westcarb.org
West Coast Regional Carbon Sequestration Partnership

# NETL Annual Review Meeting


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# Outline

- Project overview; Phase II pilots
- Identifying, characterizing, and screening basins
- Source-sink matching and selection of best options
- Terrestrial baselines and supply curves

# WESTCARB Tasks

- Source-sink matching for geologic sequestration
- Terrestrial sequestration baselines and supply curves
- Technology deployment issues: risk, regulations, monitoring, public outreach
- Selection of best options and field pilots

# Project Milestones

| Milestone | Description | Status |
|---|---|---|
| 1 | Finalize GIS database framework | Complete |
| 2 | Populate GIS database with geologic and terrestrial sequestration data | California and Nevada geologic layers complete; California terrestrial nearly complete; other states under way |
| 3 | Finalize protocols for monitoring and verification of geologic storage sites | In progress |
| 4 | Complete risk assessment framework for geologic storage | Draft framework complete |
| 5 | Analyze impacts of $CO_2$ capture technologies on other power plant emissions | In progress |
| 6 | Complete assessment of regulatory and permitting issues | Geologic and terrestrial near completion |
| 7 | Establish plan to overcome technology deployment obstacles | In progress |

# Project Milestones (continued)

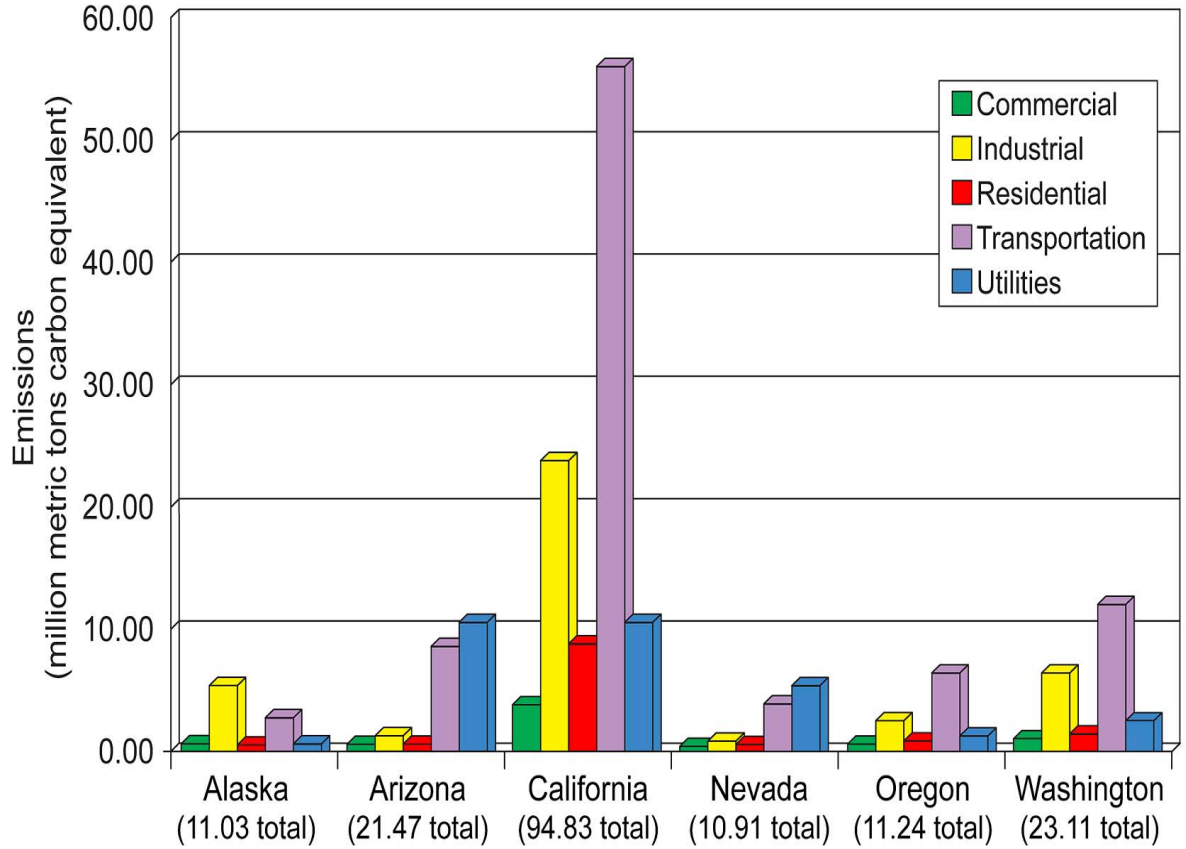
| Milestone | Description | Status |
|---|---|---|
| 8 | Establish research teams to develop and test sequestration-related curricula | Emphasis currently on other outreach opportunities |
| 9 | Hold multi-stakeholder technology/policy public meeting | Held Oct. 27, 2004 in Portland, OR |
| 10 | Develop and implement public outreach plan | In progress |
| 11 | Establish feasibility algorithms for evaluating the viability of geologic storage sites | Nearly complete |
| 12 | Rank geologic sequestration options for the WESTCARB region | Draft methodology in place |
| 13 | Establish state-by-state terrestrial supply curves | California complete; 3 other states under way |
| 14 | Submit action plans for implementing pilot validation reports | Pilots being identified |

# The California Energy Commission Leads A Strong Multi-Sectoral 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, Region 9 EPA, WA Dept. of Natural Resources)
- **Oil and Gas Companies** (AERA, BP, Chevron Texaco, ConocoPhillips, Occidental Petroleum, Shell)
- **NGO's** (Pacific Forest Trust)
- **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, Golder Associates)
- **Public Outreach/Education** (American Petroleum Institute, Cal State Bakersfield, Cal Poly, SF Dept. of Environment, Science Strategies, Western State Petroleum Association, Cement Industry Environmental Consortium)

# WESTCARB States Account for 11% of U.S. $CO_2$ Emissions

- **Within WESTCARB, transportation accounts for 53%, utilities 13%, and industry 23% emissions**
- **Largest point sources are power plants, oil and gas producing field operations, oil refineries, and cement plants**



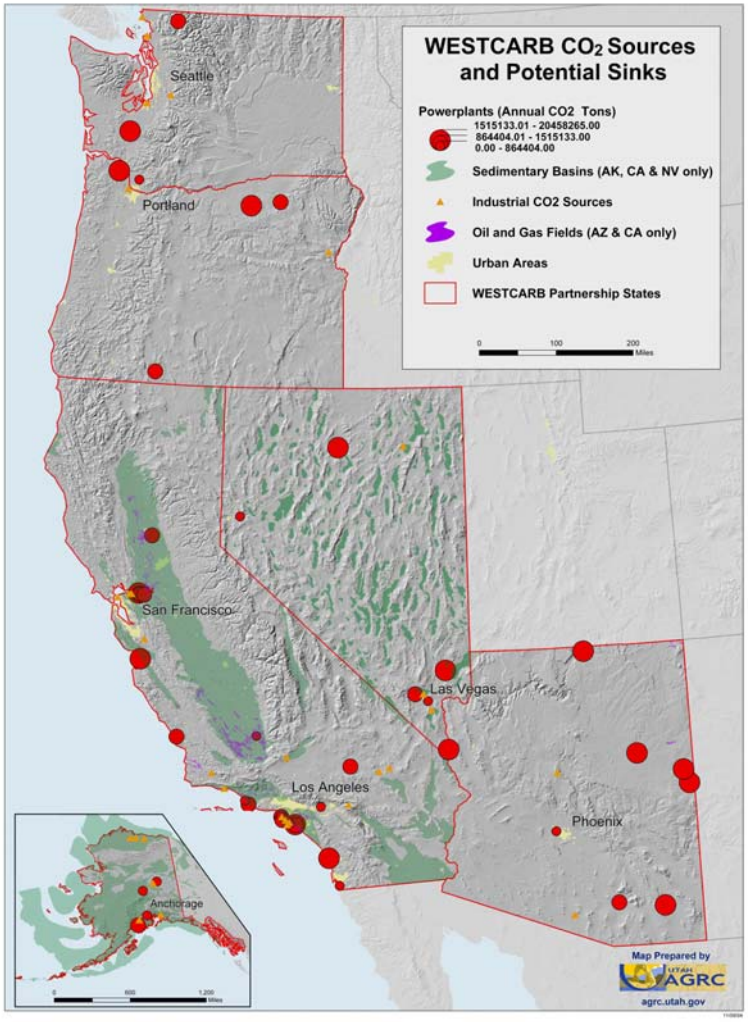

Data Source: EPA $CO_2$ emission inventories for 1999 fossil fuel combustion

# Steps in Source-Sink Matching for WESTCARB Region

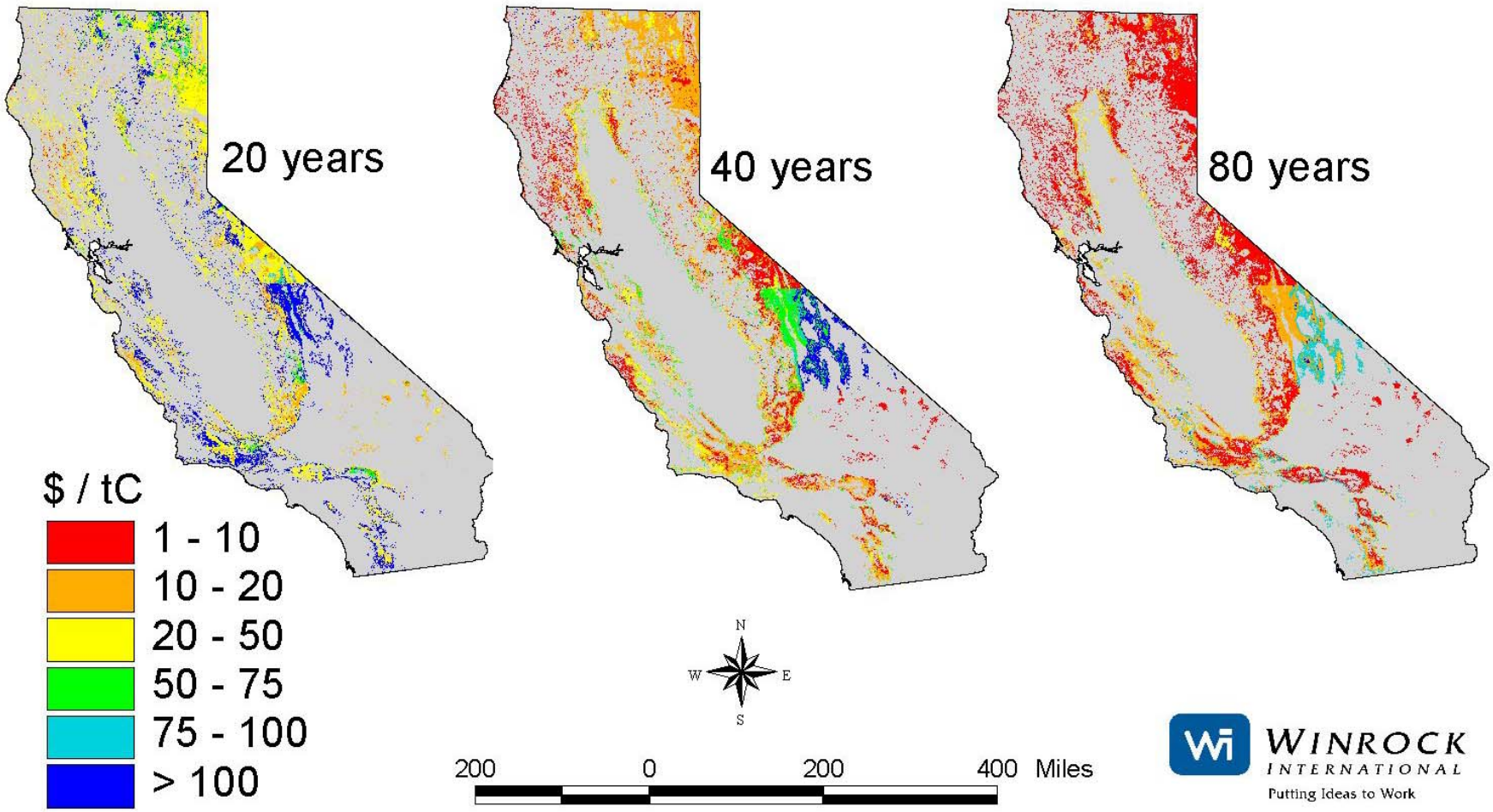
- Identify and characterize point sources
- Identify and characterize sedimentary basins
- Identify and characterize oil and gas fields and coal beds within sedimentary basins
- Screen basins – a preliminary screen based on depth, size, restricted surface access, lack of seals, yields subset for further analysis
- Do GIS-based economic analysis of source-sink combinations
- Use overlay of decision analysis to incorporate intangible factors in identifying best opportunities

# Point Source and Sink Data Has Been Assembled in GIS Layers

- Characterized sources account for about 80% of total industrial and utility sector emissions
- Other layers contain: oil and gas fields, quaternary faults, topography, population centers, parks and restricted access lands,mines, rivers, roads, etc.
- Data resides at Utah AGRC, public accessibility, part of national database

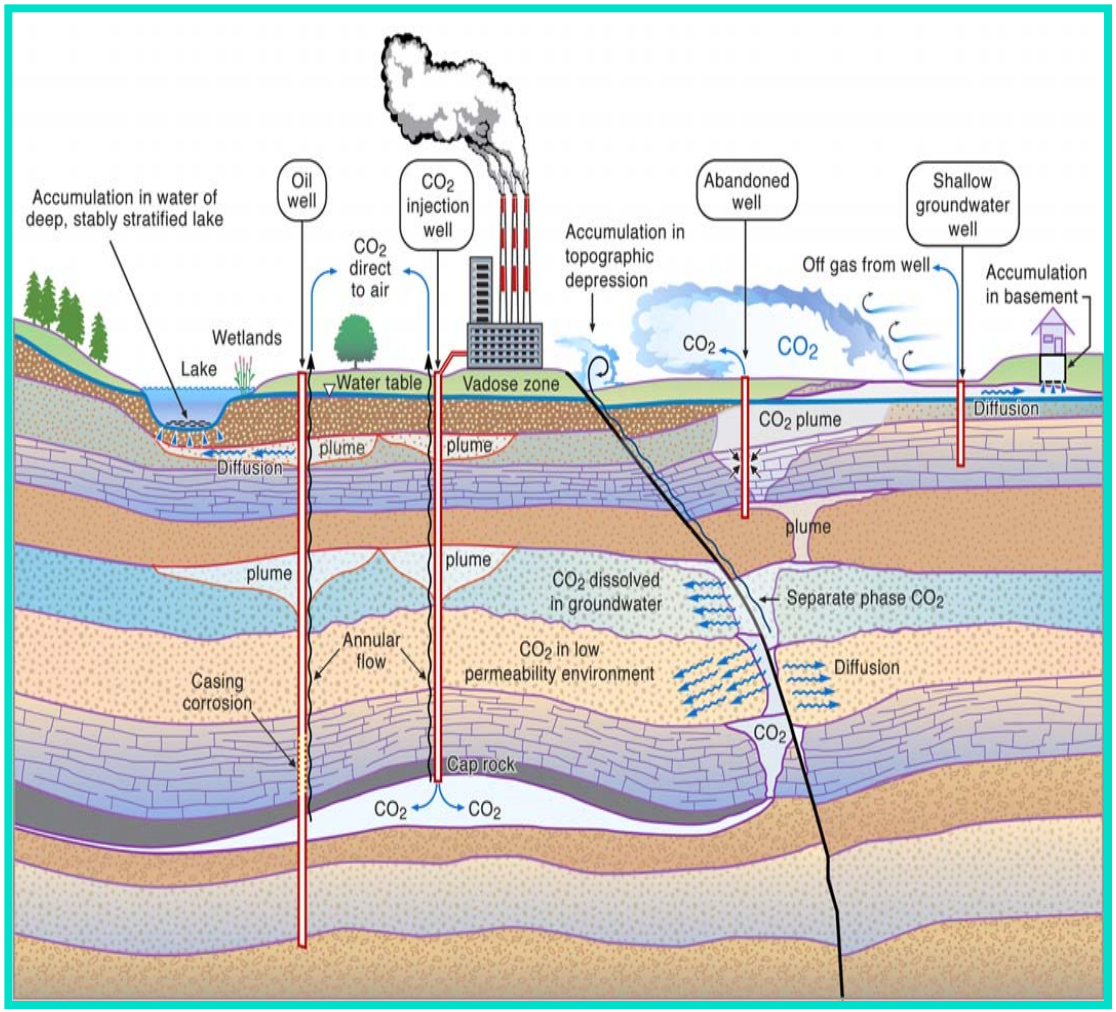


# Baselines and Supply Curves Quantify Major Terrestrial Options



# Regional Screening Needs an Assessment of HSE Risk

- Spreadsheet model for scoring health, safety, and environmental risks due to leakage
- Three primary controlling characteristics
  - Potential for primary containment
  - Potential for secondary entrapment
  - Dispersive capacity



# Public Outreach: What Has Been Done

- Westcarb Website established
- Participation in the Outreach Working Group of the Carbon Sequestration Regional Partnerships
  - Presentations from industry and environmental organizations
  - Risk Communication workshop
  - Development of Carbon Sequestration Risk Q&As
- Supported DOE's Sacramento scoping meeting for the programmatic EIS
- 3-4 middle school teachers from the region to DOE-sponsored Keystone Institute program
- Presentation to California Climate Action Registry annual meeting
- Interview on TechNet
- Discussions with Ventura County Business Development executive
- Development of public acceptance measures for Westcarb Decision Analysis tool
- Portland, Oregon Public Forum

# Public Forum Held in Portland, OR, for Public Agencies, Industry, Academia, Others

- Panel 1: Climate Change in Pacific Northwest and Societal Response
  - Alan Mix, Oregon State University
  - Jae Edmonds, Pacific Northwest National Laboratory
  - Sam Sadler, Oregon Department of Energy
  - Carol Jolly, Washington Governor's office
  - Virinder Singh, PaciCorp
- Panel 2: Terrestrial and Geologic Sequestration Opportunities
  - David Hyman, DOE NETL
  - Lynn Orr, Stanford University, GCEP
  - John Kadyzewski, Winrock
  - Larry Myer, WESTCARB

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## Climate Change in the Pacific Northwest

### A Forum on Opportunities for Managing Impacts through Carbon Sequestration

**Portland, Oregon**
**October 27, 2004 1:00–4:45 p.m.**

**Purpose**

This informational forum will characterize climate change projections for the Pacific Northwest as well as technical and policy measures that could help temper or manage any adverse impacts. Particular emphasis will be given to "carbon sequestration," a collection of technologies and land management techniques that reduces net emissions of $CO_2$, the predominant "greenhouse gas."

Speakers will represent a diverse set of Northwest perspectives and will include scientists, policymakers, government agencies, and businesses. The meeting's panel discussion format will allow ample time for audience questions and discussion. Results will help WESTCARB assess Pacific Northwest carbon sequestration opportunities and issues for the U.S. Department of Energy.

**Who Should Attend**

- Natural resource and environmental protection agencies
- Energy, agriculture, range, and forest interests
- Researchers, university faculty and students
- Legislators, community leaders, and other decisionmakers
- Conservation and environmental groups
- Other interested citizens

**How to Register**

**Anyone is welcome to attend the meeting, free of charge, with or without advance registration.** However, to help the meeting planners assure an effective room arrangement, we encourage you to register in advance by e-mailing your name, full business address, and phone number to Richard Zabel at **richard@westernforestry.org.** Alternatively, you may call Richard at (503) 226-1562.

**LOCATION**

**DoubleTree Hotel & Executive Meeting Center—Portland Lloyd Center**
**1000 NE Multnomah**
**Portland, OR 97232**
**Hotel phone: (503) 281-6111**

**For directions to the hotel, follow the "Directions and Transportation" link on www.doubletree.com/en/dt/hotels/index.jhtml?ctyhocn=RLLC-DT**

**Parking is available at the structure adjacent to the hotel. Bring your parking "receipt" into the meeting to be validated for free parking.**

# What We've Learned

## General Public

- People are concerned about Global Warming but very few would say they have knowledge of what is involved
- Virtually no one knows what carbon sequestration involves
- People are generally favorable towards renewables and efficiency as a response to global warming but need education about carbon sequestration

*MIT Energy Center questionnaire: Herzog et al.*

## Informed Publics

- Most environmental organizations are skeptical of technologies that promote continued use of fossil fuels
- Newspaper editorial boards are uninformed about options such as carbon sequestration; e.g. LA Times, October 2004

***In both cases, attention is low until things get close to home.***

# Westcarb and Phase 2:
# It will be about risk communication

- **All we have to do is get the numbers right**
- **All we have to do is tell them the numbers**
- **All we have to do is explain what we mean by the numbers**
- **All we have to do is show them that they've accepted similar risks in the past**
- **All we have to do is show them that it's a good deal for them**
- **All we have to do is treat them nice**
- **All we have to do is make them partners**
- **All of the above**

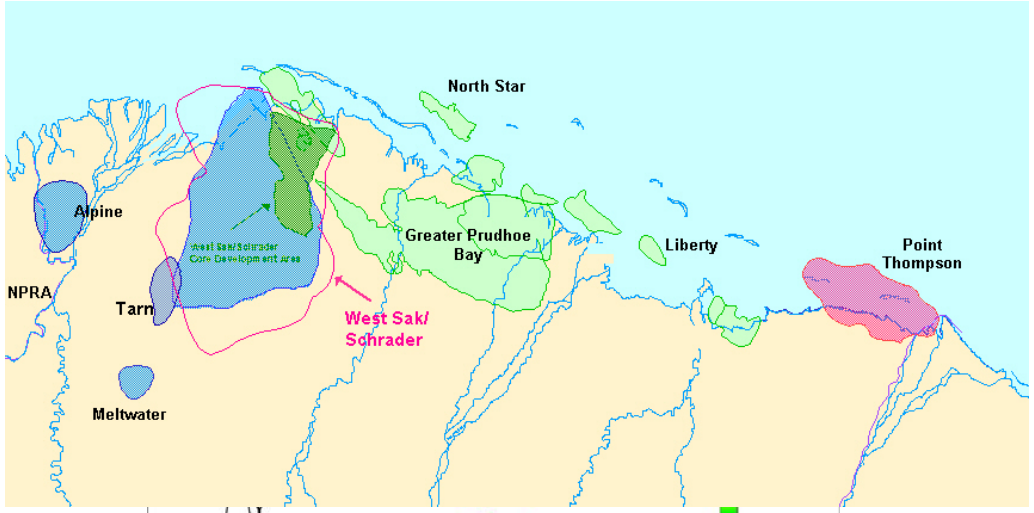
Source: Baruch Fischhoff, "Risk Perception and Communication Unplugged: Twenty Years of Process," *Journal of Risk Analysis*, 15:137-45 (1995).

