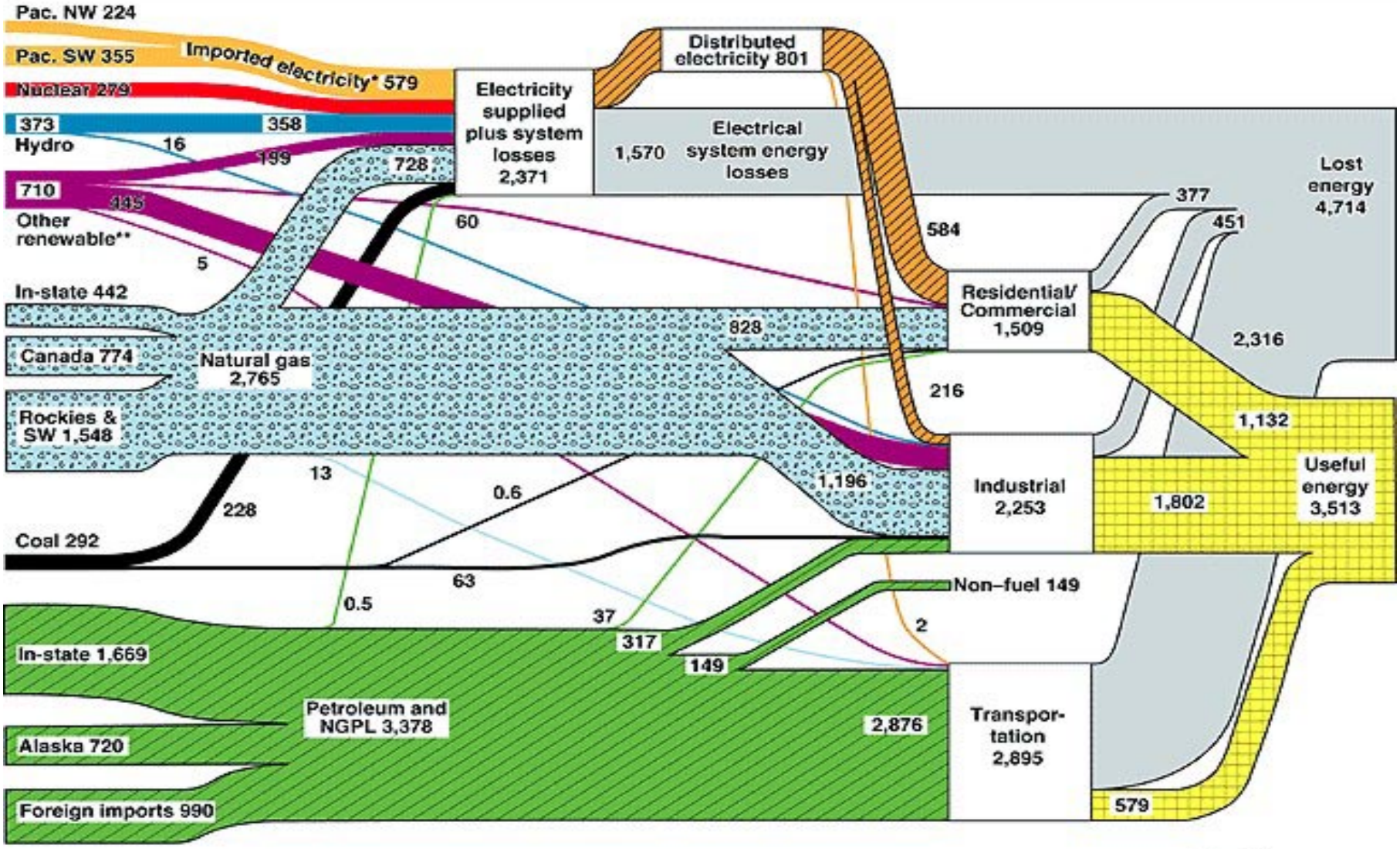
California Energy Flow Trends– 1999

Net Primary Resource Consumption ~8375 Trillion Btu (8.375 Quads)



Sources: U.S. Department of Energy's Energy Information Administration and California Energy Commission.
*Electricity flowing into the California control areas: CAISO, LADWP, and IID.
**Other renewable includes geothermal, wood and waste, solar, and wind.