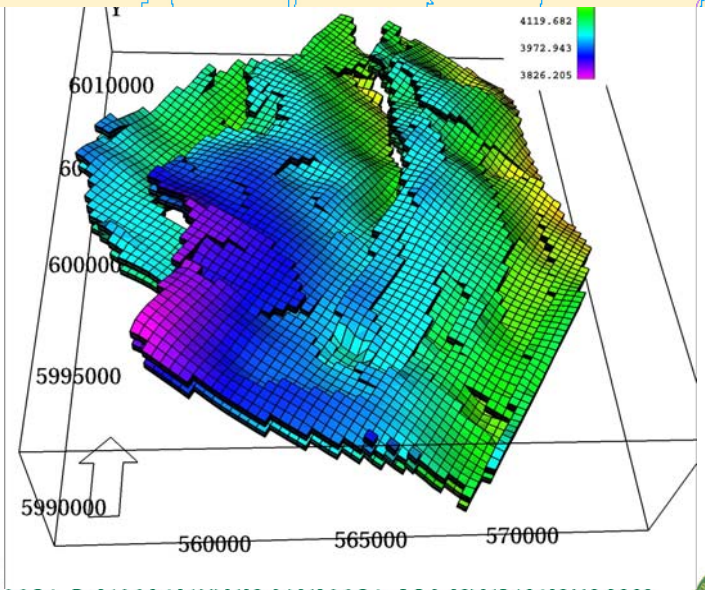
# Regulatory Issues

- Participate in IOGCC working group on geologic sequestration
- Define current regulatory structure in WESTCARB states for geologic and terrestrial sequestration activities

# Development of Monitoring Protocols

- Assess applicable monitoring methods at sites of potential interest
  - Schrader Bluff
  - Ventura
- Work with partners to assemble data
- Use modeling to assess methods



# Terrestrial and Geologic Pilots will be Proposed

- Pilots will be representative of best sequestration options, unique technologies and approaches, in region
- Pilots involve site-specific focus for
  - Testing technologies
  - Defining costs
  - Assessing leakage risks
  - Gauging public acceptance
  - Testing regulatory requirements
  - Validating monitoring methods

# Candidate Phase II Pilots Presented at October 28 Annual Meeting

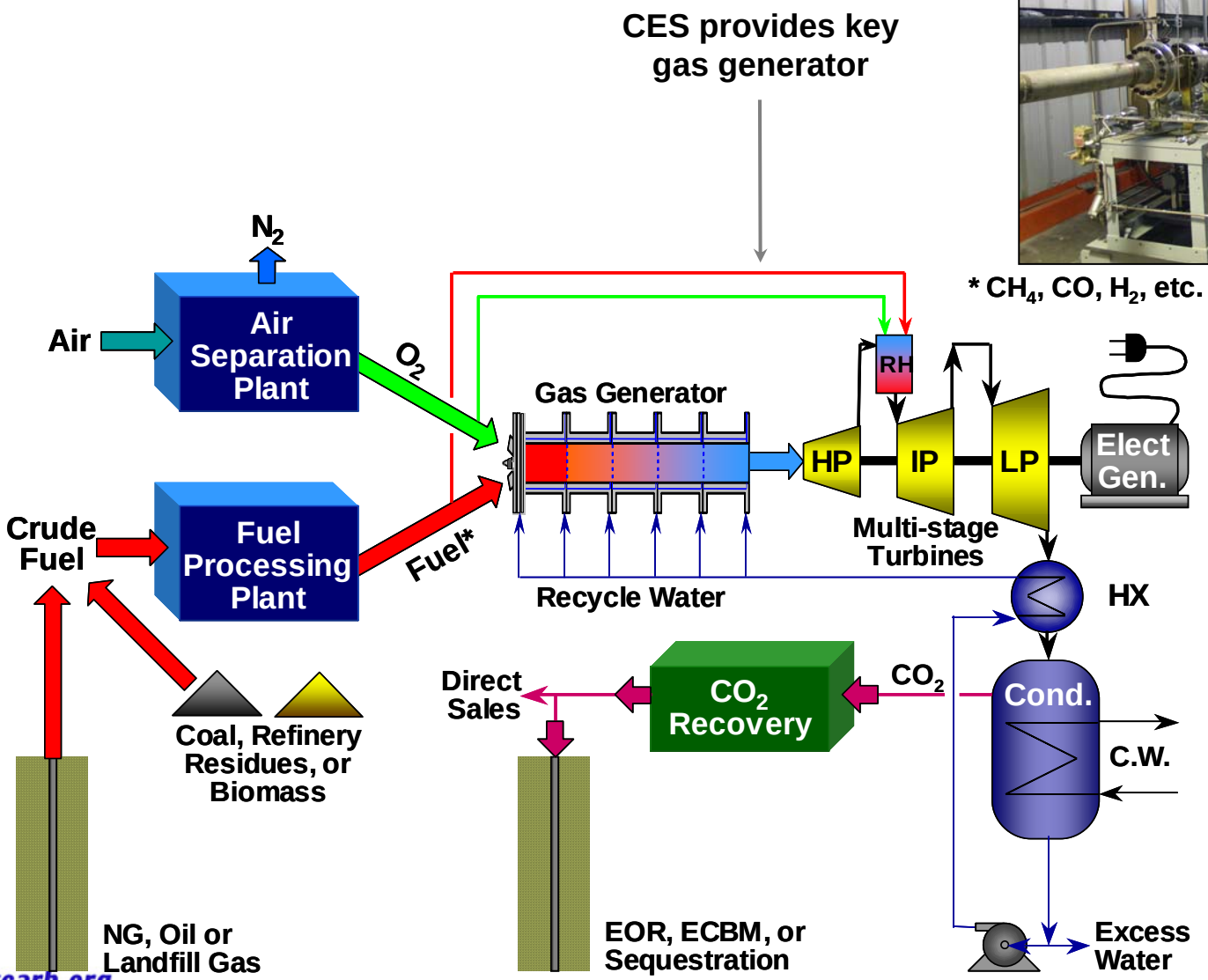
## Geologic Pilot Candidates

- Clean Energy Systems Kimberlina Pilot
- Shell Ventura Pilot
- Cement Industry Environmental Consortium Separations Technologies
- Praxair Advanced Amine Absorption Technologies

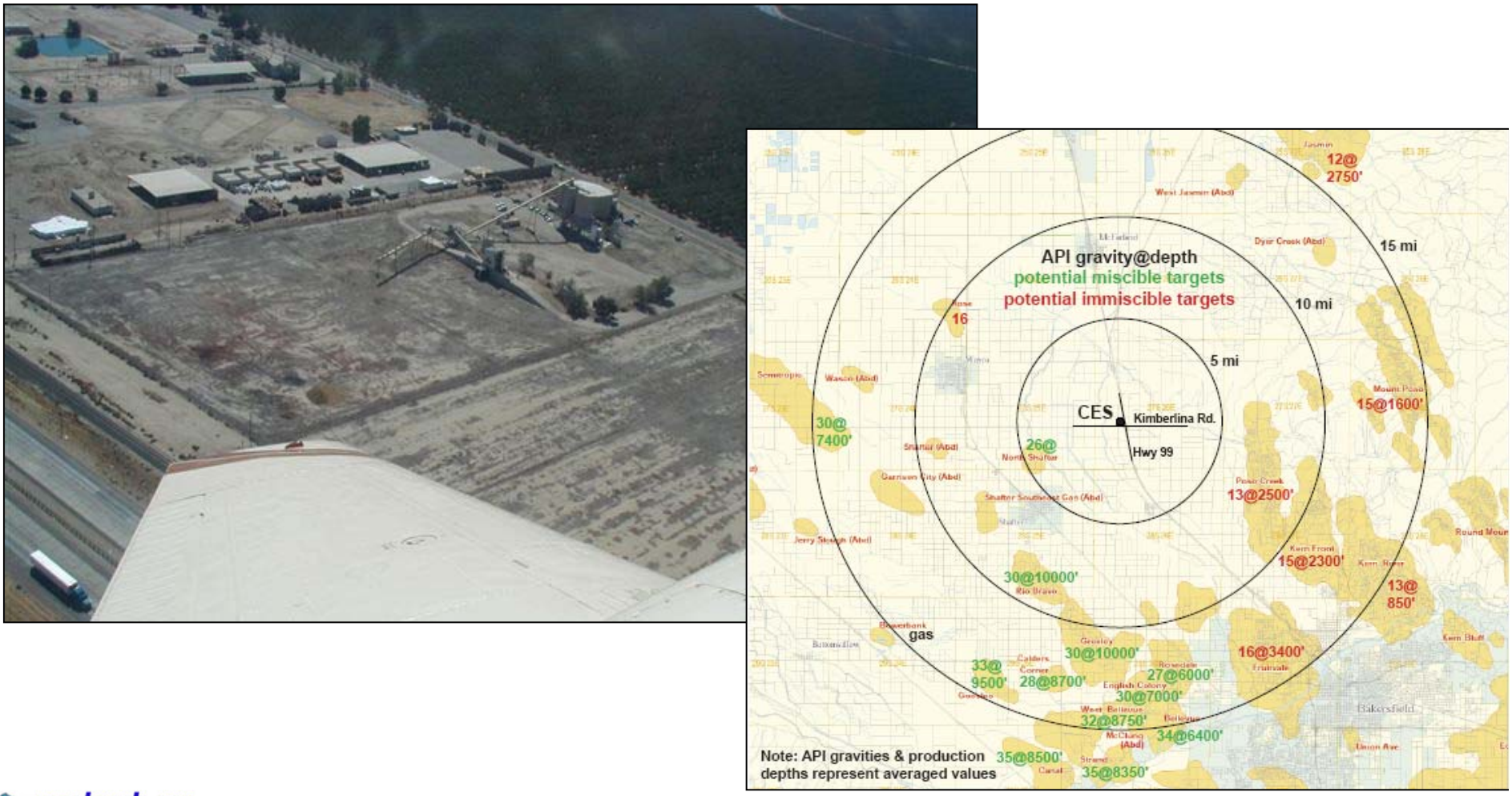
## Terrestrial Pilot Examples

- Forestation of Underproducing Lands
- Forest Fuel Treatment/Biomass Energy
- Forest Management/ Conservation
- Restoration/Management of Southern vs. Hardwood Bottomlands

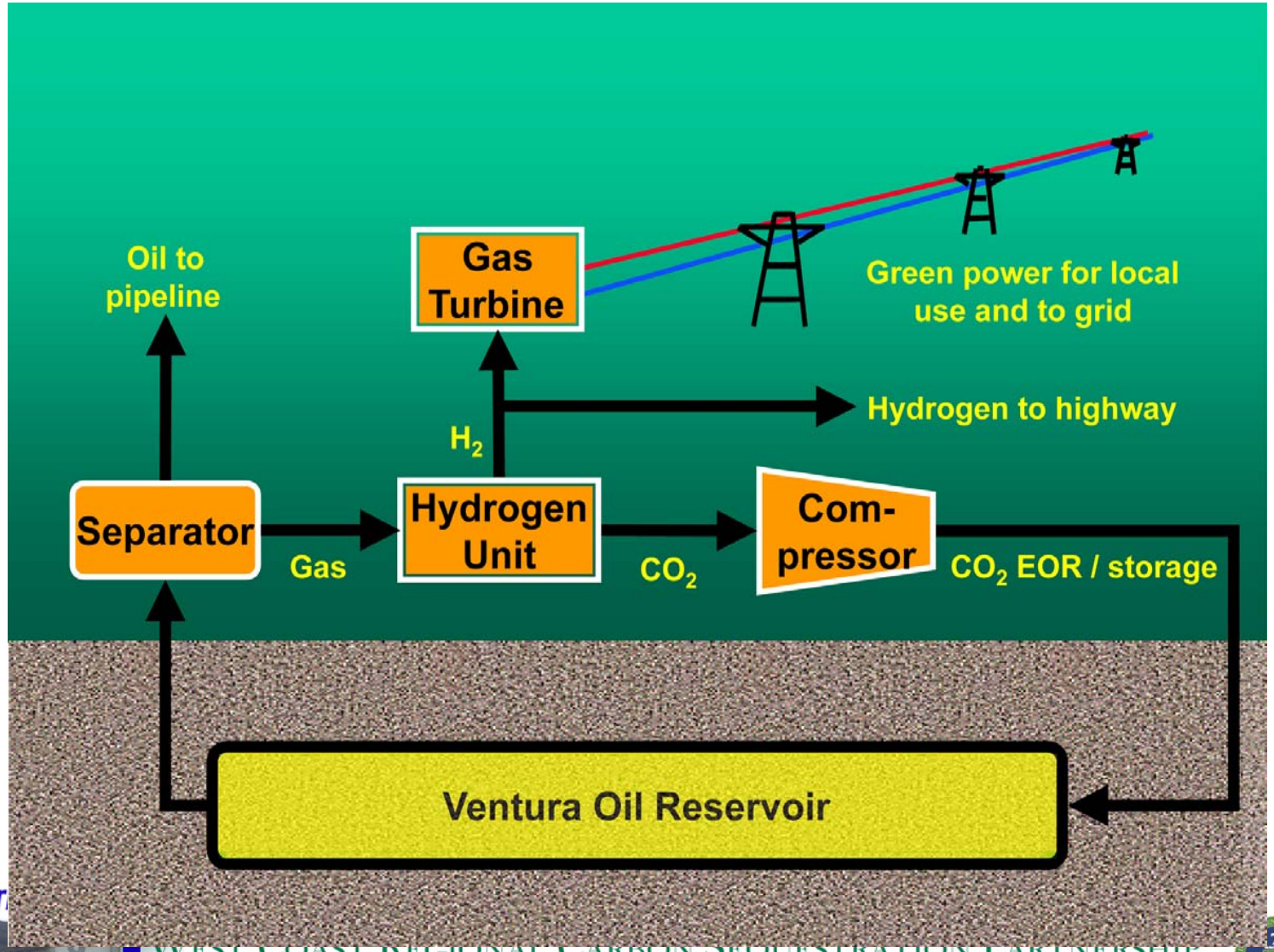
# CES Process


CES provides key gas generator
* $CH_4$, CO, $H_2$, etc.
$N_2$
Air
Air Separation Plant
$O_2$
Gas Generator
RH
HP
IP
LP
Elect Gen.
Multi-stage Turbines
Crude Fuel
Fuel Processing Plant
Fuel*
Recycle Water
HX
Direct Sales
$CO_2$ Recovery
$CO_2$
Cond.
C.W.
Coal, Refinery Residues, or Biomass
NG, Oil or Landfill Gas
EOR, ECBM, or Sequestration
Excess Water

# Carbon Sequestration Options



# Shell Ventura Pilot Concept



# Cement Industry Environmental Consortium Carbon Capture and Reuse Project

- California is largest producer of cement in US
- Each ton of cement yields 1 ton $CO_2$ - average plant produces 1 million tons cement/yr (11plants producing 13 M tons)
- Bench scale testing underway
  - Temperature Swing Adsorption
  - Enzymatic Recovery
- Next step: field pilot test

# Praxair Advanced Amine Absorption Technology

- Oxygen tolerant processes
- Application of amine blends
- Can be retrofit to current infrastructure
- Technology demonstrated at pilot scale; ready for commercialization

# An Integrated Terrestrial Pilot Proposal

- Use GIS to locate 3-4 sites for integrated pilot project
  - Reforestation
  - Fire Management
  - Biomass energy
  - Forest management and conservation
- Key technical issue – MMV
  - Test California Climate Registry accounting protocols

# Next Steps

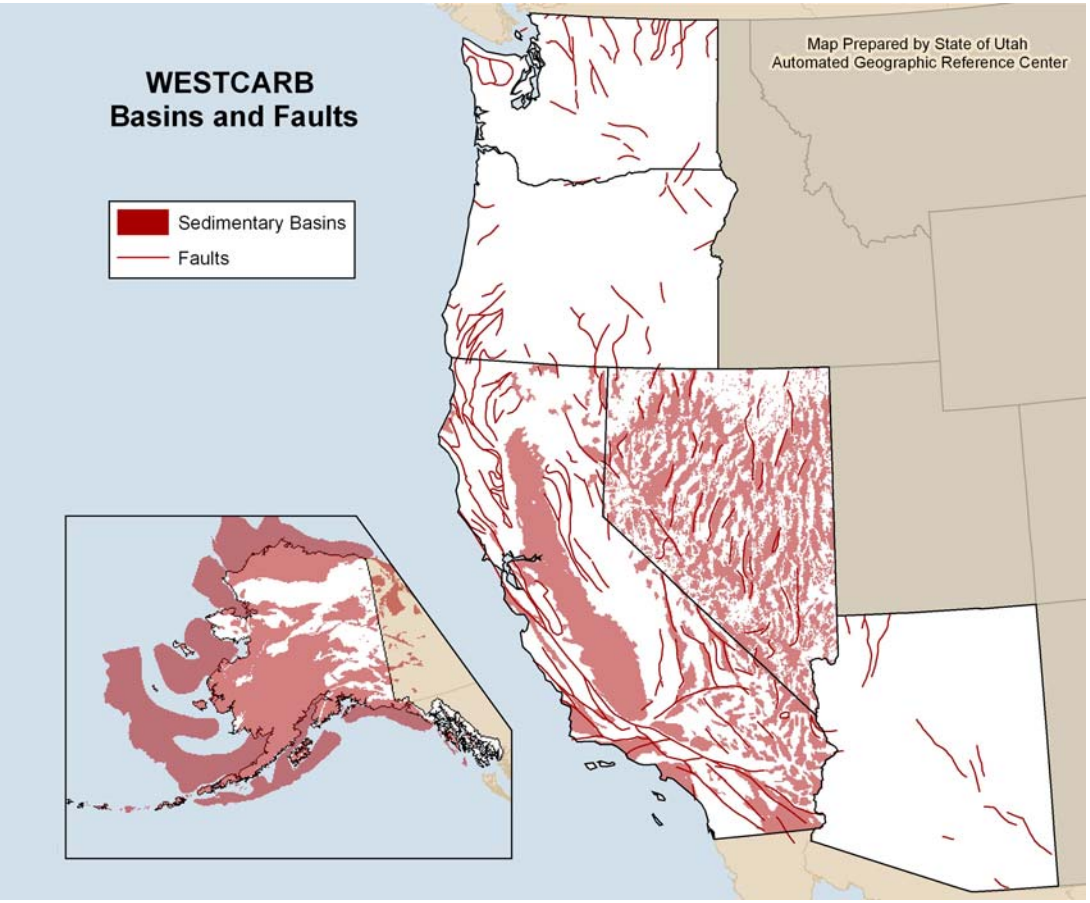
- Finalize list of candidate pilots; assure interested WESTCARB participants have input
- Finalize selection process; incorporate decision analysis
- Transparency is important

# Large Sedimentary Basins are Potential Sinks

- **Large capacity in oil and gas fields in California and Alaska**
- **Coal beds are potential sinks in Alaska and Washington**
- **Potential for offsetting costs with EOR, EGR, and ECBM**

# Geologic Sink Data is Assembled in GIS Layers

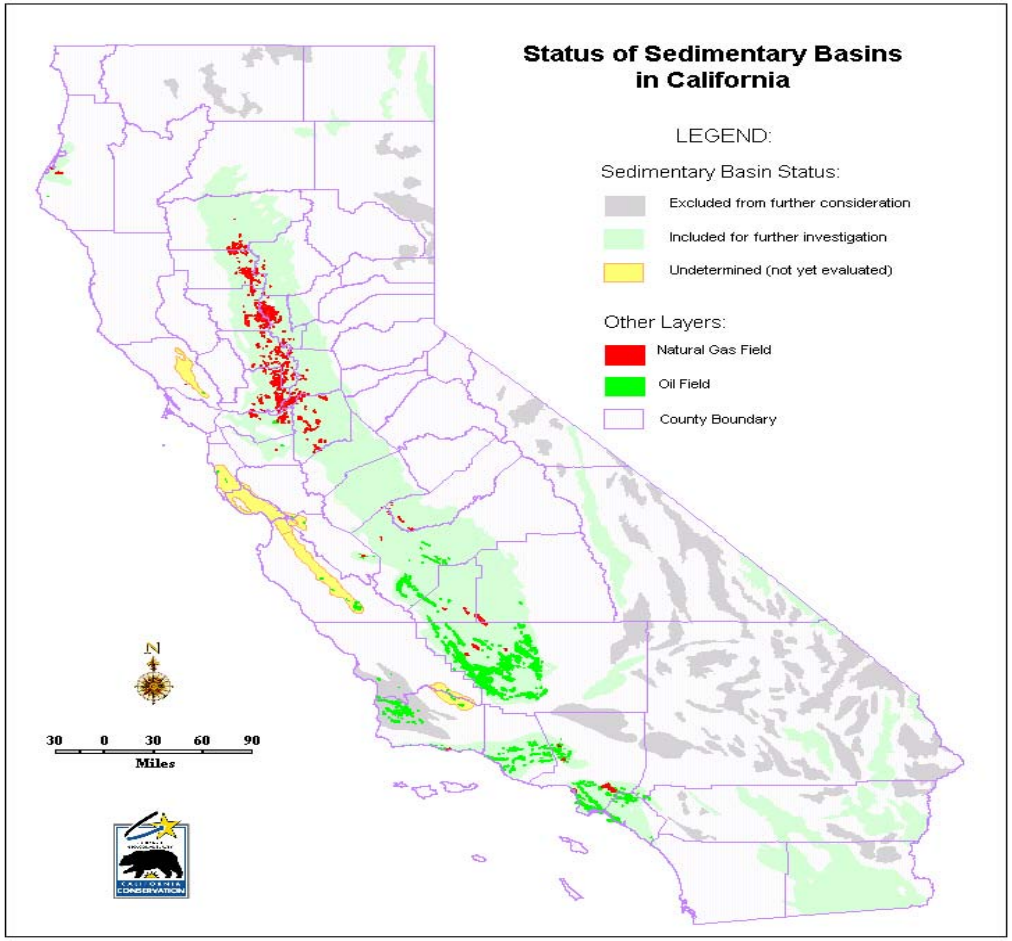
- Sedimentary basins form base layer
- Other layers contain: quaternary faults, topography, population centers, parks and restricted access lands,mines, rivers, roads, etc.
- Data resides at Utah AGRC



# Preliminary Screening Eliminated 74 of 101 Basins in California

- Screening criteria included: depth (<800m), presence of porous, permeable sediments, presence of seals, restricted access (parks, Indian lands, military installations

- Data from literature and well logs



# Oil and Gas Field GIS Layer is Attributed by Field Tables

| | |
|---|---|
| Field Code: | VE024 |
| Field: | Honor Rancho Oil |
| Discovery Well Operator: | The Texas Co. |
| Discovery Well: | Honor Rancho A (NCT-1) 1 |
| Section: | 6 |
| Township: | 4N |
| Range: | 16W |
| Meridian: | SB |
| Discovery Date: | 8/1/1950 |
| Deepest Well Operator: | Southern California Gas Co. |
| Deepest Well: | Wayside Unit 28 |
| Section: | 7 |
| Township: | 4N |
| Range: | 16W |
| Meridian: | SB |
| Depth (ft.): | 11,747 |
| Field Area (ac.): | 450 |
| Cum. Oil Prod. (MBO): | 31,098 |
| Cum. Gas Prod. (MMCF): | 52,992 |
| Base Fresh Water (ft.): | 1,150 |