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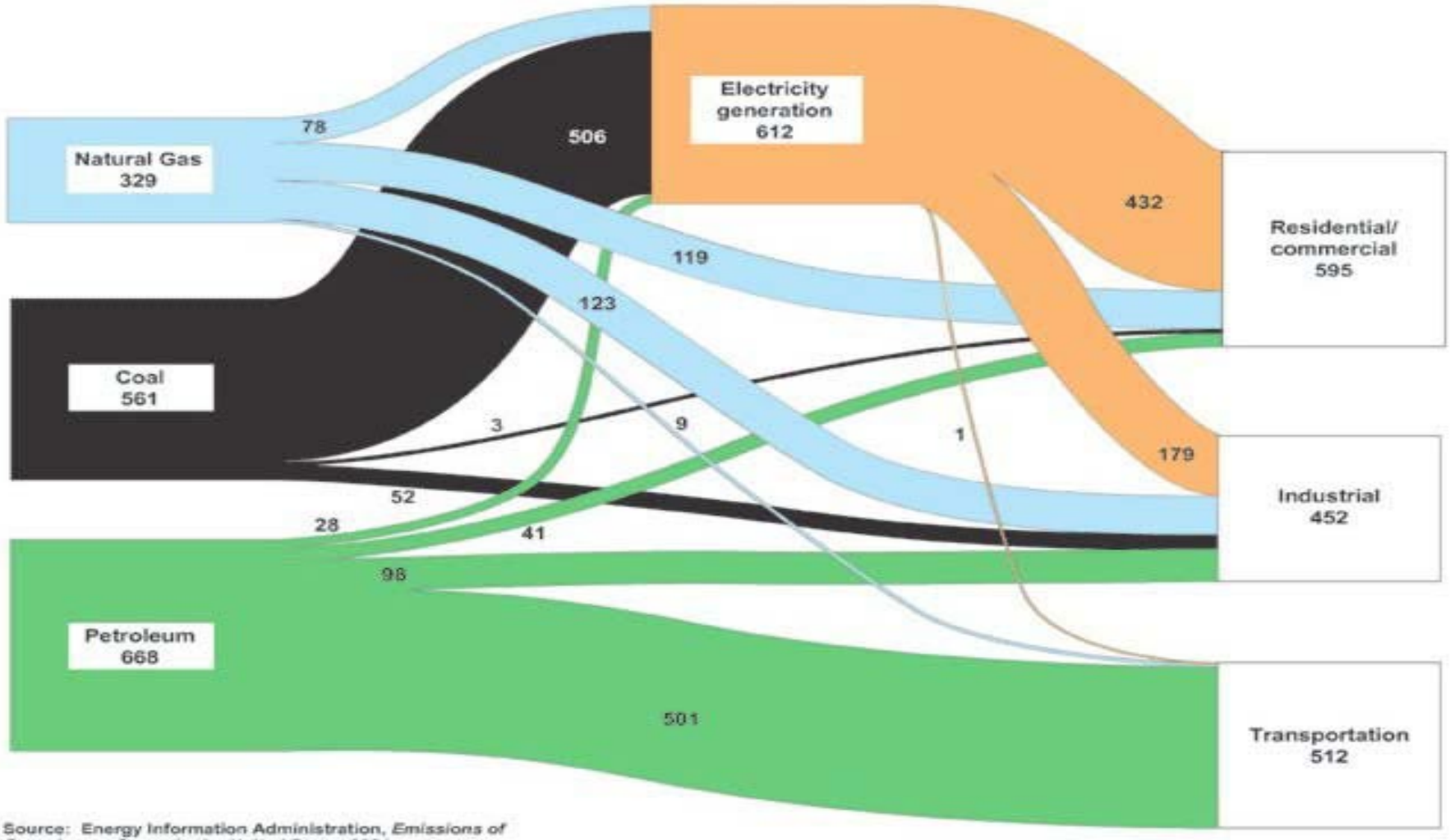
US 2001 Carbon Emissions: 1547 MtC



Source: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2001*
*Includes adjustments of 14.8 million metric tons of carbon (MtC) from U.S. territories, less 26.4 MtC from bunker fuels
Note: Numbers may not equal sum of components because of independent rounding

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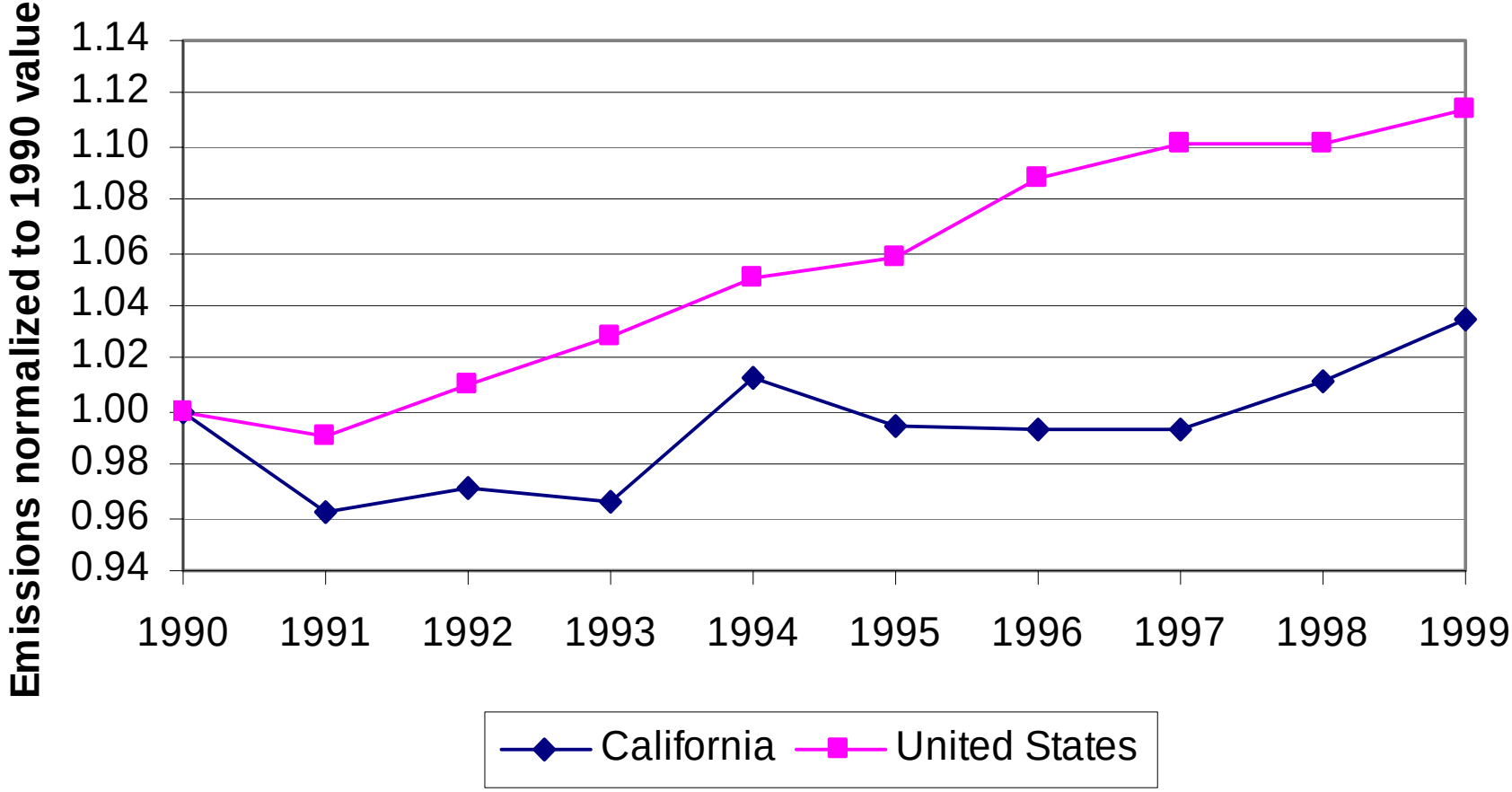
1990-1999 Relative Gross Greenhouse Gas Emissions for California