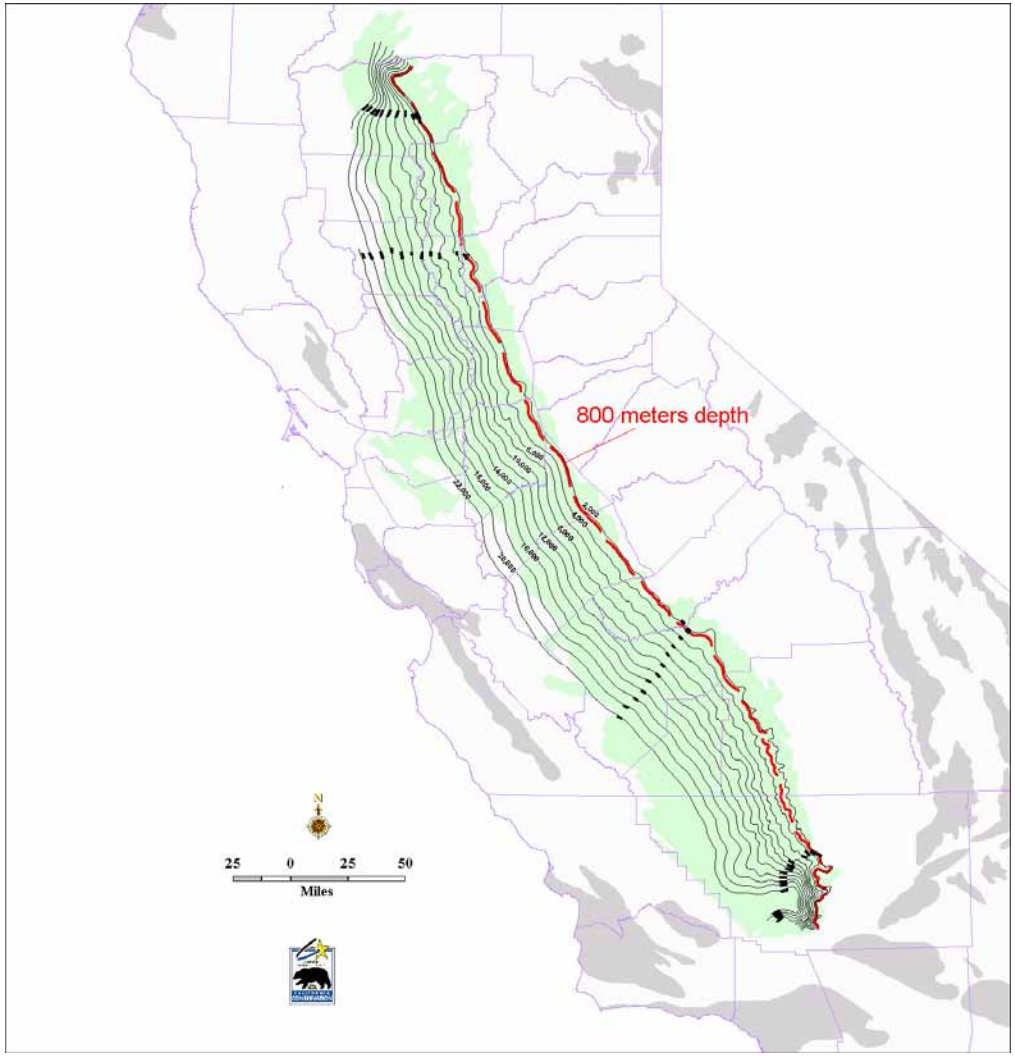
# Zone Table Provides Detailed Data for Each Field

| | |
|---|---|
| Field Code: | VE024 |
| Zone: | Modelo |
| Fm. (Wayside Mbr.) | |
| Age: | U. |
| Miocene | |
| Oil or Gas (O/G): | O |
| Date of Discovery: | |
| 12/1/1950 | |
| Zone Status (P/A/SI): | |
| P | |
| API Gravity: | |
| API Range Min.: | 35 |
| API Range Max.: | 39 |
| GOR: | |
| GOR Range Min.: | 550 |
| GOR Range Min.: | 1,250 |
| Sp. Gravity: | |
| Sp. Gravity Range Min.: | 0.470 |
| Sp. Gravity Range Max.: | 0.765 |
| BTU: | 1,066 |
| BTU Range Min.: | |
| BTU Range Max.: | |
| Cum. Oil (MBO): | 29,094 |
| Cum. Gas (MMCF): | 47,601 |
| No Pool Breakdown: | |
| Depth (ft): | |
| Depth Range Min. (ft): | 6,481 |
| Depth Range Max. (ft): | 10,000 |
| Thickness (ft): | |
| Thickness Range Min. (ft): | 94 |
| Thickness Range Max. (ft): | 310 |
| Producing Area (ac.): | |
| 400 | |
| Porosity (%): | |
| Porosity Range Min. (%): | 7 |
| Porosity Range Max. (%): | 26 |

| | |
|---|---|
| Perm. (md): | |
| Perm. Range Min. (md): | 20 |
| Perm. Range Max. (md): | 179 |
| Pressure (lb/ft): | |
| Pressure Range Min. (lb/ft): | 2,962 |
| Pressure Range Max. (lb/ft): | |
| 4,500 | |
| Temperature (°F): | 190 |
| Temperature Range Min. (°F): | |
| Temperature Range Max. (°F): | |
| Salinity (ppm NaCl): | |
| Salinity Range Min. (ppm NaCl): | 11,200 |
| Salinity Range Max. (ppm NaCl): | 24,800 |
| TDS (ppm): | 20,200 |
| TDS Range Min. (ppm): | |
| TDS Range Max. (ppm): | |
| Seal: | Modelo Fm. |
| Seal Thickness (ft.): | |
| Seal Thickness Range Min. (ft.): | 5 |
| Seal Thickness Range Max. (ft.): | 50 |
| Trap Type: | |
| Stratigraphic | |
| Fault Intensity: | L |
| ERP 1: | Gas |
| Injection | |
| ERP 1 Start: | 1954 |
| ERP 1 Stop: | 1956 |
| ERP 2: | |
| Waterflood | |
| ERP 2 Start: | 1959 |
| ERP 2 Stop: | 1966 |
| ERP 3: | |
| Waterflood | |
| ERP 3 Start: | 1972 |
| ERP 3 Stop: | 1975 |

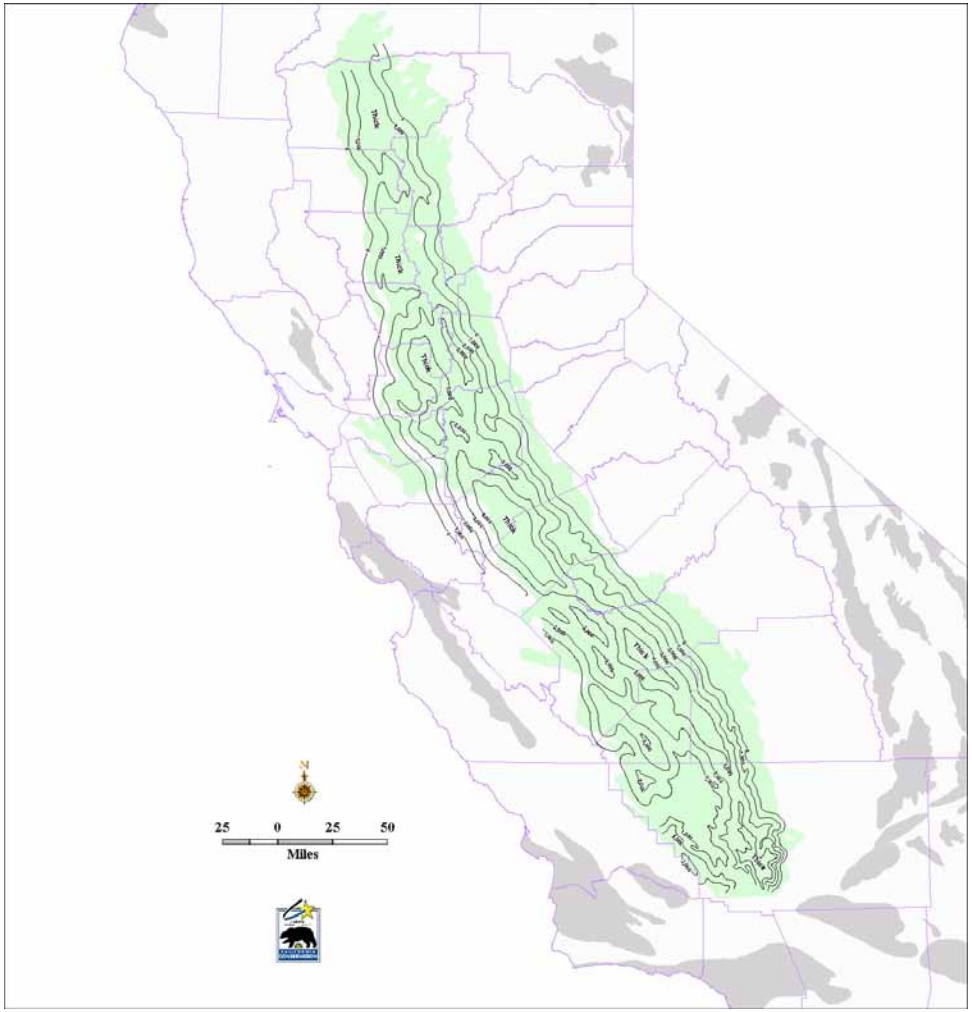
# Depth to Basement Maps Made for Major Basins

- Sediment depths of up to 22,000ft in the Sacramento and San Joaquin basin



# Sand Isopach Map Provides Basis for Rough Estimate of Capacity

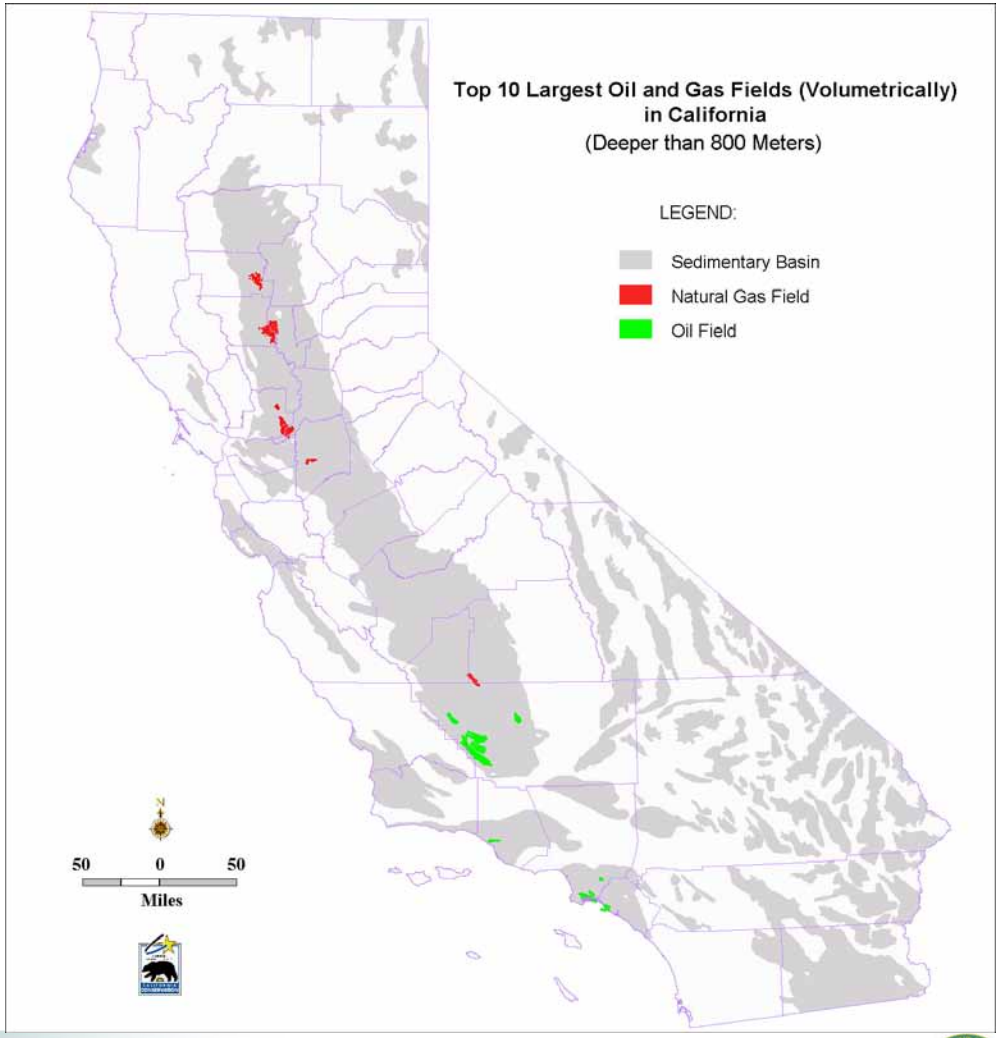
- Sand thickness calculated for interval from 2625ft (800m) to 10,000ft.
- Sequence stratigraphy not taken into account
- Sand thickness in excess of 4000ft found in several areas



# Top 10 Oil and Gas Fields are Major Targets

- Large fields found in Sacramento, San Joaquin, Los Angeles and Ventura Basins

- Top 10 oil producers range from 875,000 to 2,585,000MBO; top 10 gas producers range from 186,000 to 3,500,000MMCF



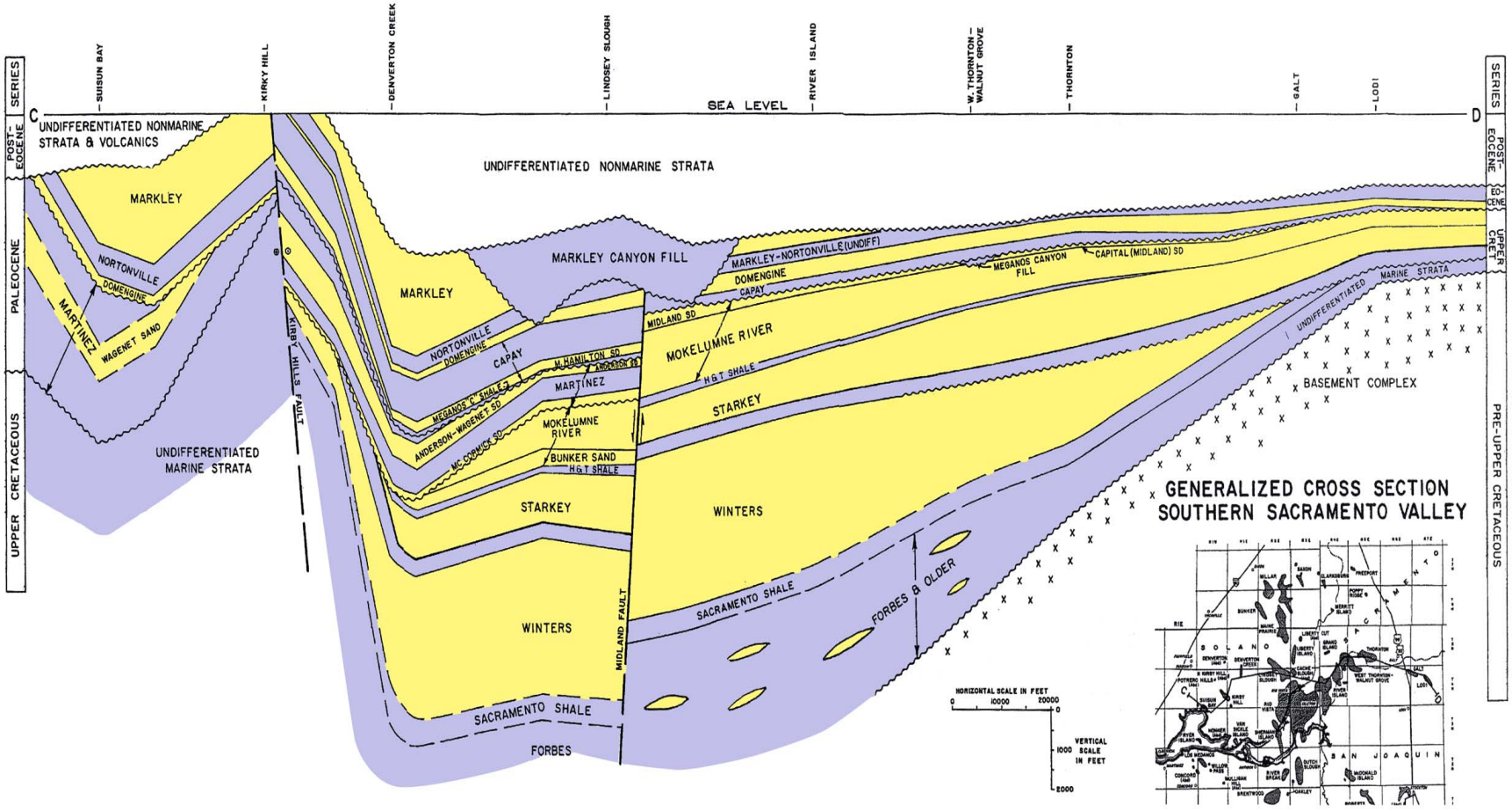
# California $CO_2$ EOR Potential

Of the 172 major onshore California oil reservoirs, 88 reservoirs, with 31.9 billion barrels of OOIP and 22.1 billion barrels of "stranded oil", are favorable for $CO_2$-EOR.

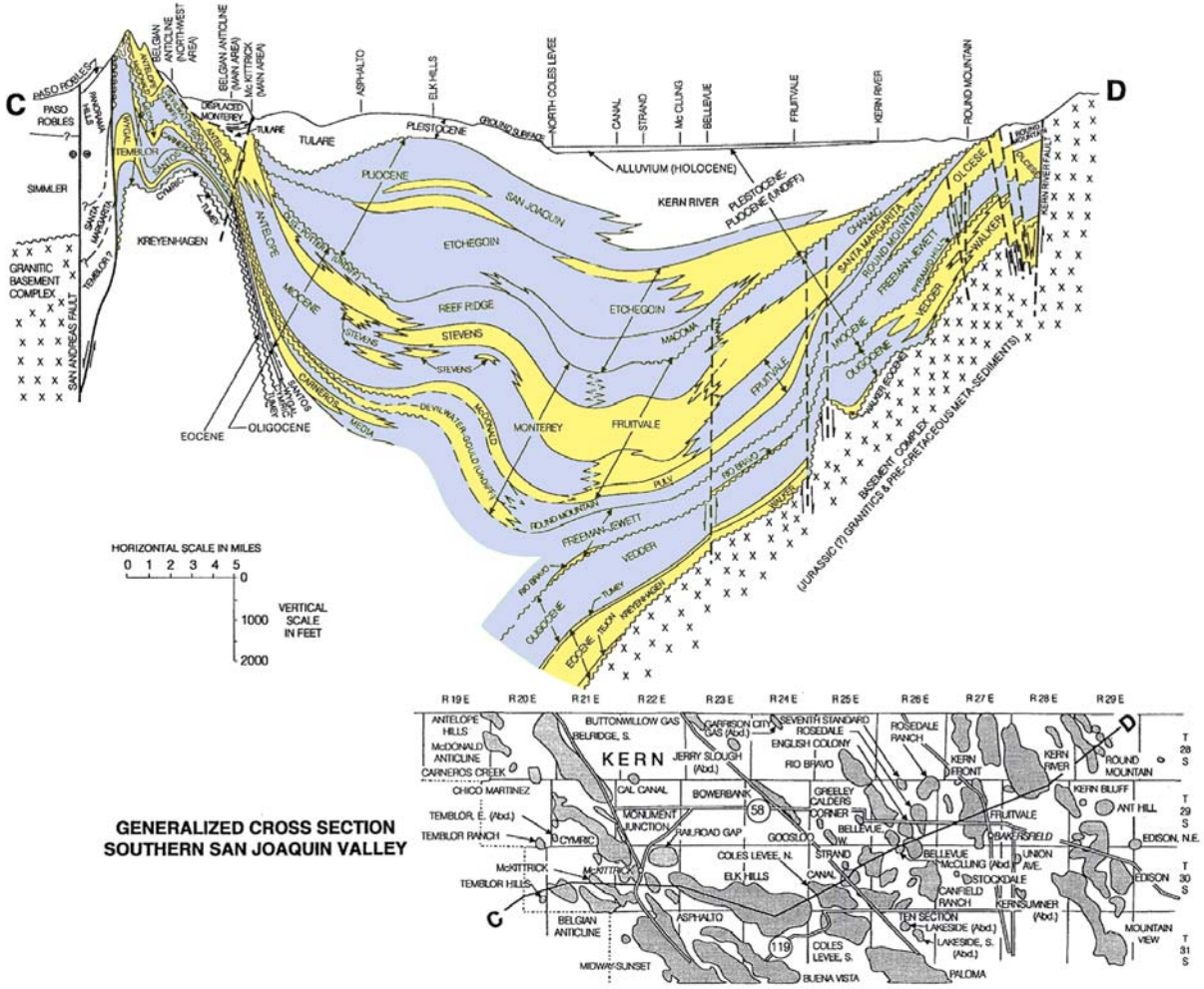
| Basin | No. of Reservoirs | OOIP (Billion Bbls) | Cumulative Recovery/Reserves (Billion Bbls) | ROIP (Billion Bbls) |
|---|---|---|---|---|
| San Joaquin | 29 | 11.9 | 3.8 | 8.1 |
| Los Angeles | 36 | 14.1 | 4.2 | 9.9 |
| Coastal | 23 | 5.9 | 1.8 | 4.1 |
| TOTAL | 88 | 31.9 | 9.8 | 22.1 |