Integrated Energy Systems: Requires a Portfolio of Options

- Partnerships
- CRADAs
- Collaborative research

Test facilities

Systems engineering

Power

Infrastructure

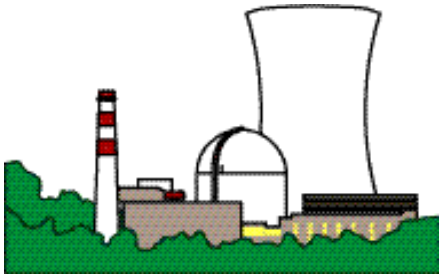
Fuels

Storage/ conversion

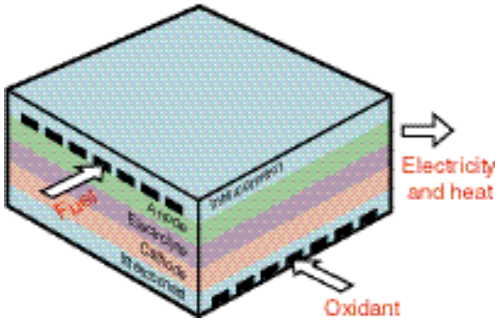
Infrastructure

Fuels

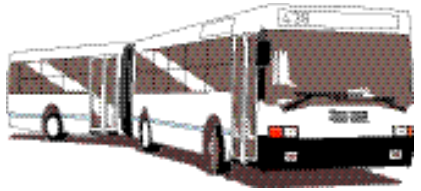
Transportation



- Renewable
- Fossil
- Nuclear
- Hydro



- Batteries
- Fuel cells
- Flywheels
- Hydrogen



- Automotive
- Heavy-duty vehicles
- Mass transportation

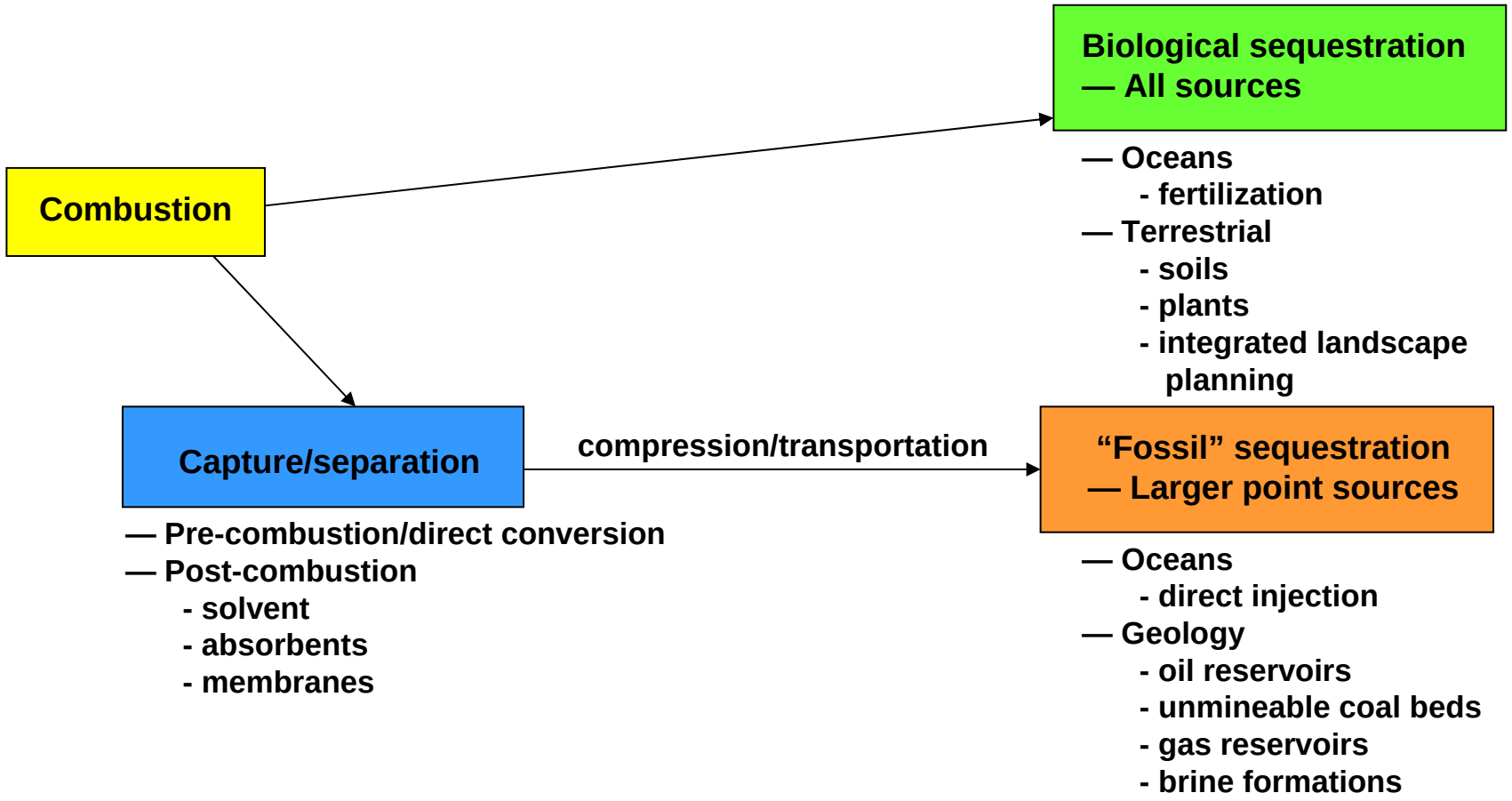
This Integrated Approach Must Address Cross-Cutting Policy/Technology Issues

- Policy issues such as deregulation and changes in tax code to reduce CO_2 emissions
- Comparative and life-cycle analyses vis-à-vis other technology options
- Improved understanding of coupled biogeochemical cycles (e.g., H_20, 0_2, N) and their relationship to the carbon cycle
- Improved and validated simulation models
- Monitoring and validation of technology effectiveness

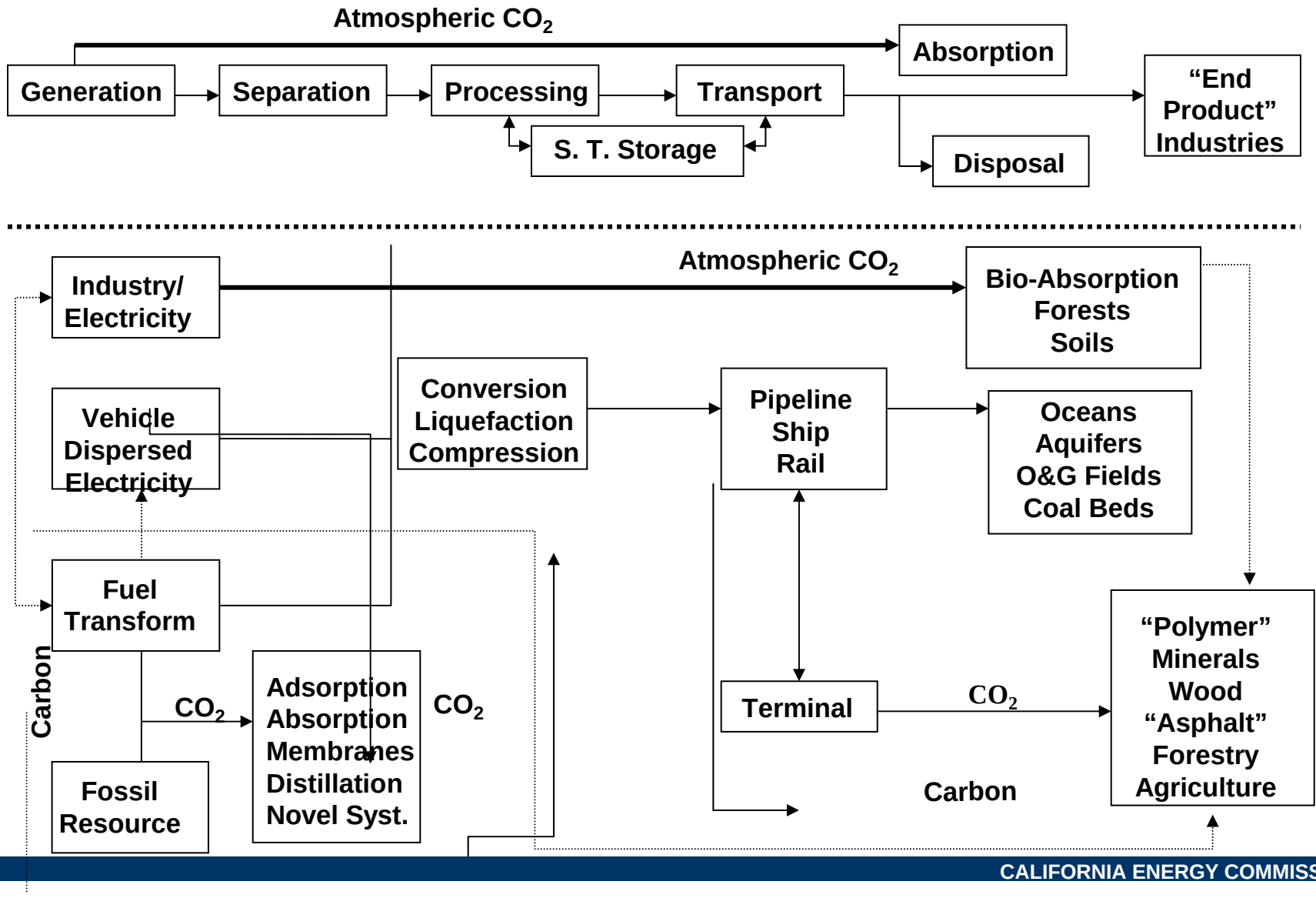
Integration of Sequestration R&D Efforts Should Consider System Technology Platforms