Source: ARI, 2004

# Generalized Cross-section of Southern Sacramento Basin

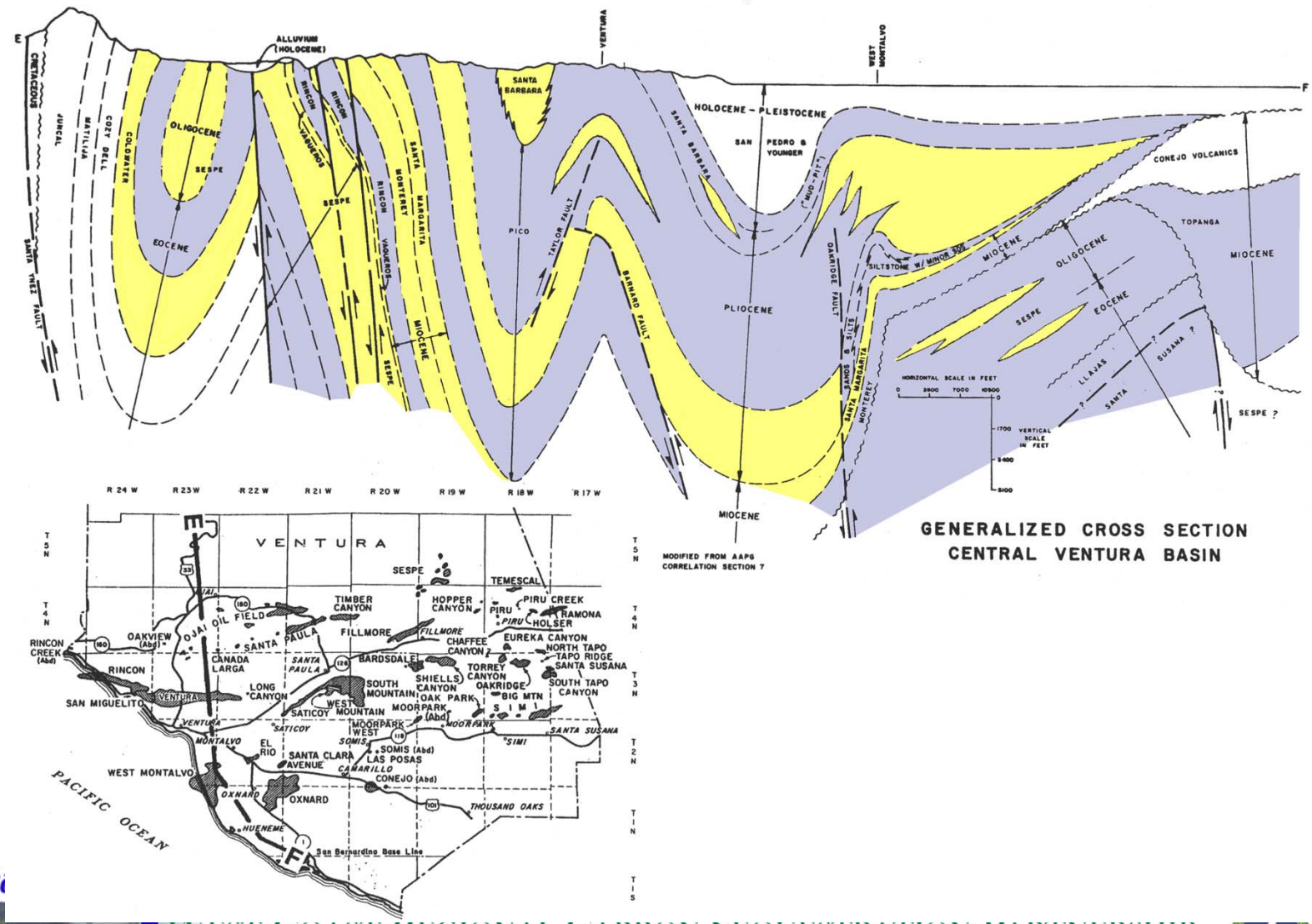


# Generalized Cross-section of Southern San Joaquin Basin



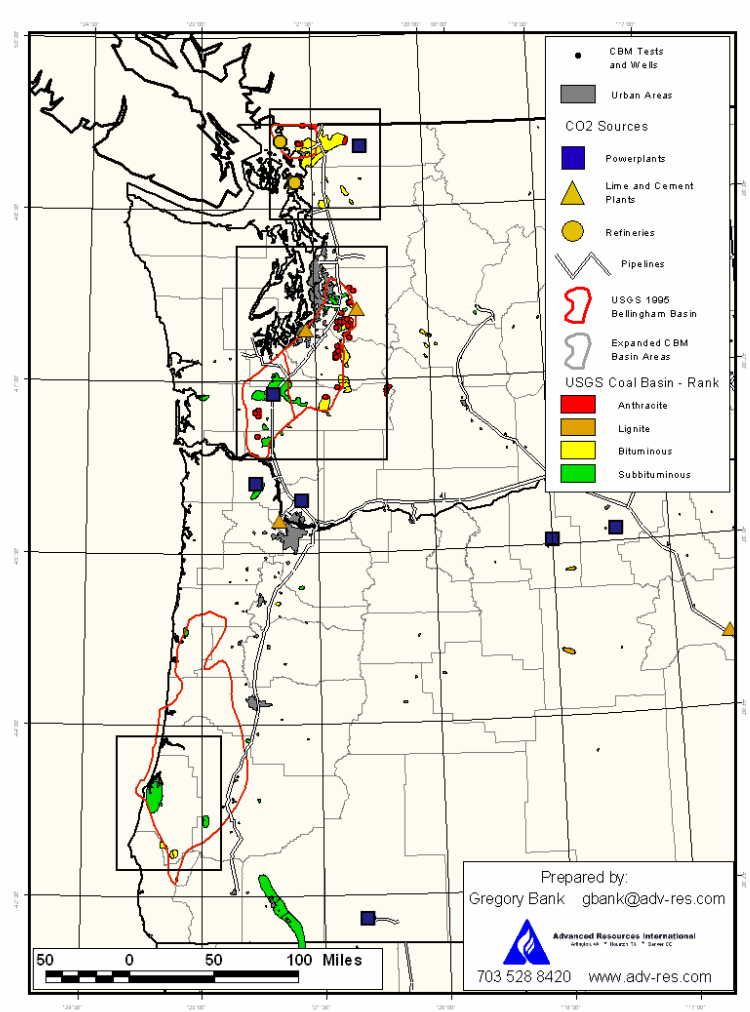

GENERALIZED CROSS SECTION
SOUTHERN SAN JOAQUIN VALLEY

# Generalized Cross Section of Ventura Basin



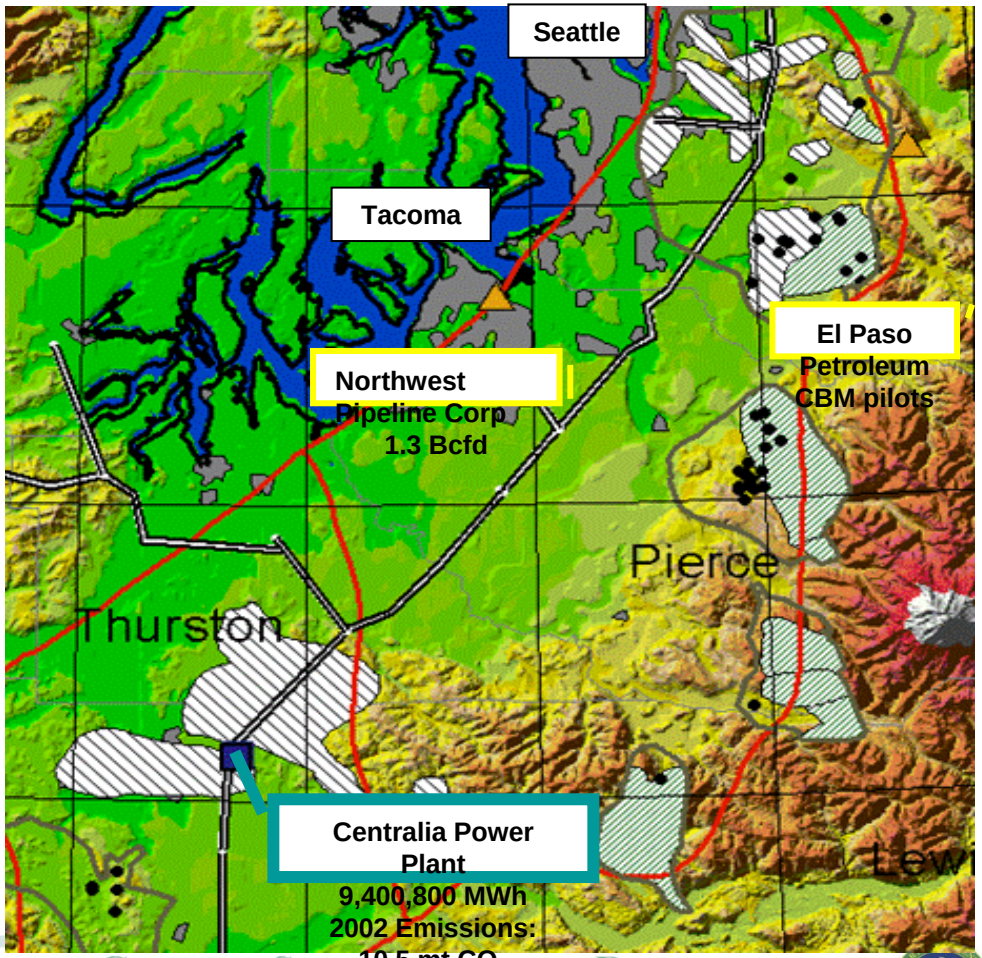
# Eocene Coal Region in Oregon-Washington has been Characterized

- Bellingham Basin, northern WA: good coal development, some $CO_2$ sources
- Puget, WA: best ECBM potential and large $CO_2$ sources
- Coos Bay, OR: poor coal development and few $CO_2$ sources

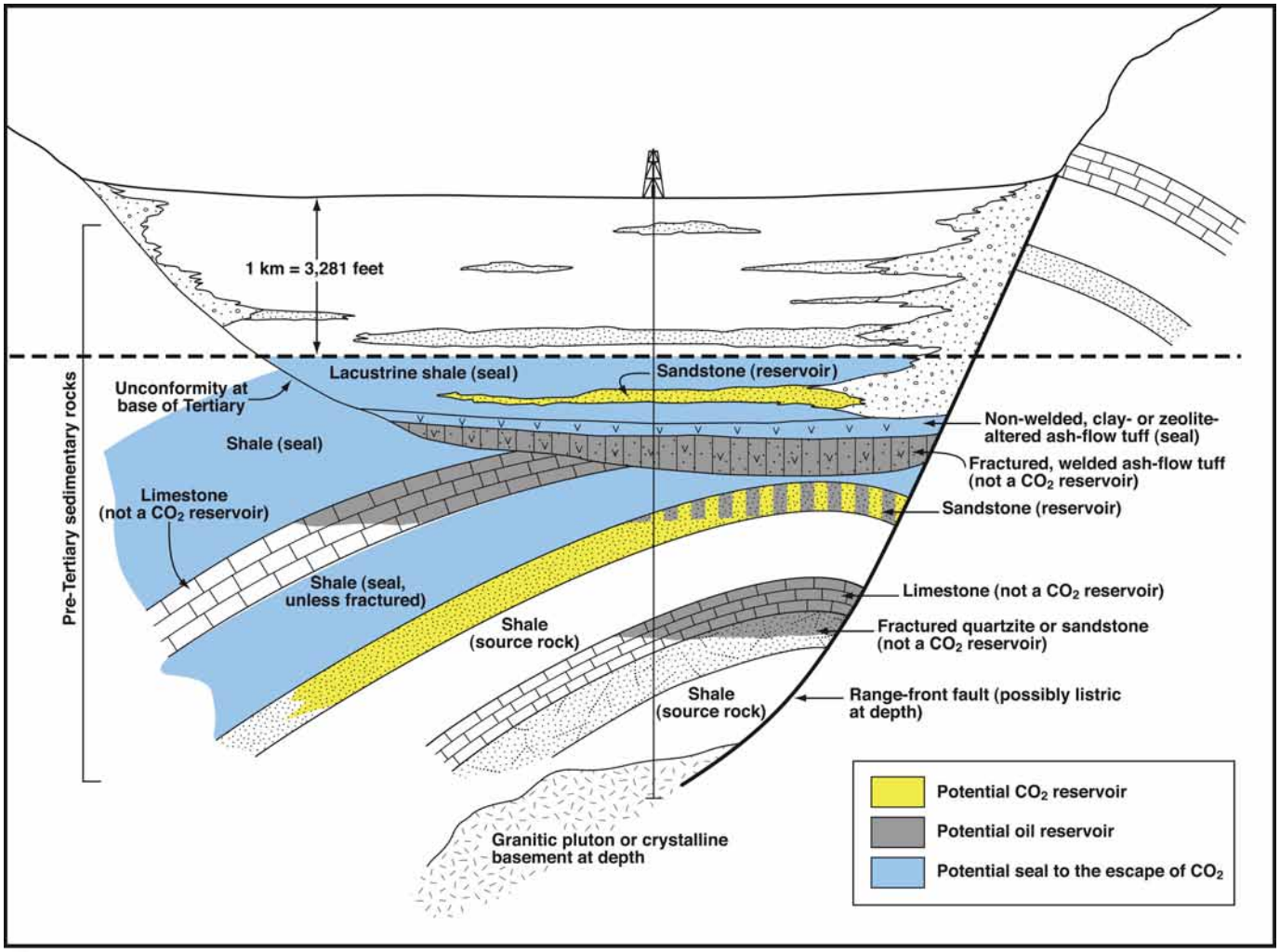


# Puget, WA Deep Coals Could be Sink for Centralia Plant

- Favorable coal rank: sub-bituminous in the W to anthracite in E
- El Paso Production pilot tested 5 md permeability in coals

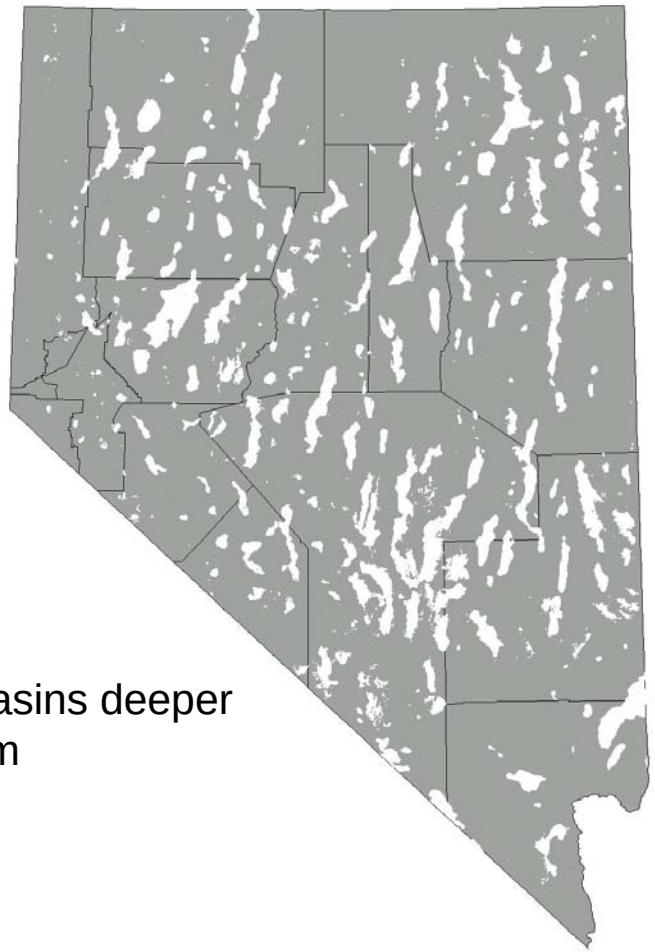


# Conceptual Model of Nevada Oil and Deep Brine Formations



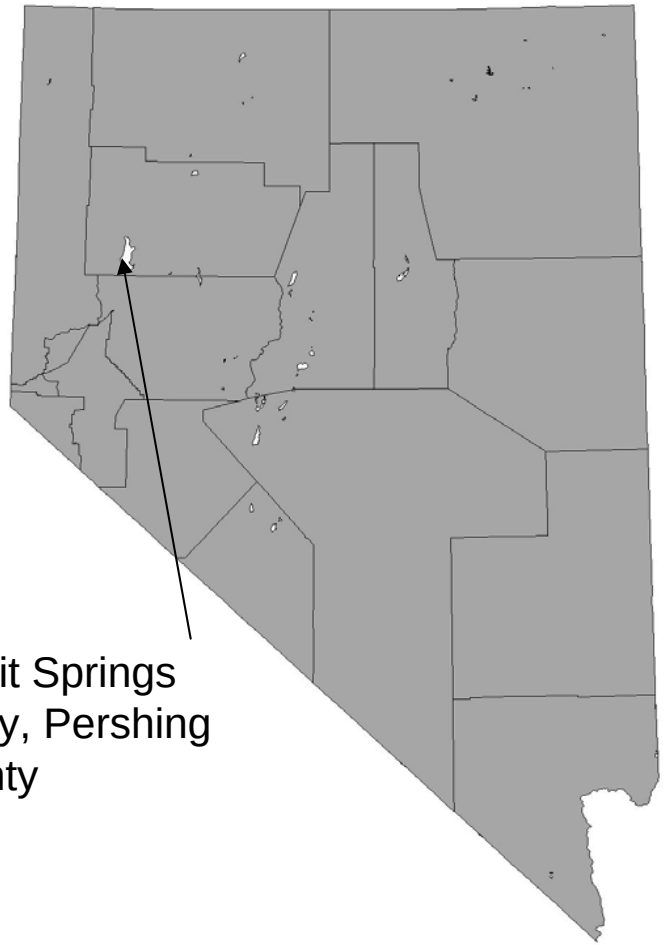
# Multiple Levels of Screening Almost Completely Eliminates Storage Potential

Greater than 1K valley fill - white.
R. Hess



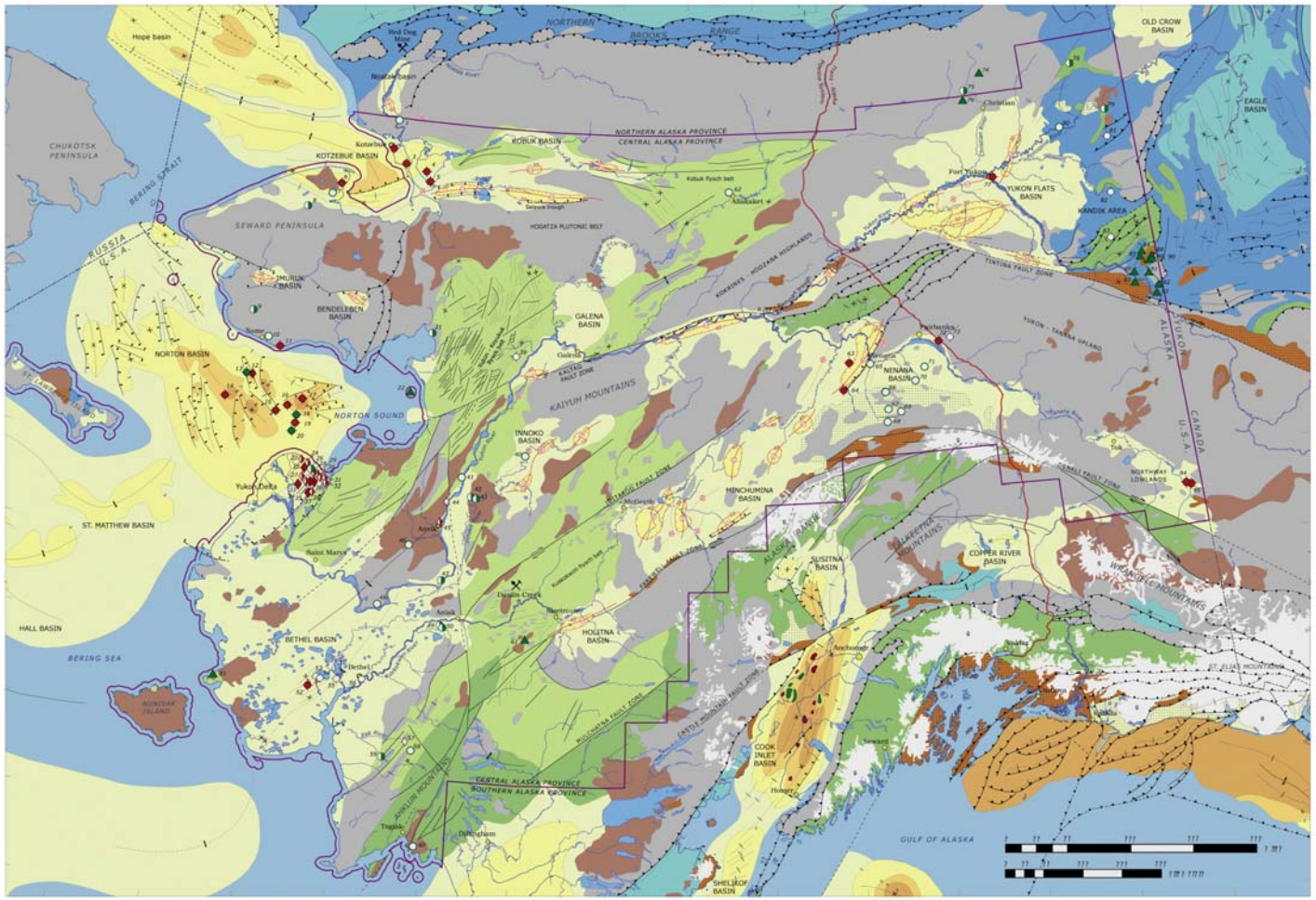
White: basins deeper than 1 km

White areas are 1 kilometer or greater depth after removing areas of physical and political restraints.
R. Hess



Granit Springs Valley, Pershing County

# At Least Six Basins in Alaska Contain Sediments Greater Than 1km Thick




*A.* Sedimentary basins and selected geologic features of regional importance.

Geology compiled and modified by S.M. Trautman and R.G. Stanley from Kirschner (1986). Indications of petroleum compiled by R.G. Stanley and S.M. Trautman from Miller and others (1959), from other sources described in text, and from field work by R.G. Stanley and others, 1994-1997 and 2002

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# DOE Carbon Sequestration Regional Partnership Meeting

Richard Rhudy

EPRI

November 16, 2004

Pittsburgh, PA

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# Source Characterization

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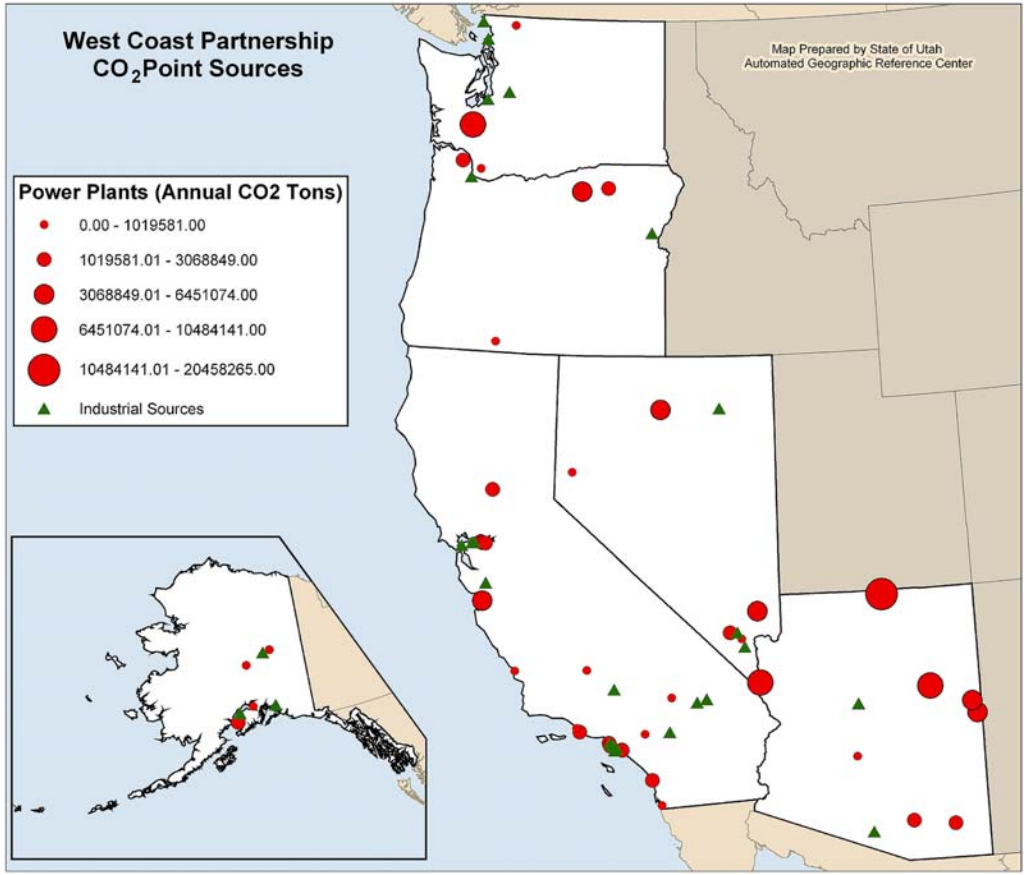
# Point Source Data Has Been Assembled in GIS Layers

- Characterized sources account for about 80% of total industrial and utility sector emissions
- GIS layers are attributed with emissions and plant operating data
- Data resides at Utah AGRC, part of national database