- Carbon processing (separations and capture)
- Biological absorption (terrestrial, oceans)
- Engineered solutions (geological, oceans)
- Advanced characterization and monitoring technologies
- Utilization of validated modeling and simulation decision tools

Systems approach: 100,000-foot level



Carbon Capture and Sequestration's Relationship to Fossil Energy System



Overall Recommendations for a Future R&D Program Report are Straightforward

- Technologies should be cost-effective and benign
- R&D must be integrated with other related programs
- R&D program must be flexible and must target a variety of approaches
- Use field investigations to increase understanding of processes at field scale

Any Government-Funded R&D Program Must Address These Concerns

- **Risk/uncertainty**
  - Costs
  - Environment
  - Safety and health
  - Technical feasibility and efficiency
- **Environmental**
  - Understanding dangling impacts
  - Uncertainties of new “disposal” options
- **Verification**
  - Immediate effectiveness of technology
  - Need for monitoring for longer-term storage
- **Perceptions**
  - Public
  - Industry

To Address the Intersection of Technology/Science/Public Policy Issues, DOE has Developed a Set of Regional Carbon Sequestration Partnerships

- Answer for technology - Sites for geological and terrestrial sequestration
- Answer for science - Address risk and containment
- Address public policy - Regulatory requirements and public perceptions

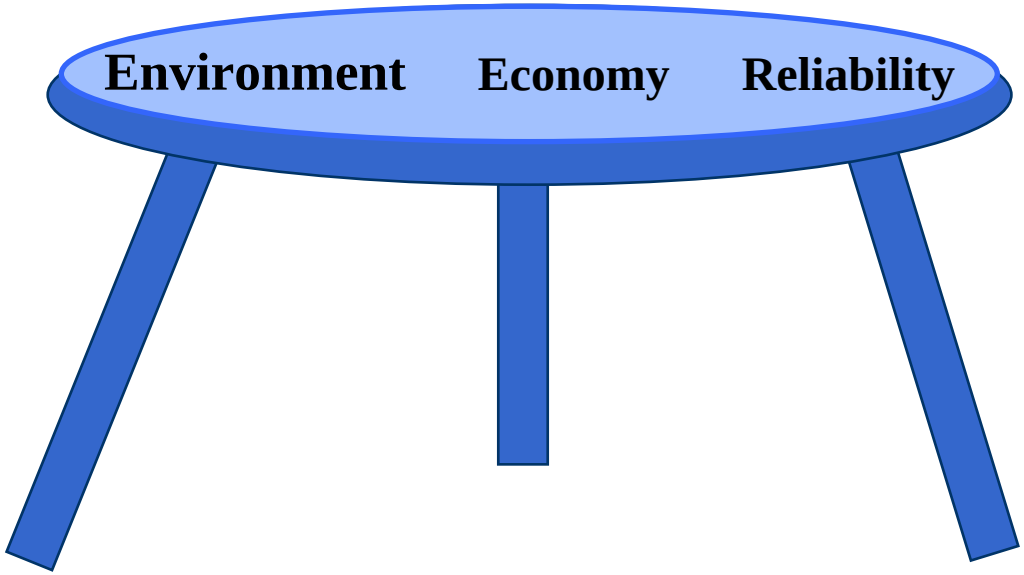
We will Couple Current California R&D Efforts with Precepts of Carbon Management for The West Coast Regional Partnership

- **End-use efficiency and demand-side technologies**
  - buildings and appliance technologies
  - manufacturing, agriculture, water efficiency
  - storage and conversion technologies
- **Clean technologies**
  - renewables and small-scale fossil
  - generation and control technologies that enhance environment
  - new technologies with collateral benefits
- **Enabling technology improvement and development**
  - models, sensors, monitoring systems to improve T&D system operation and integration of DG
  - science base and model improvements to evaluate impacts of energy systems
  - development of new integrated systems and economic models to improve understanding of market structure

California is Aggressively Working to Reduce CO_2 Emissions

- California Building and Appliance Energy Efficiency Standards
- California Tailpipe Law: TBL
- Climate Action Registry
- Renewable Portfolio standard
- Potential for hybrid and fuel cell advances: ARB initiatives

Carbon Management and West Coast: An Appropriate Paradigm for State R&D Programs



Couple state and external issues

Long-term solutions couple to current events

Integration with external R&D provides flexibility

Regional Partnership Overview

- Partnership will evaluate options and opportunities for CO_2 capture and storage, transport, regulatory permitting, public outreach, monitoring and verification, and the environmental efficacy of sequestration
- Partnership consists of state and local agencies, academia, research laboratories, energy producers and users, and non-profit organizations, in a multi-state region
- Two phases:
  1. **data collection, assessment and planning;**
  2. **pilot demonstrations**

Partnership Has Been Designed to Advance Practical Applications of Carbon Sequestration

- Capture, transport and geological storage options
- Terrestrial sequestration opportunities
- Regulatory analysis and permitting
- Monitoring and verification
- Economic and environmental efficacy
- Public outreach and education
- Information on regional source/sink relationships

California Energy Commission Has Assembled a Strong Team

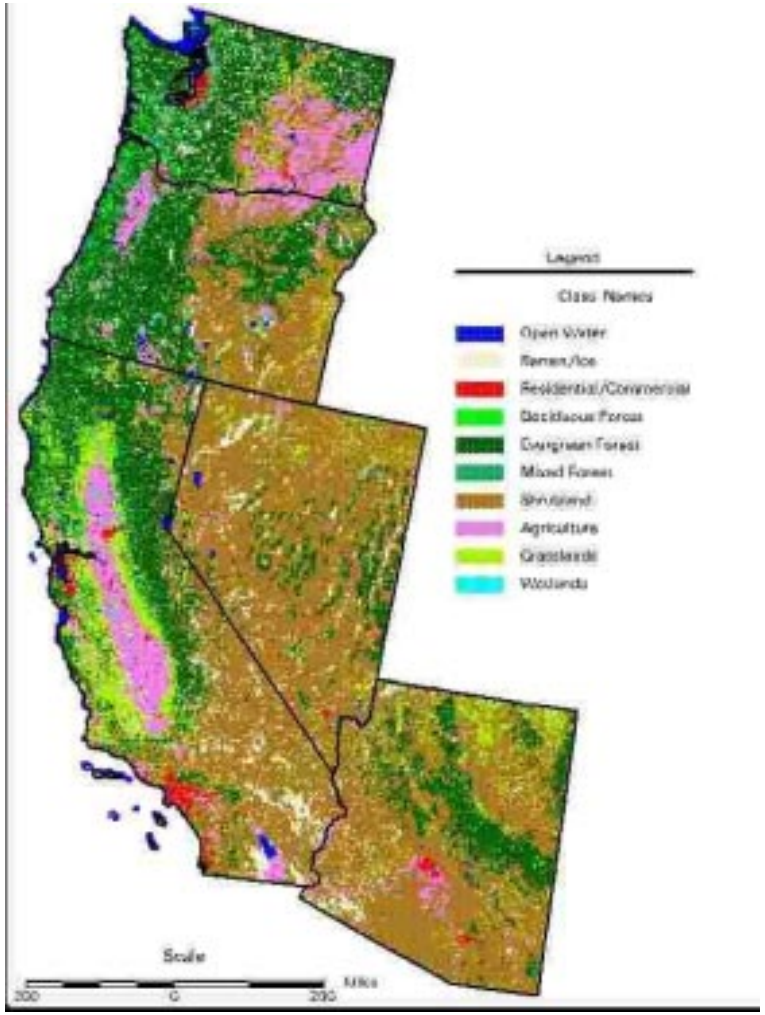
- **Policy and Coordination** (Western Governor's Association)
- **State Resource Management, Environmental Protection, and Regulation** (CA Dept. of Forestry and Fire Protection, CA Dept. of Oil, Gas and Geothermal Resources, CA Geologic Survey, CAL EPA, OR Dept. of Forestry, Nevada Bureau of Mines and Geology, WA Dept. of Natural Resources)
- **Oil and Gas Companies** (AERA, BP, Chevron Texaco, ConocoPhillips, Occidental Petroleum, Shell)
- NGO's (Pacific Forest Trust, Natural Resources Defense Council)
- **Utilities** (Pacific Corp., Salt River Project, Sierra Pacific Resources, TransAlta)
- **National Lab and Research Institutions** (Electricity Innovation Institute, Kearney Foundation, LBNL, LLNL, MIT, Stanford-GCEP, Winrock)
- **Engineering Companies** (Advanced Resources International, Clean Energy Systems, KinderMorgan, Nexant, SFA Pacific, Terralog)
- **Public Outreach/Education** (Cal State Bakersfield, Cal Poly, SF Dept. of Environment, Science Strategies, Western State Petroleum Association)

The Region Forms a Coherent Study Unit

- Commonality in terrestrial sinks in WA, OR, and Northern CA
- Significant CO_2 source - over 11% of US anthropogenic emissions
- Commonality and large potential capacity in geological sinks in CA, NV, and AZ
- Significant potential for offsetting costs with EOR and EGR in California and Alaska North Slope