# WESTCARB Point Source Selection

| | Fossil Power Generation | Petroleum Refining | Cement & Lime | Natural Gas Processing |
|---|---|---|---|---|
| Alaska | 6 | 6 | 0 | 3 |
| Arizona | 10 | 0 | 2 | 0 |
| California | 21 | 21 | 11 | 2 |
| Nevada | 5 | 1 | 2 | 0 |
| Oregon | 3 | 0 | 1 | 0 |
| Washington | 4 | 5 | 2 | 0 |

# WESTCARB Point Source Summary

Fossil Power Generation

- About 83% of total fossil power emissions
- Data from EIA and EPA National Databases

Petroleum Refining

- All refineries listed in EIA data for the region
- $C0_2$ estimated by factor from Canadian report

Cement & Lime Manufacturing

- All plants in the region
- $CO_2$ estimated using EPA/EIA and industry accepted method

Natural Gas Processing

- 5 Plants located; no data on $CO_2$, but amounts small

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# Options Cost

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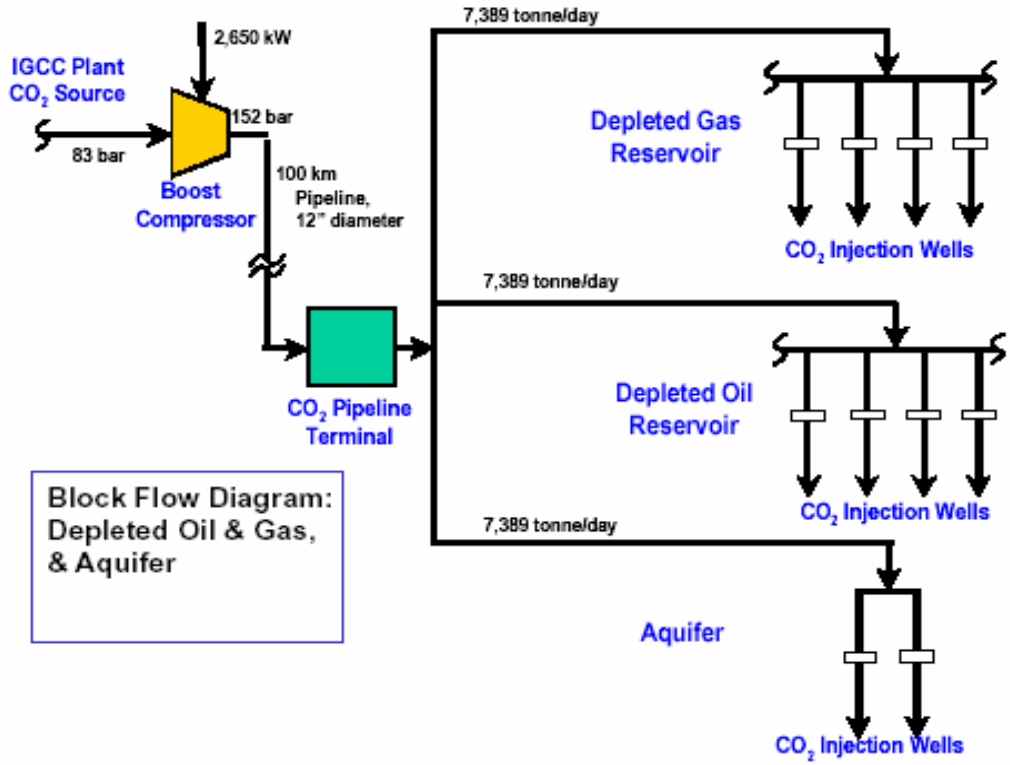
# $CO_2$ Sequestration: Overview




Source: *Economic Evaluation of CO2 Storage and Sink Enhancement Options* (TVA Report to DOE)

Capture → Transport → Storage →

# GIS Models for Geological Carbon Sequestration

- $CO_2$ Capture Cost Model
  - Provided by SFA Pacific
- $CO_2$ Storage Capacity Model
- $CO_2$ Injectivity and Injection Cost Model
- $CO_2$ Transportation Cost Model
- Source-Reservoir Matching Model

# $CO_2$ Capture Cost Models

- **SFA Pacific, Inc. has developed three draft, transparent, Excel spreadsheet models**
  - **New power plants**
  - **Retrofit of existing power plants**
  - **Large industrial boiler and furnace flue gas.**
- **Designed for flexibility to change all the key inputs**
- **The comparable transparency assures maximum objectivity.**

# $CO_2$ Capture Cost Models: Other Systems

- Retrofit of existing "generic" industrial boiler or furnace flue gas with an amine $CO_2$ scrubber.
- Natural gas was assumed the fuel of choice
- A natural gas boiler cogeneration is utilized to effectively meet the amine system needs and the $CO_2$ compressor.
- The industrial flue gas composition and amount is a key input and provisions are made to add additional flue gas cleanup required before the amine system.
- Due to the large range in sizes of potential industrial $CO_2$ capture, the unit capital costs have a capacity to unit capital cost percentage adjustment factor.

# $CO_2$ Storage Capacity Model

$$Q = V * p * e * \rho_{CO_2}$$

- Q = storage capacity of entire aquifer ($MtCO_2$)
- V = total volume of entire aquifer ($km^3$)
- p = reservoir porosity (%)
- e = storage efficiency (%)
- $p_{CO2}$ = $CO_2$ density ($kg/m^3$)

- Required Reservoir Data:
  - Geographical Extent and Thickness
  - Reservoir Porosity
  - Reservoir Pressure and Temperature (may be estimated from depth)

# $CO_2$ Injectivity Model

**User Controlled Inputs:**

$CO_2$ flow rate

Downhole injection pressure

**Reservoir Characteristics:**

Depth

Thickness

Permeability

Pressure

Temperature

→

**Intermediate Calculations:**

$CO_2$ viscosity

$CO_2$ mobility

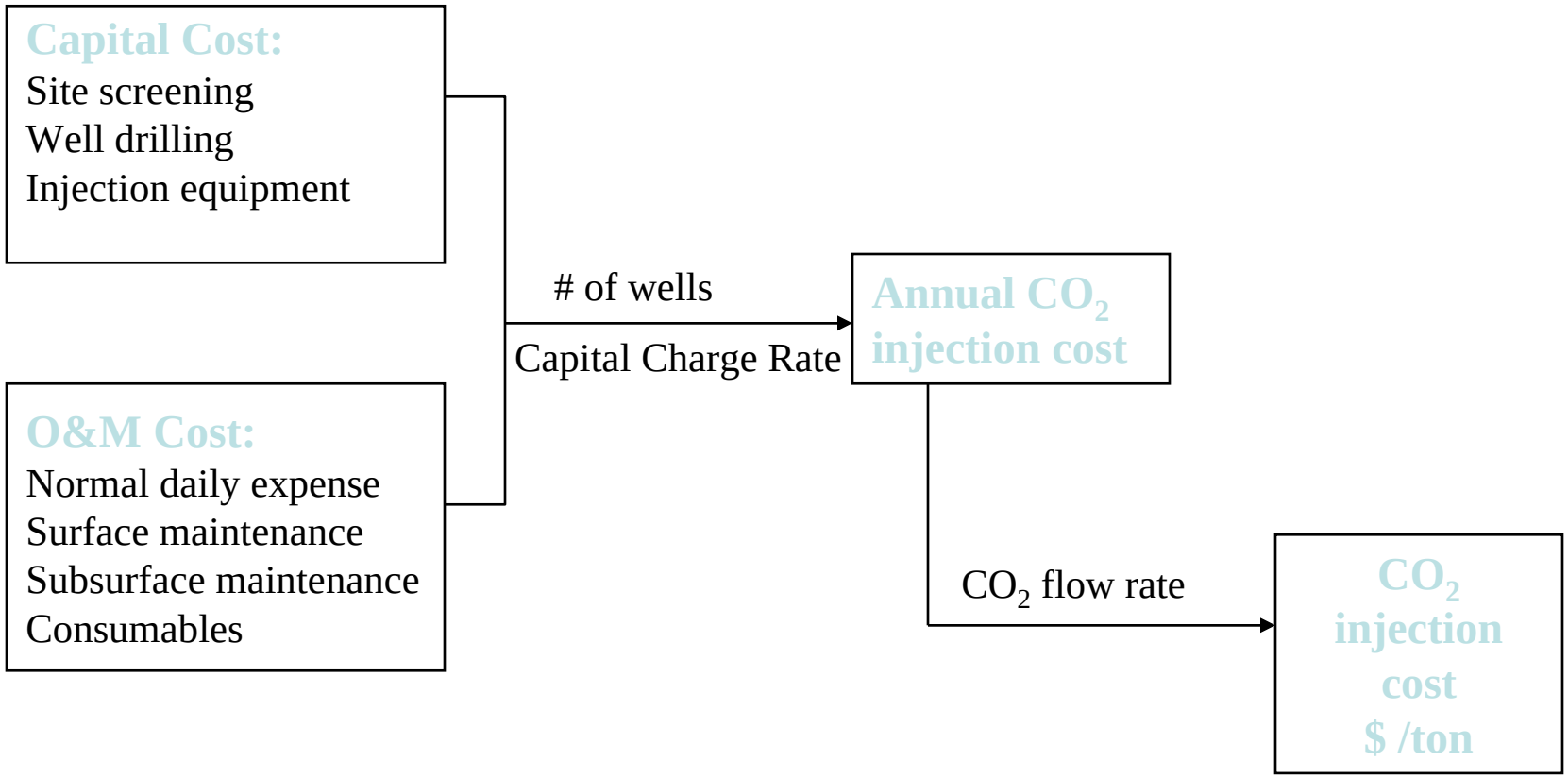
**$CO_2$ injectivity rate per well**

→

**Final Output:**

**# of injection wells**

# Injection Cost Estimation

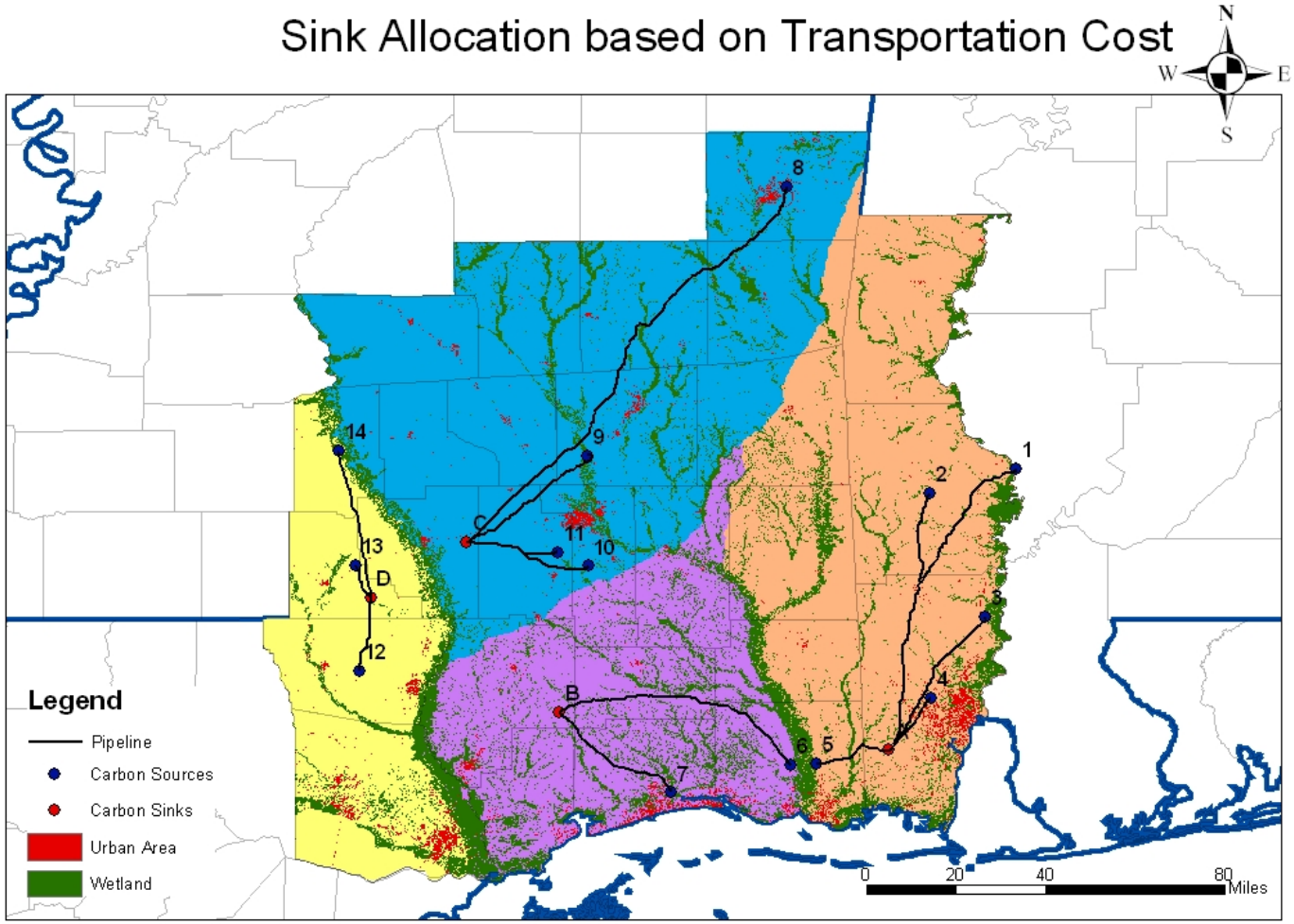


# $CO_2$ Transportation Cost Model

- Pipeline Diameter
  - D = *f* ($CO_2$ flow rate)
- Lowest-Cost Pipeline Route Selection
  - Existing right-of-way
  - Land use and land cover
  - River crossing
  - Railroad/road crossing
  - Population density
  - Slope
- Pipeline Construction and O&M Cost

# Lowest-Cost Pipeline Route Selection

Sink Allocation based on Transportation Cost

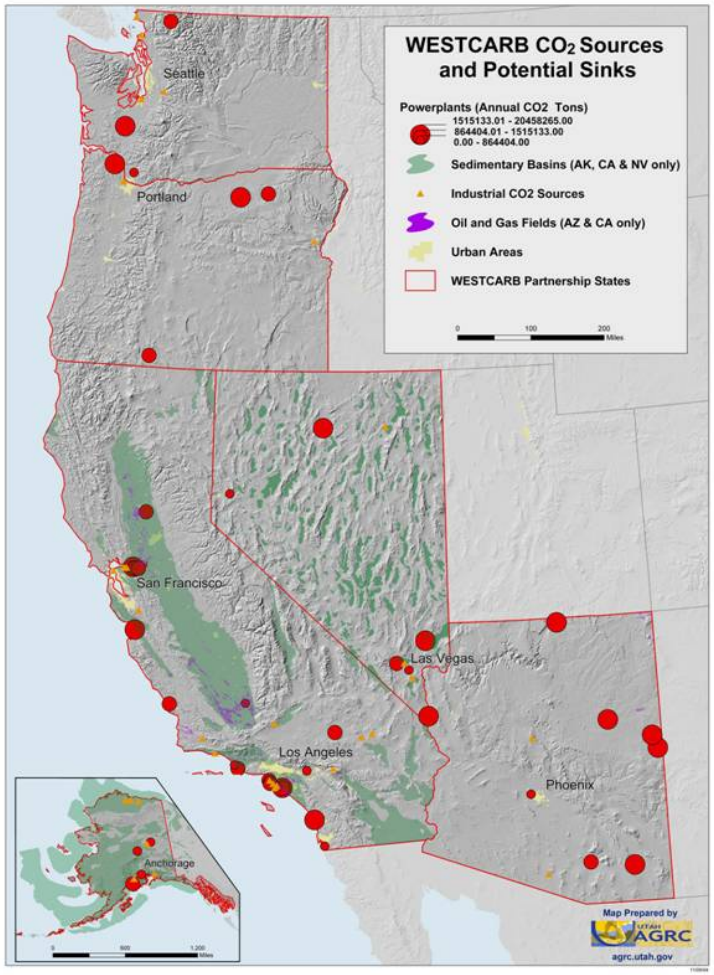


# Source-Reservoir Matching

- One-to-one matching
  - For a given $CO_2$ source, identify $CO_2$ reservoir(s) that minimize the total transport and injection cost under the capacity constraint
- Many (sources) to one (reservoir) matching
  - Sharing pipeline
  - Minimize the total cost of the sub-system under the capacity constraint
- Many-to-many matching
  - System analysis that considers capture, transport, and storage costs subject to capacity constraints

# Source-Reservoir Matching

- While data collection not complete, data may be insufficient for some sources and sinks
- May result in unrealistic economics and those cases will not be evaluated in Phase 1



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# Permitting & Regulations

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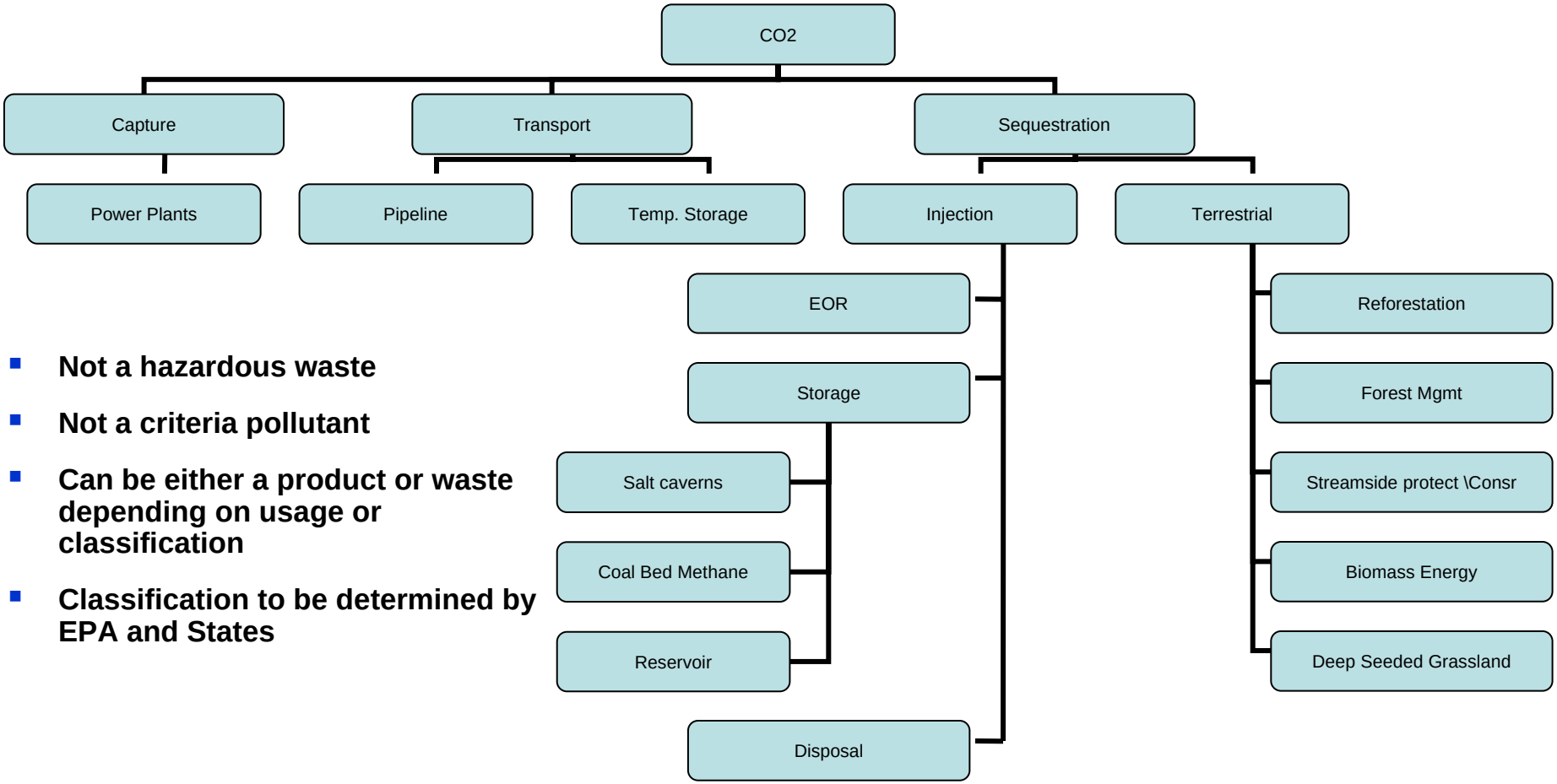
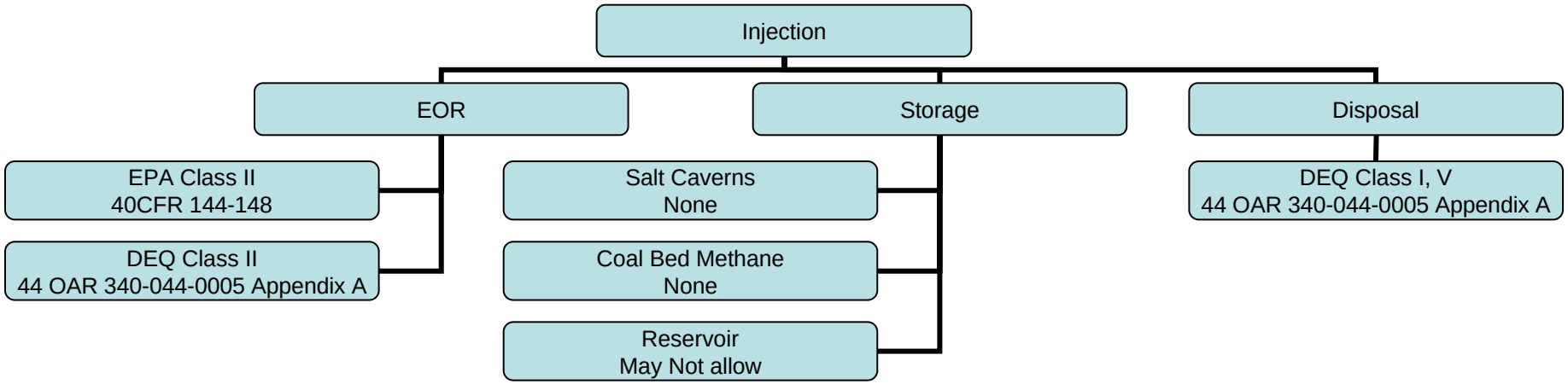
# Regulatory and Permitting Issues for Geologic and Terrestrial Sequestration of $CO_2$




- **Not a hazardous waste**
- **Not a criteria pollutant**
- **Can be either a product or waste depending on usage or classification**
- **Classification to be determined by EPA and States**