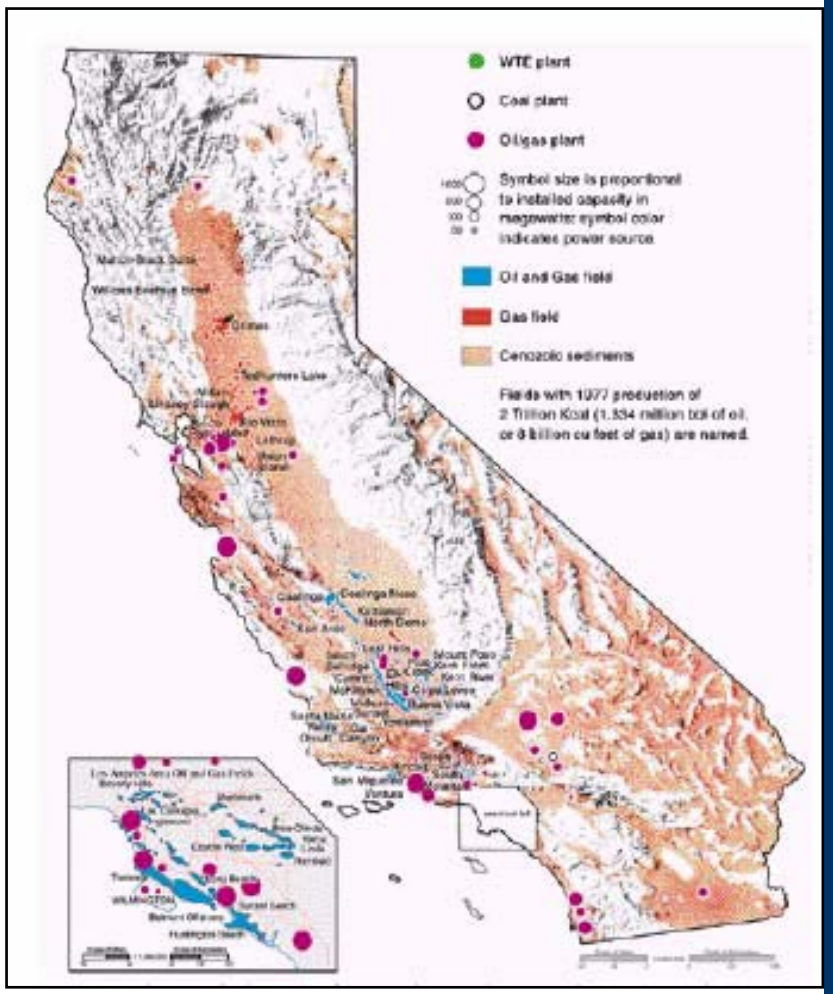
Regional Characterization; Data Collection

- Terrestrial data includes land use, land cover, hydrology, soil maps, crop yields, land ownership, etc.
- Point source data for power plants and major industrial sources; location, amount, processes
- Transportation data with focus on pipelines, including right-of-ways and topography
- Geologic data includes location, depth, formation properties, etc.



Regional Characterization; Data Integration

- Winrock will develop two point terrestrial baselines for WA, OR, AZ, and CA
- Complementary effort by Kearney Foundation on soil carbon storage in California
- Consolidated GIS-based geologic sequestration database to be developed
  - **Source, transport, and site data**
  - **Cooperative effort with WGA, Utah AGRC, MIT, and CA Geologic Survey**



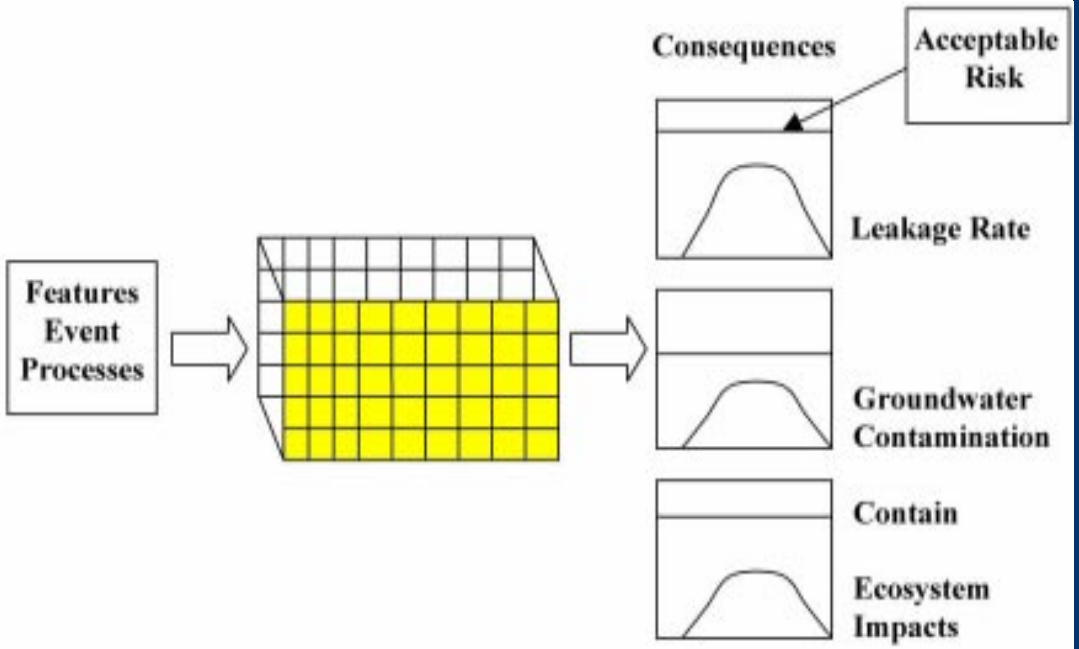
Power plants and oil/gas fields in California

Technology Deployment Issues

- Develop an action plan to address environmental efficacy and regulations; focus on strategy for pilot projects and larger-scale deployments
- Life cycle analysis of impact of CO_2 capture, transport and storage options on other emissions
- Compile and assess regulations and permits; current and future

Technology Deployment Issues (Cont'd)