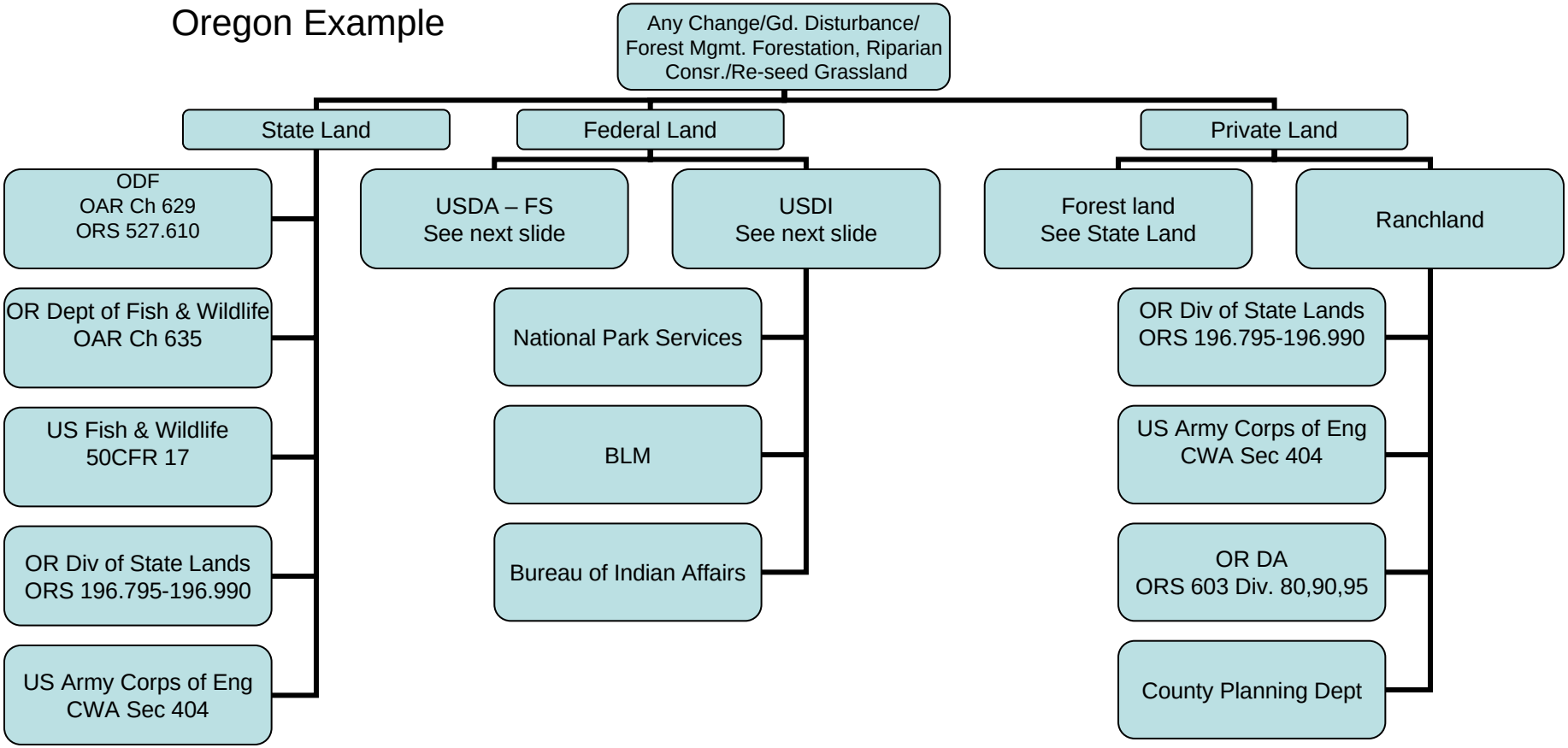
# Regulatory and Permitting Issues for Geologic Sequestration of $CO_2$

## Oregon Injection Options



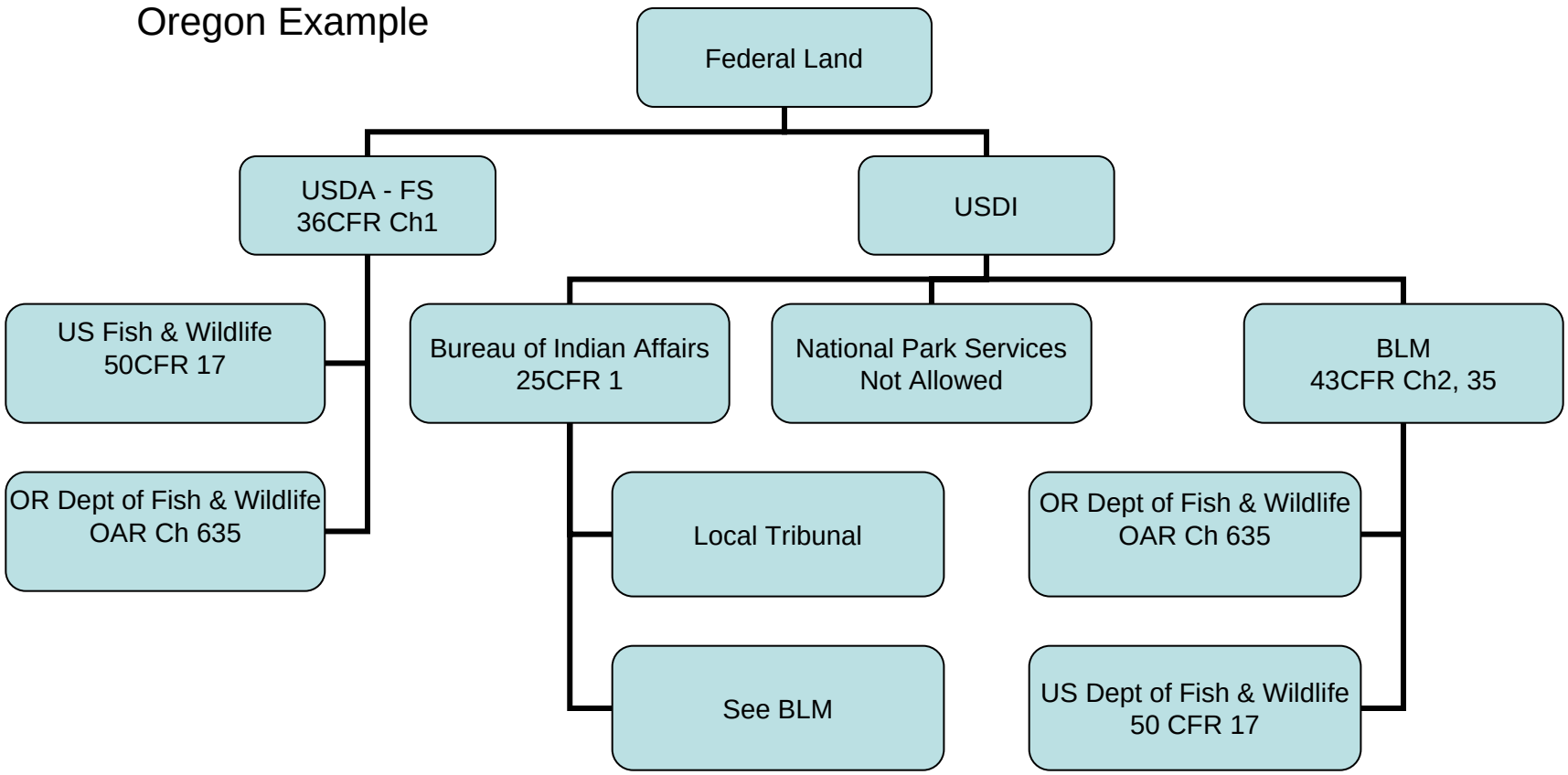
# Regulatory and Permitting Issues for Geologic and Terrestrial Sequestration of $CO_2$

Oregon Example



# Regulatory and Permitting Issues for Terrestrial Sequestration of $CO_2$

Oregon Example



# Regulatory and Permitting Issues for Geologic and Terrestrial Sequestration of $CO_2$

| Options<br>(Easy to difficult) | Reasons |
|---|---|
| EOR | In operation<br>Class II wells for State with primacy, EPA w/o |
| US Dept of Agriculture – Forest Service | Permit from US Forest Service<br>US Fish and Wildlife (Endangered species review)<br>State Fish and Wildlife (State endangered species review) |
| US Dept of Interiors -- BLM | Permit from BLM<br>US Fish and Wildlife (Endangered species review)<br>State Fish and Wildlife (State endangered species review) |
| State Forestlands | Permit from State Forest and Fire Dept.<br>State Dept of Fish and Wildlife<br>US Fish and Wildlife<br>Water Right or usage Permit<br>US Army Corps of Eng. (OR)<br>Div. of State Lands (OR)<br>CEQA (CA) SEPA (WA) review |
| Private Forestlands<br>Private Ranchlands | Permit from State Forest and Fire Dept.<br>State Dept of Fish and Wildlife<br>US Fish and Wildlife<br>Water Right or usage Permit<br>County Planning Dept (OR, WA)<br>US Army Corps of Eng. (OR)<br>Div. of State Lands (OR)<br>CEQA (CA) SEPA (WA) review |
| US Dept of Interiors – Indian Lands | Permit from BLM<br>US Fish and Wildlife (Endangered species review)<br>State Fish and Wildlife (State endangered species review)<br>Local Tribunal |
| Subsurface Storage and Disposal | Uncertain depending on classification of CO2 as product or waste |
| Biomass | Local Air Permit (new source review)<br>NPDES Permit<br>County Planning Dept<br>Permit from State Forest and Fire Dept.<br>State Dept of Fish and Wildlife<br>US Fish and Wildlife<br>Water Right or usage Permit<br>US Army Corps of Eng. (OR)<br>Div. of State Lands (OR)<br>CEQA (CA) SEPA (WA) review |
| US Dept of Interiors – National Parks | No way |

**$CO_2$ Sequestration Ranking Options**
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**Increasing difficulty**

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# Risk

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Pittsburgh, PA

# Introduction

**The basis for the tool came from the realization that HSE risk is fundamentally related to three basic characteristics of a geologic carbon sequestration site:**

**(1) Potential of the primary target formation for long-term containment of $CO_2$;**

**(2) Potential for secondary containment if the primary target formation leaks;**

**(3) Potential to attenuate and/or disperse leaking $CO_2$ if the primary formation leaks and secondary containment fails.**

# Three Fundamental Characteristics

## (1) Primary Containment

Primary Seal
Depth
Reservoir

## (2) Secondary Containment

Secondary Seal
Shallower Seal(s)
Reservoir

## (3) Attenuation Potential

Surface characteristics
Hydrology
Existing wells
Faults

**Attributes**

# Attributes of Primary Containment

Properties

## Primary Seal

Thickness
Lithology
Demonstrated sealing
Lateral continuity

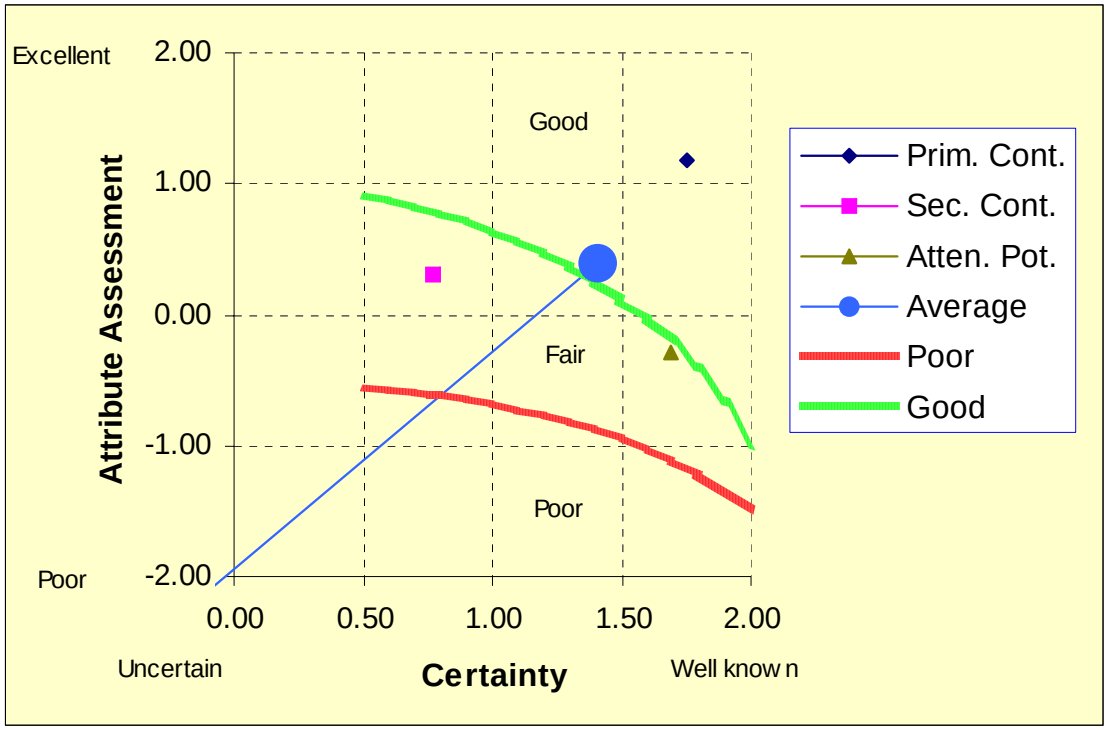
## Reservoir

Lithology
Perm., poros.
Thickness
Fracture or primary poros.
Pores filled with…
Pressure
Tectonics
Hydrology
Faults
Deep wells

## Depth

Distance below ground

# Example of Preliminary Graphical Result




| Chart Details | |
|---|---|
| Total Average Certainty: | 1.41 |
| Total Average Attribute: | 0.40 |
| Magnitude of Total Average: | 2.78 |
| Prim. Cont. Weighting factor: | 1 |
| Sec. Cont. Weighting factor: | 1 |
| Atten. Pot. Weighting factor: | 1 |

Ventura Oil Field.

# Summary

- A HSE screening risk assessment framework has been developed based on three fundamental characteristics of a $CO_2$ sequestration site:

  1) Primary containment potential

  2) Secondary containment potential

  3) Attenuation potential

- This is a *screening* risk assessment (SRA) tool.
- HSE SRA is just one component of site selection.
- Testing and further development is underway.

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# Option Evaluation Criteria

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# Assessment Purpose

- The assessment is intended to help identify the best regional opportunities for carbon sequestration in the West Coast Region
- Subsequent analysis of actual pilot candidates will involve assessments at a greater level of specification, and perhaps quantification
- This is a working draft of the methodology

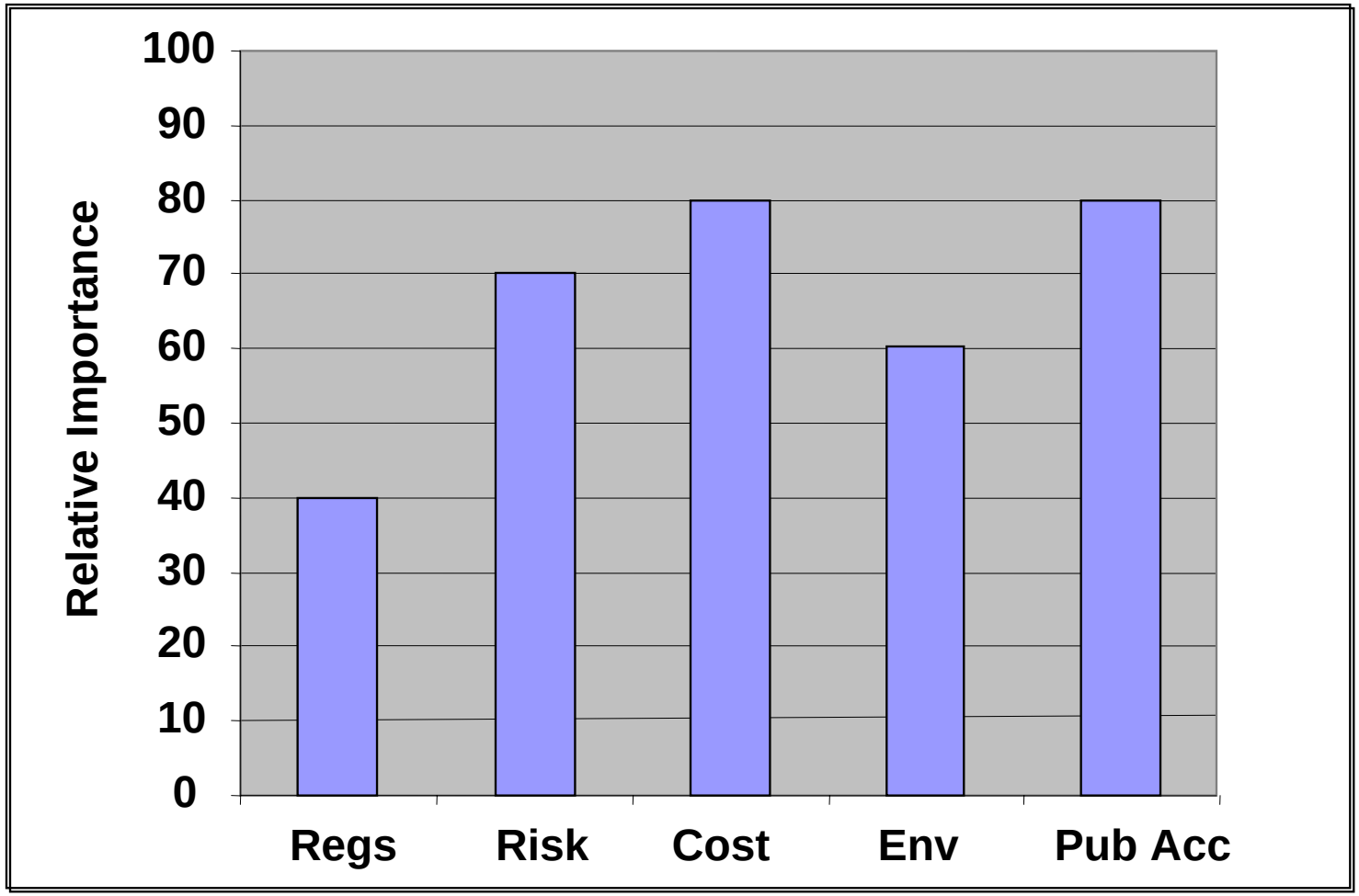
# Five Major Objectives Have Been Identified

1. Cost
2. Risk
3. Regulations and permitting
4. Environmental enhancements
5. Public acceptance

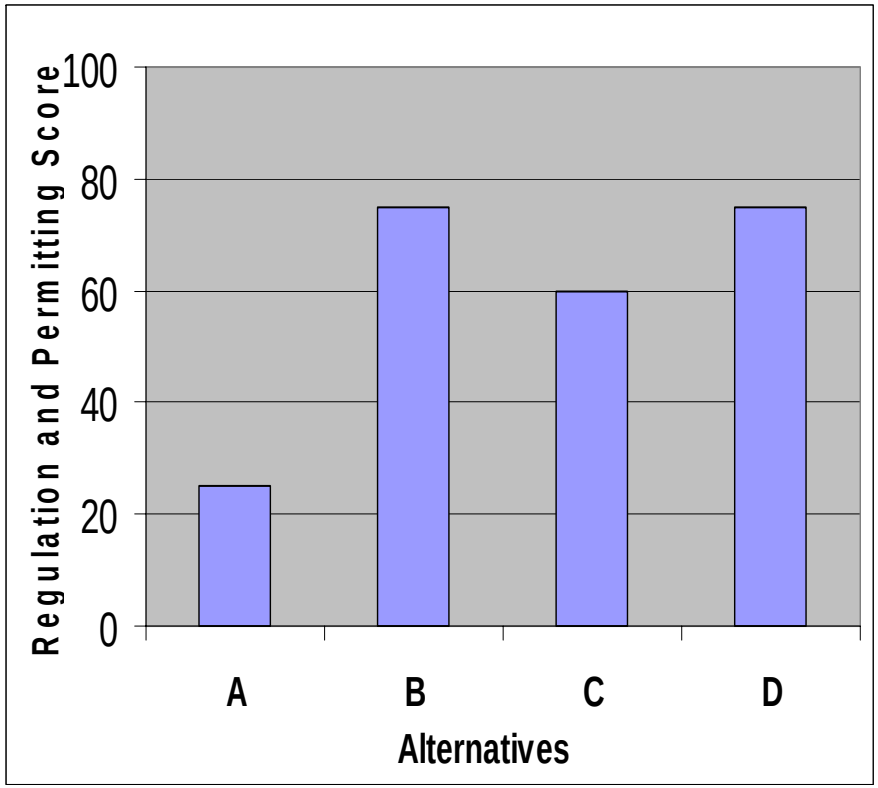
# The Value of Regional Alternatives Will Be Measured Using Metrics for Each of the Important Factors

- **Cost of Capture, Transport, and Sequestration (one metric)**
  - **Metric:** $/ton of $CO_2$ captured and sequestered
  - **Preference:** Cheaper is better
- **Risk (one metric)**
  - **Metric:** Capability of the storage media to prevent leakage and HSE impacts
  - **Preference:** Alternatives that minimize leakage (minimum pre-existing wells, minimum conductive faults, multiple seals, structural trap, etc.)
- **Regulations and permitting (one metric)**
  - **Metric:** Difficulty of obtaining permits or meeting regulations where the alternative would sited (existing land use)
  - **Preference:** Private land where with facilities would be easiest (Class II wells may exist at this site)

# The Relative Importance is Assessed for Each Objective



# Each Alternative Will Be Evaluated for Its Performance with Respect to Each Objective



# Comparison of Alternatives Is Achieved by Combining Importance and Performance

| | | | | | | Overall | |
|---|---|---|---|---|---|---|---|
| Alternatives | Regs | Cost | Env | Pub Acc | Risk | Score | Rank |
| A | 25 | 60 | 70 | 55 | 50 | 198 | 3 |
| B | 75 | 40 | 50 | 40 | 40 | 181 | 4 |
| C | 60 | 50 | 80 | 75 | 75 | 238 | 1 |
| D | 75 | 70 | 60 | 45 | 55 | 208 | 2 |

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Regional Carbon Sequestration Partnerships Annual Program Review Meeting
November 16, 2004

# Status Report: Baselines and Carbon Supply for the WESTCARB Region

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# Acknowledgements


***Winrock:***

Timothy Pearson
David Shoch
Brent Sohngen
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Sean Grimland
Scott Sweet