- **Develop risk assessment framework for geologic sequestration**
  - **Builds on previous work by LBNL, CCP, and LLNL**
  - **Develop features, events and processes (FEPs)**
  - **Quantify failure probability and consequence**
- **Develop protocols for monitoring and verification**
  - **Builds on previous work by LBNL, LLNL, CCP, and others**
  - **Perform simulations to assess monitoring technique sensitivities**



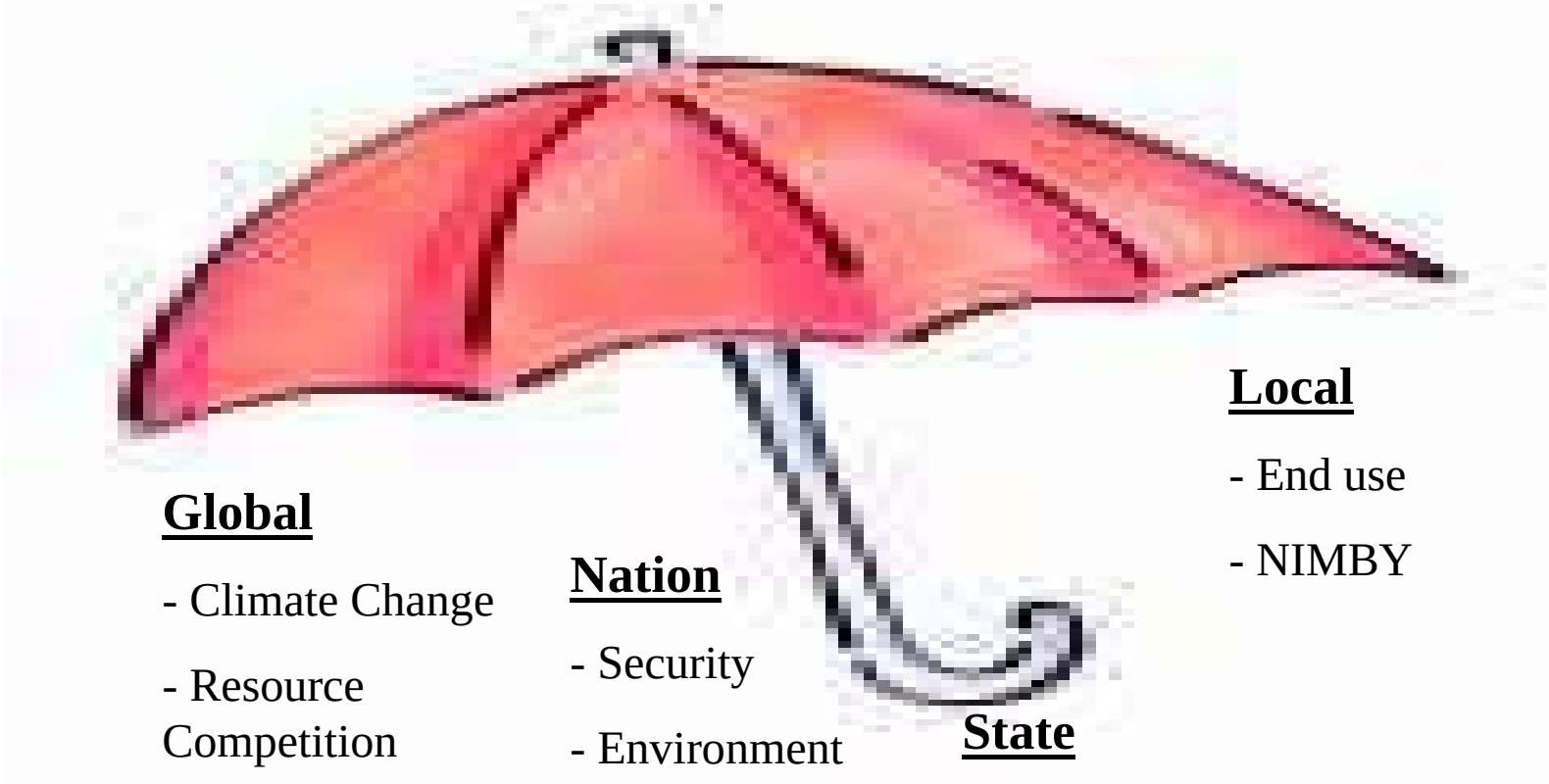
Public Outreach

- Create Partnership web site
- Use existing channels, e.g.. State forestry depts.
- Develop University and K-12 curricula; work with WGA
  - CSUB Geo-technology Training Center
  - Cal Poly Center for Teacher Education
- Hold stakeholders' meeting
- Advice from NGOs,other stakeholders
- Prepare action plan

West Coast Regional Partnership Will Be a Springboard for Deployment of New Technologies

- Determine suite of technologies best suited for region based on
  - Sources
  - Sinks
  - Current/future infrastructure
- Determine regulatory issues and infrastructure needs for technology deployment
- Develop educational materials to enhance public acceptance of technologies and evaluation of impacts related to public opinion
- Identify least cost options associated with sequestration alternatives
- Evaluate environmental and public health risks and develop mitigation strategies

Carbon Management: An Umbrella for Global, National, State and Local Issues



Global

- Climate Change
- Resource Competition

Nation

- Security
- Environment
- Economy

State

-Affordability
- Environment
- Reliability

Local

- End use
- NIMBY

Driving to a Sustainable Future: The "E"s are Linked

- Environment
- Energy
- Economics
- Equity
- Education