***CDF:***

Dean Cromwell
Mark Rosenberg
Doug Wickizer

***CEC:***

Guido Franco

***WADNR:***

Tony Ifie
Bob Bannon
Dave Wischer
Bruce Glass

***ODF:***

Jim Cathcart
Jim Wolf
Andrew Herstrom

***Oregon State:***

Jimmy Kagan

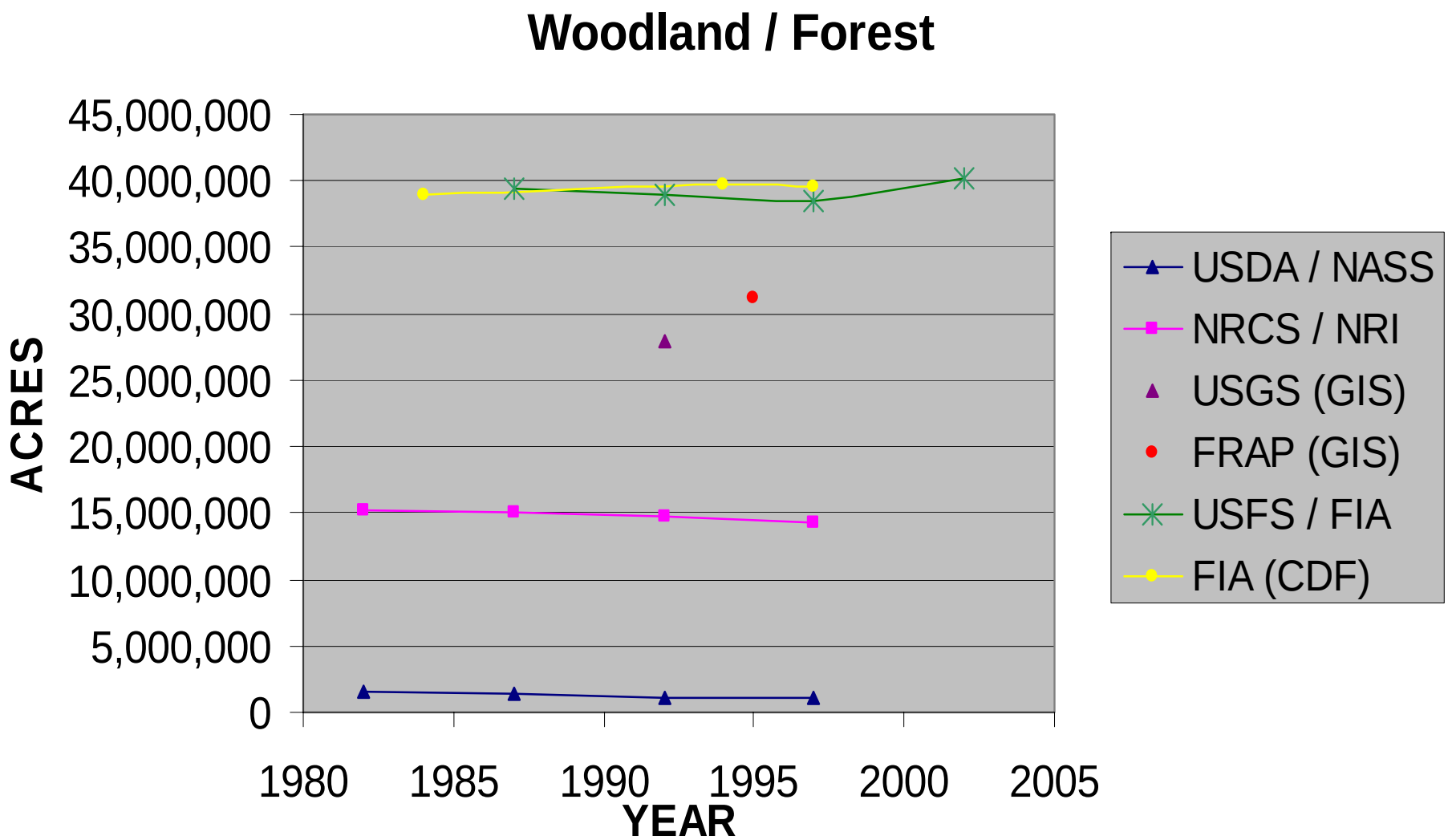
# Summary

- Baselines
  - California complete
  - Status of Oregon, Washington and Arizona
- Carbon Supply
  - California
  - Oregon

# Baseline:

- Has two components:
  - Land-use change between two points in time
  - Corresponding changes in carbon stocks
- To obtain a trend need at least three points in time and two time intervals

# California Forest Area by Different Sources



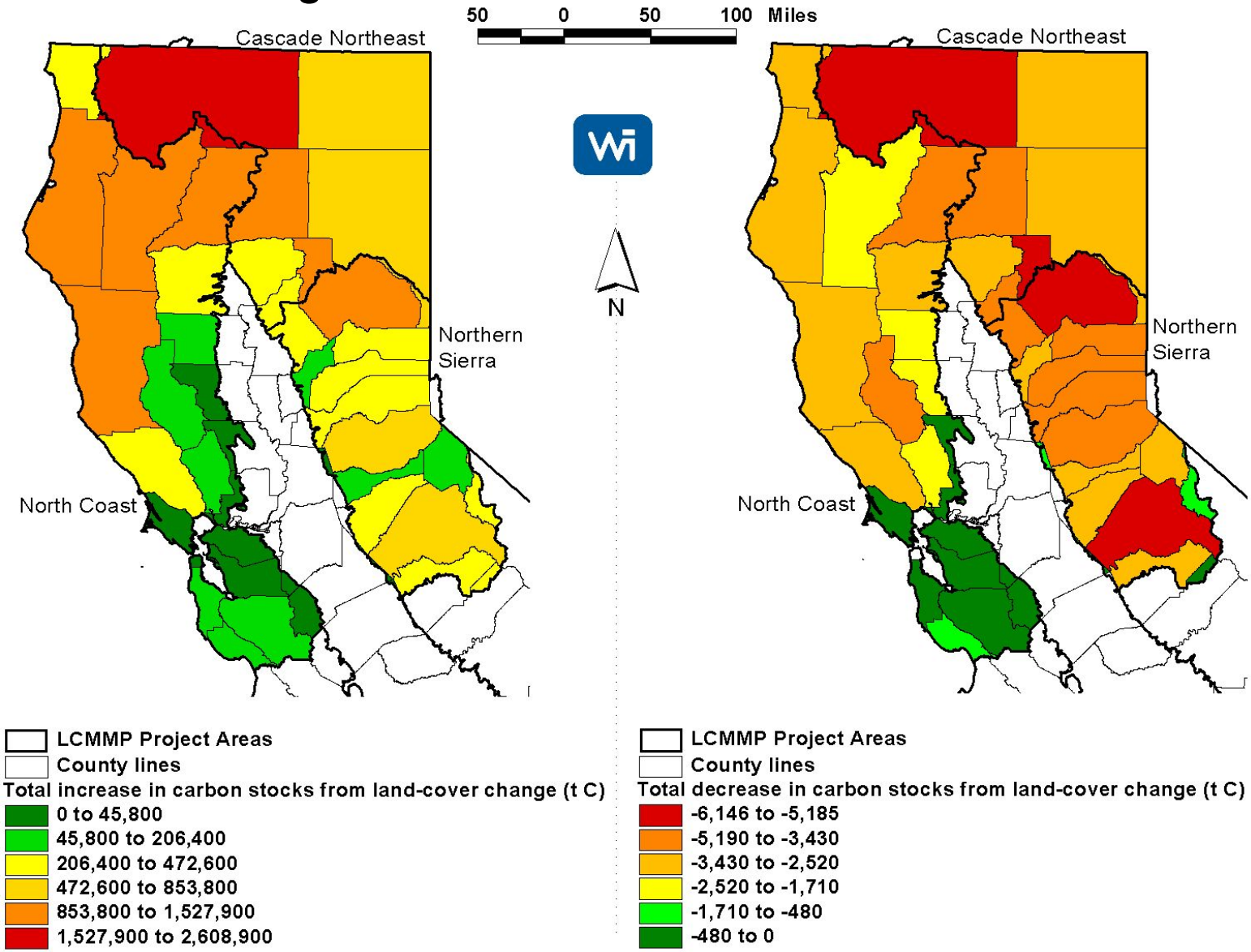
## Emissions and Removals by Cause of Change

| MMTCO2/yr | Forests | Rangelands |
|---|---|---|
| Fire | -1.55 | -0.14 |
| Harvest | -1.40 | -0.03 |
| Development | -0.01 | -0.004 |
| Other/Unverified | -0.79 | -0.10 |
| Regrowth | +10.96 | +0.46 |

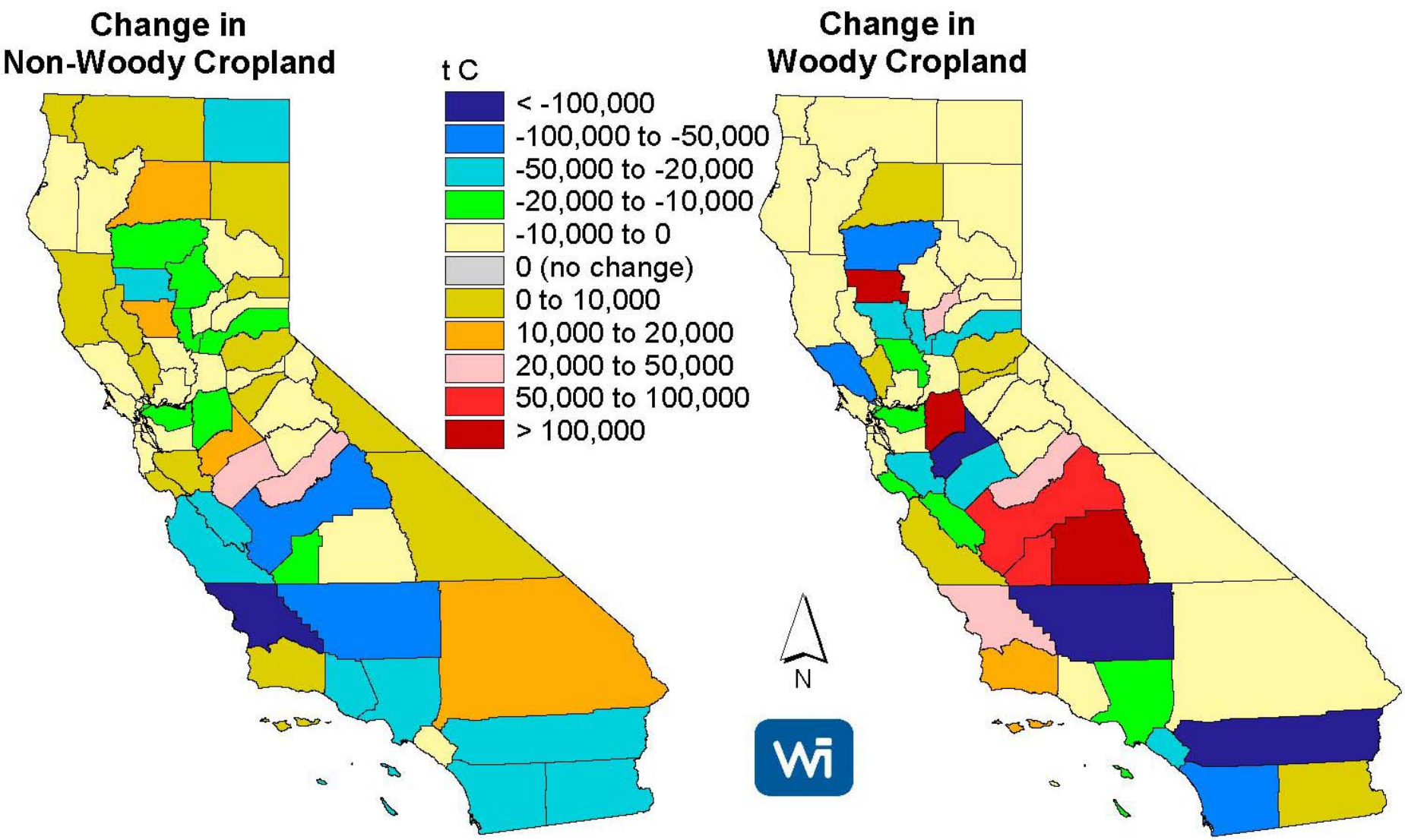
# Approach for California

- Land-use change:
  - Forests and rangelands: GIS-based analysis in five regions
    - Obtain degree of change in canopy (at 1 hectare resolution)
  - Agriculture: USDA-NRI land-use survey analysis for entire state at county & hydrological units resolution
- Carbon stocks:
  - For forests from CDF, FIADB and literature
  - For agriculture from literature

# Carbon Stock Changes for Forest Land



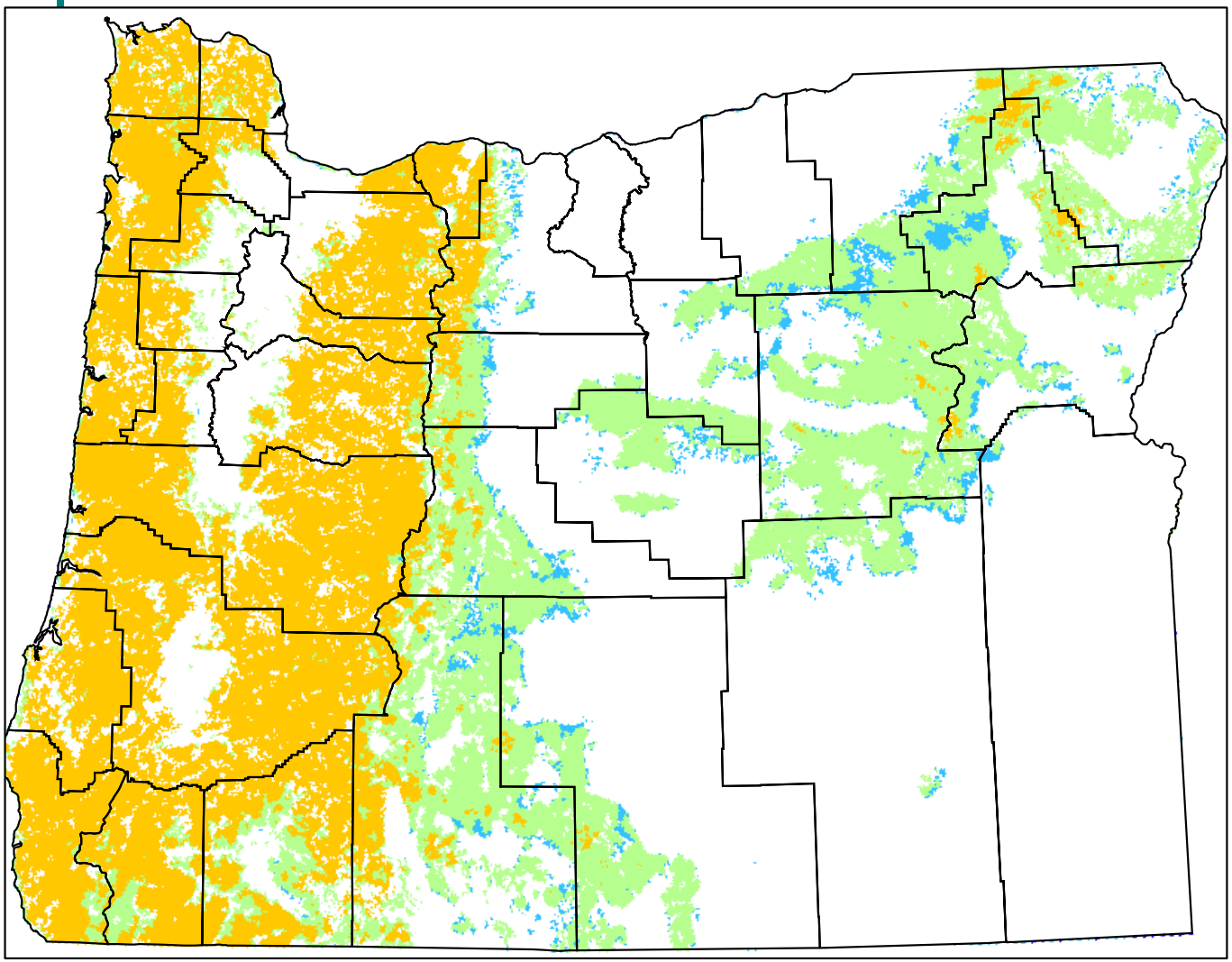
# Carbon Stock Changes in Agricultural Land for California



# Baselines for Oregon and Washington

- Forest and Rangelands
  - Datasets used for California not available
  - Will use combination of FIA and available spatial data for fire and harvest
- Agricultural Lands
  - Same methods as California

# Baseline for Fire

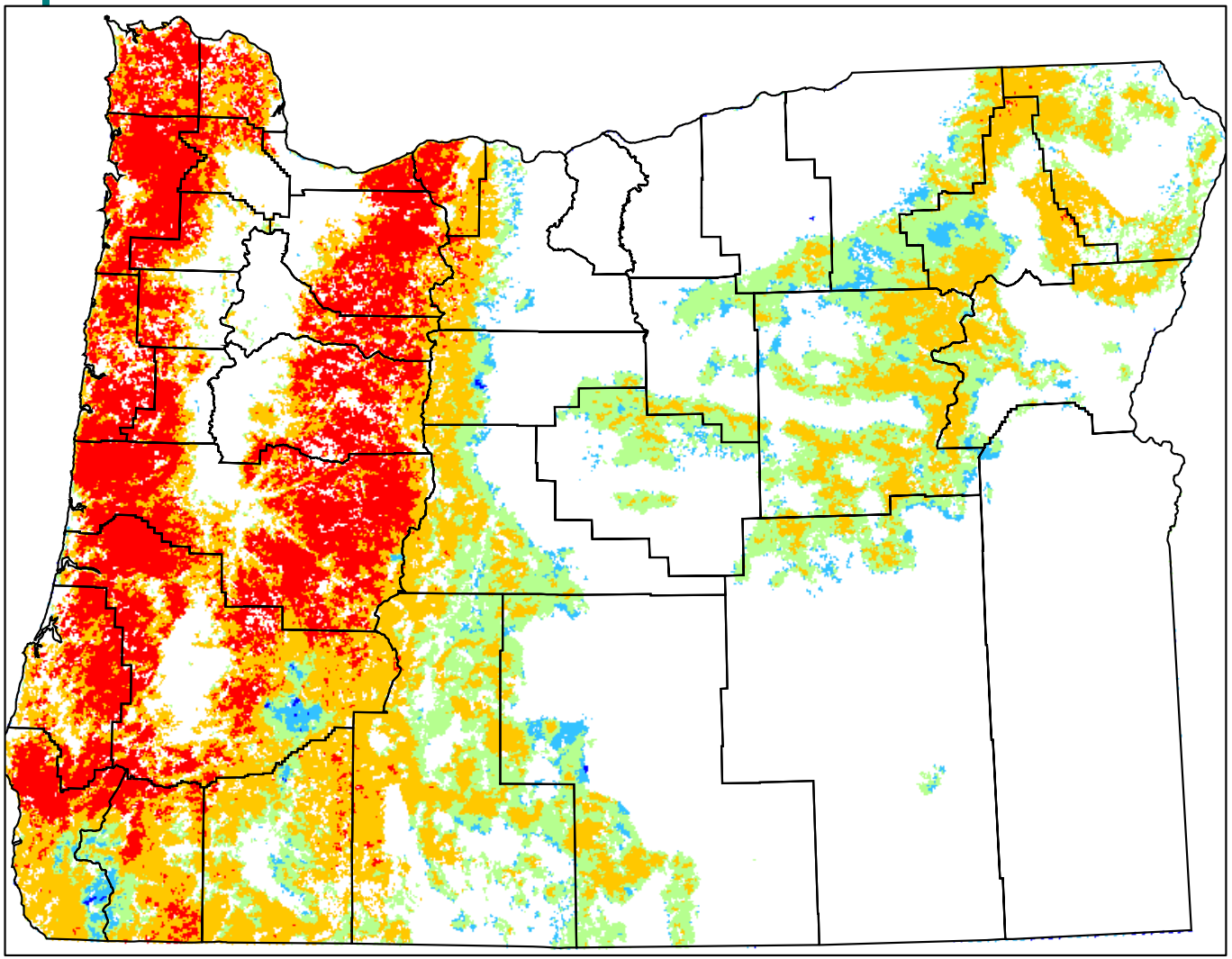


**Forest Areas**

**Mean Sept. NDVI**
**1990 – 2003**

**NDVI Mean**

- 0.81 - 0.90
- 0.61 - 0.80
- 0.41 - 0.60
- 0.21 - 0.40
- 0.01 - 0.20

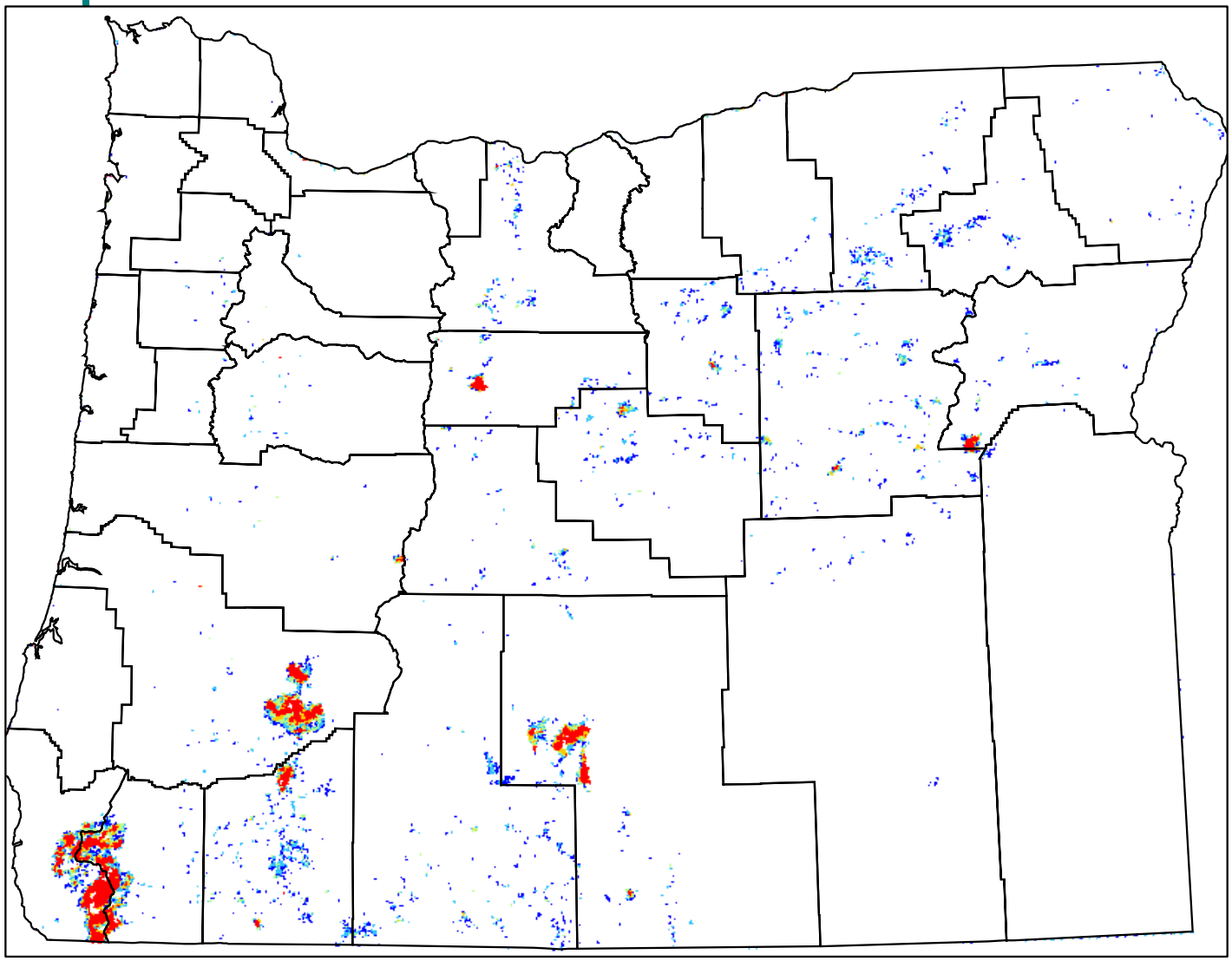


**Forest Area**

**NDVI Sept.2002 from max. values**

**NDVI 2002**

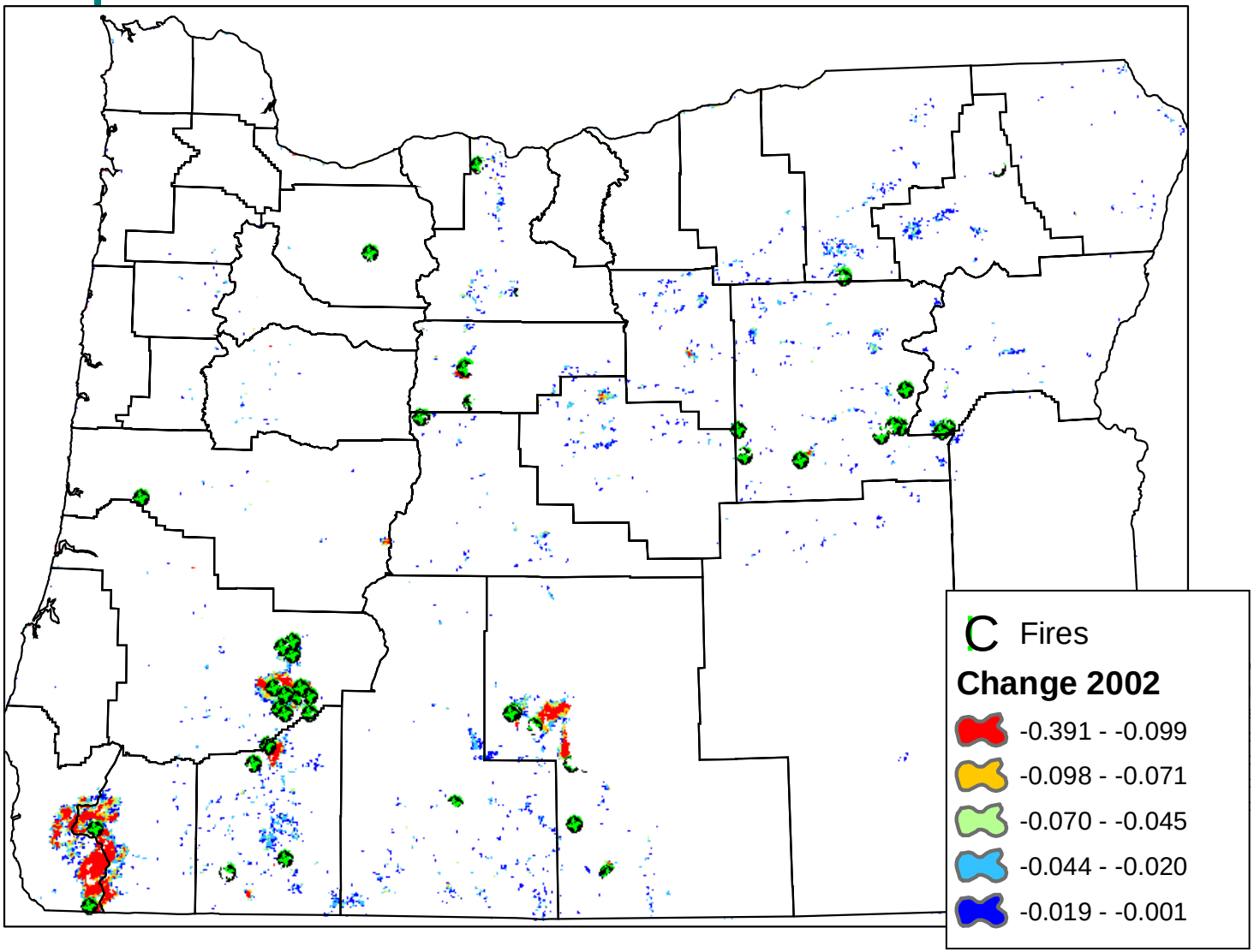
- 0.81 - 0.90
- 0.61 - 0.80
- 0.41 - 0.60
- 0.21 - 0.40
- 0.00 - 0.20



**Negative Change in Forest Areas between Mean & 2002 NDVIs**

**Change 2002**

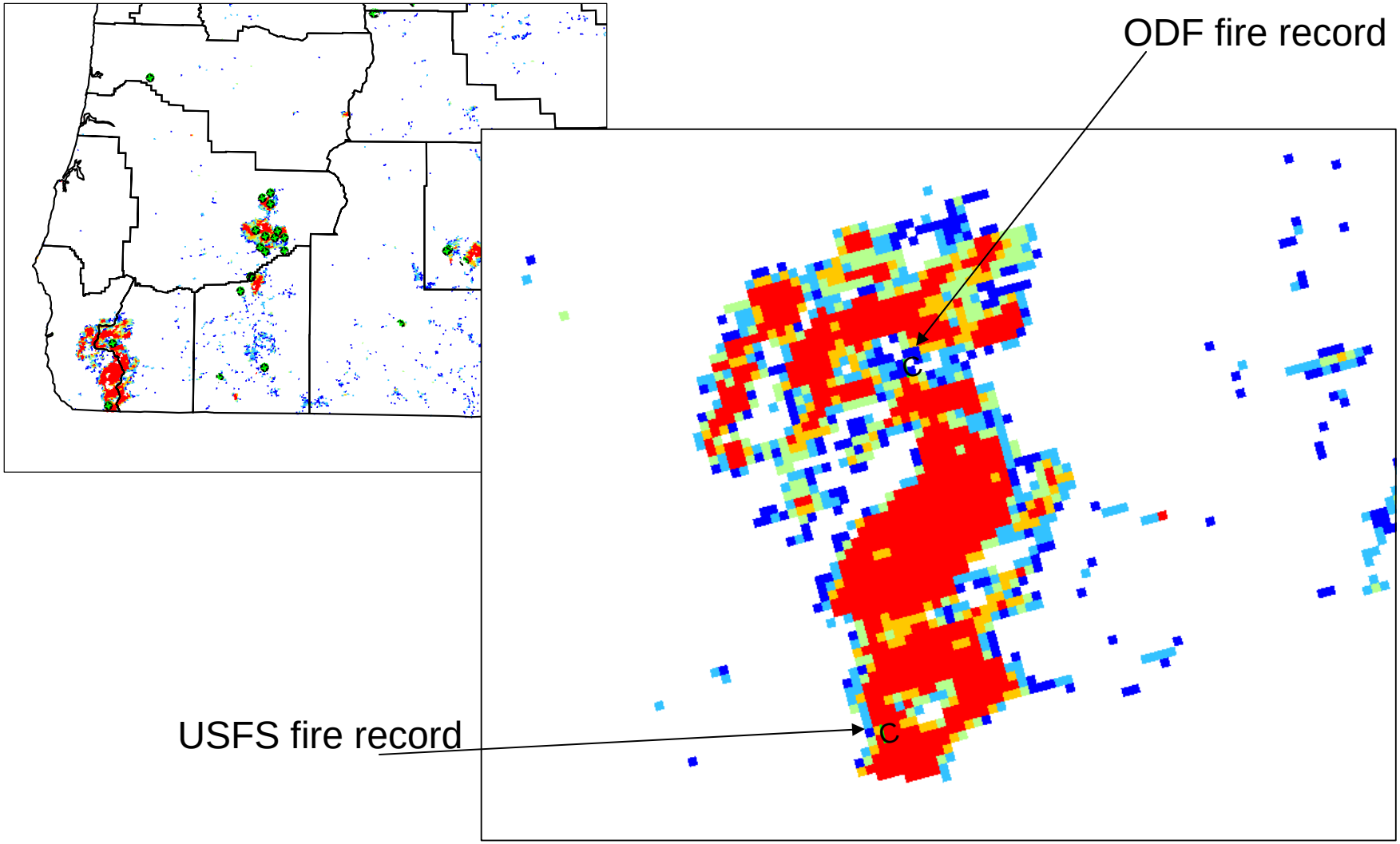
- -0.391 - -0.099
- -0.098 - -0.071
- -0.070 - -0.045
- -0.044 - -0.020
- -0.019 - -0.001




**Negative Change in Forest Areas between Mean & 2002 NDVIs**

Fire records come from ODF and USFS. There are a few overlapping points such as the Biscuit fire.

**ODF and USFS list the Biscuit fire damage total acres as 499,945. We measured ~369,352 acres of change.**




Agencies measure the perimeter –not area actually burned

# General approach for carbon supply

- Divide lands into three main categories:
  - Rangelands
  - Forests
  - Agriculture
- Identify options for enhancing carbon sequestration for each category
- Estimate:
  - Area available—how much and where
    - Spatial modeling and FIA data base
  - Amount of carbon sequestration over 20, 40, and 80 year periods
  - Costs (opportunity costs, conversion costs, maintenance costs, and measuring costs)

# Carbon Supply Summary:

**Afforestation of grazing lands provides the most carbon and at the least cost**

| Activity | Quantity of C—MMT $CO_2$ | | | Area available—M acres | | |
|---|---|---|---|---|---|---|
| | 20 yr | 40 yr | 80 yr | 20 yr | 40 yr | 80 yr |
| **Forest management** | | | | | | |
| Lengthen rotation | | | | | | |
| <$13.6 | **2.2-3.5** | -- | -- | 0.31 | -- | -- |
| Increase riparian buffer-width | | | | | | |
| <$13.6 | **3.91** (permanent) | | | | 0.044 | |
| **Grazing lands** | | | | | | |
| Afforestation | | | | | | |
| <$13.6 | **887** | 3,256 | 5,639 | 12.03 | 17.79 | 20.76 |
| <$2.7 | 33 | 1,610 | 4,569 | 0.20 | 5.68 | 13.34 |

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# *Rangelands*

# Convert rangelands to forests

- Determine which rangelands could support forests—suitability analysis
  - Land-use suitability analysis based on

    I. Biophysical factor-dependent suitability for forest habitats

    II. STATSGO production map-based models to map suitability for forage and biomass production

- Analysis of rates of carbon accumulation
- Economic analysis

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# *Suitability analysis for rangelands*

# Identify rangelands suitable for conversion to forests

- Analyze the relationship between existing forests and several biophysical factors using GEOMOD =“suitability for forest map”
- Cross-reference suitability map to areas of current rangelands to select areas with afforestation potential.

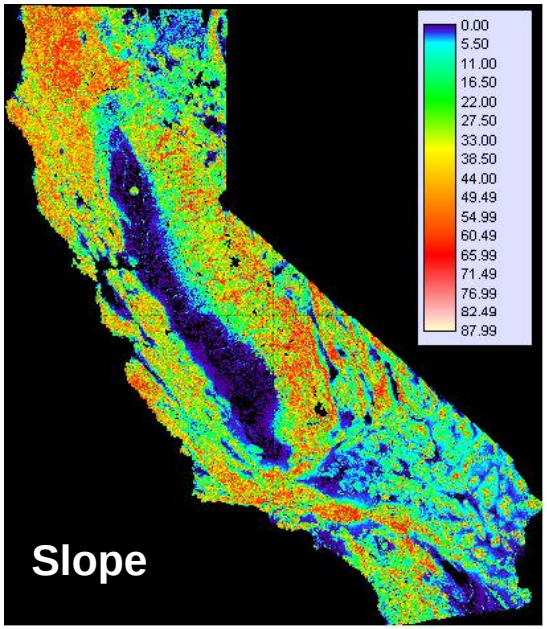
***Product = map of rangeland areas suitable to support forests***

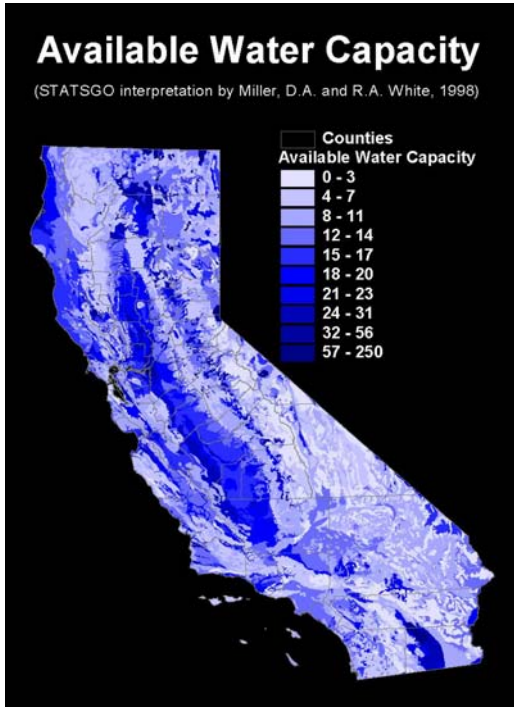
- Carbon sequestration in forest biomass derived from FIA and literature

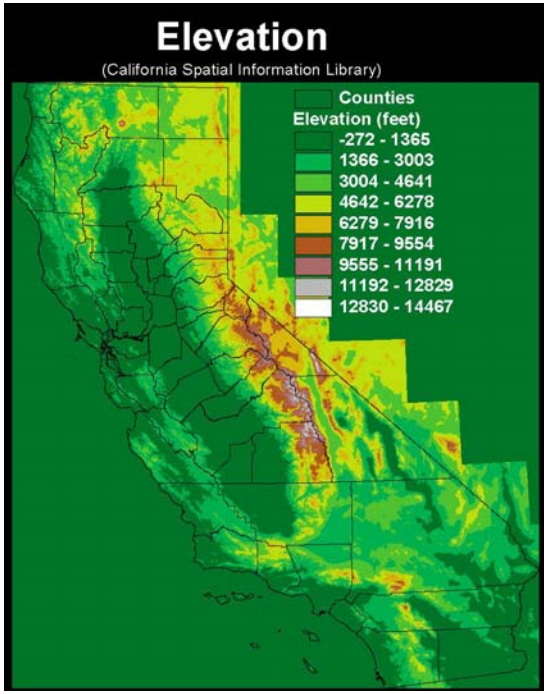
***Product = map of carbon accumulation for afforesting rangelands***

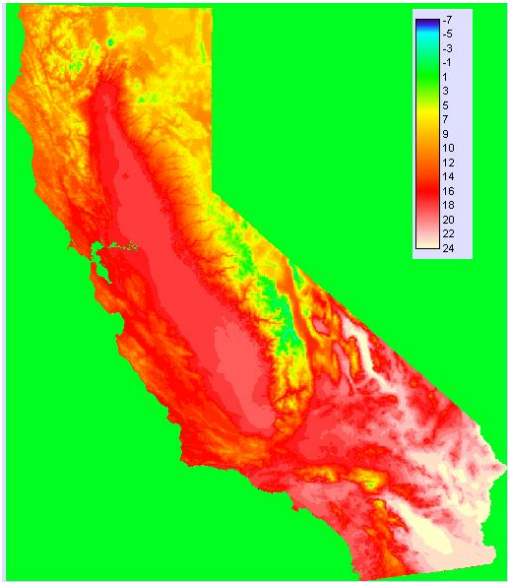
# Prepare factor maps

Combine factor maps to determine suitability for afforestation

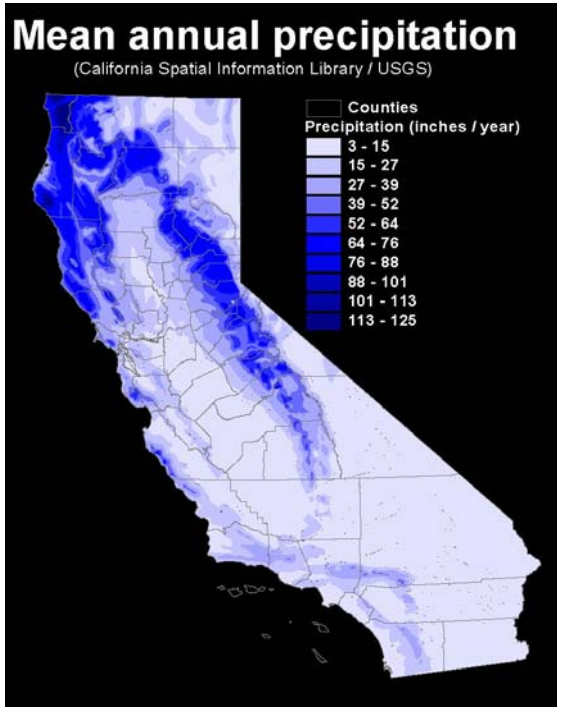


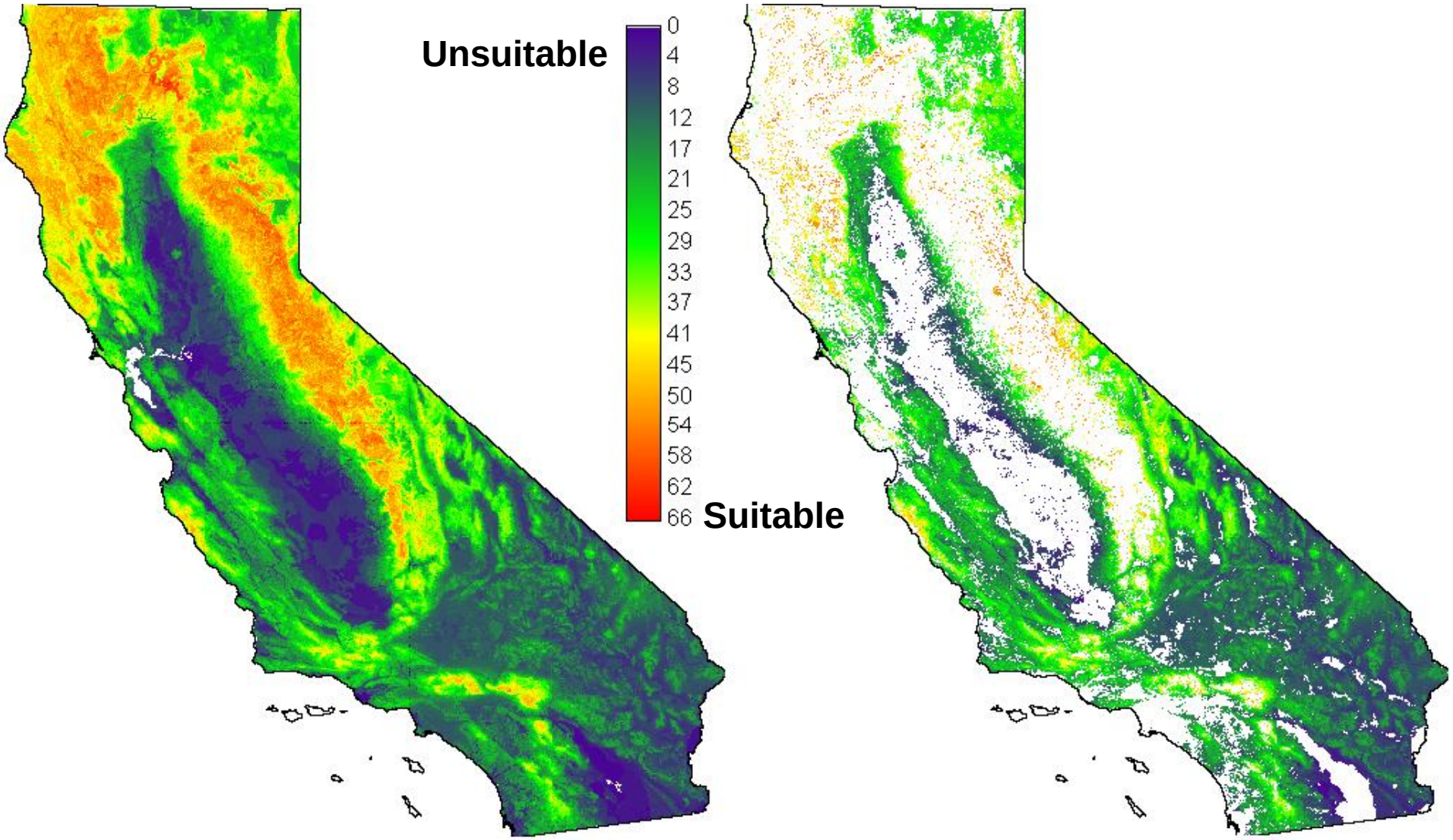




**Mean annual temperature**

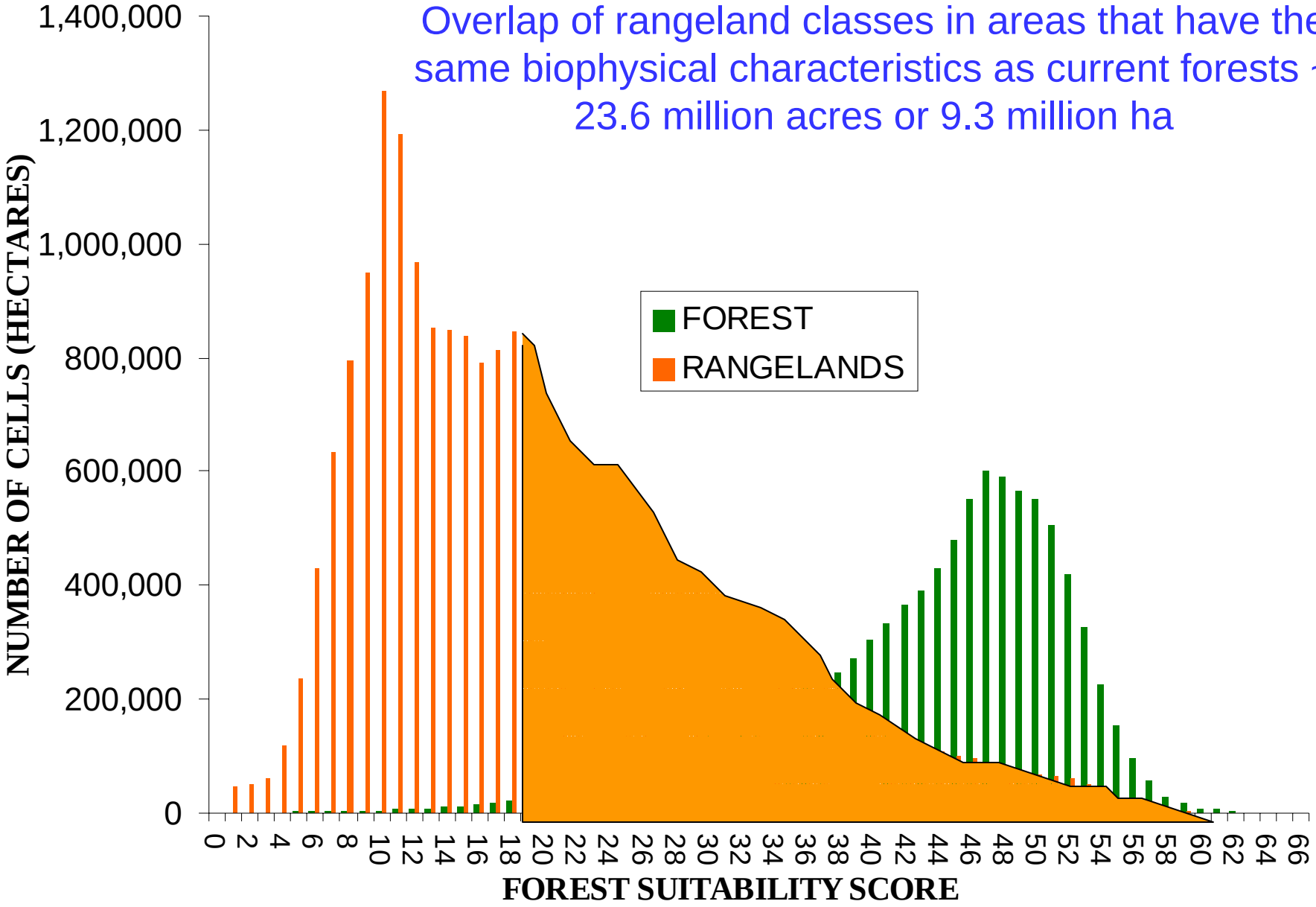


# All areas suitable for forest growth (left) and rangeland areas suitable for forest growth (right)

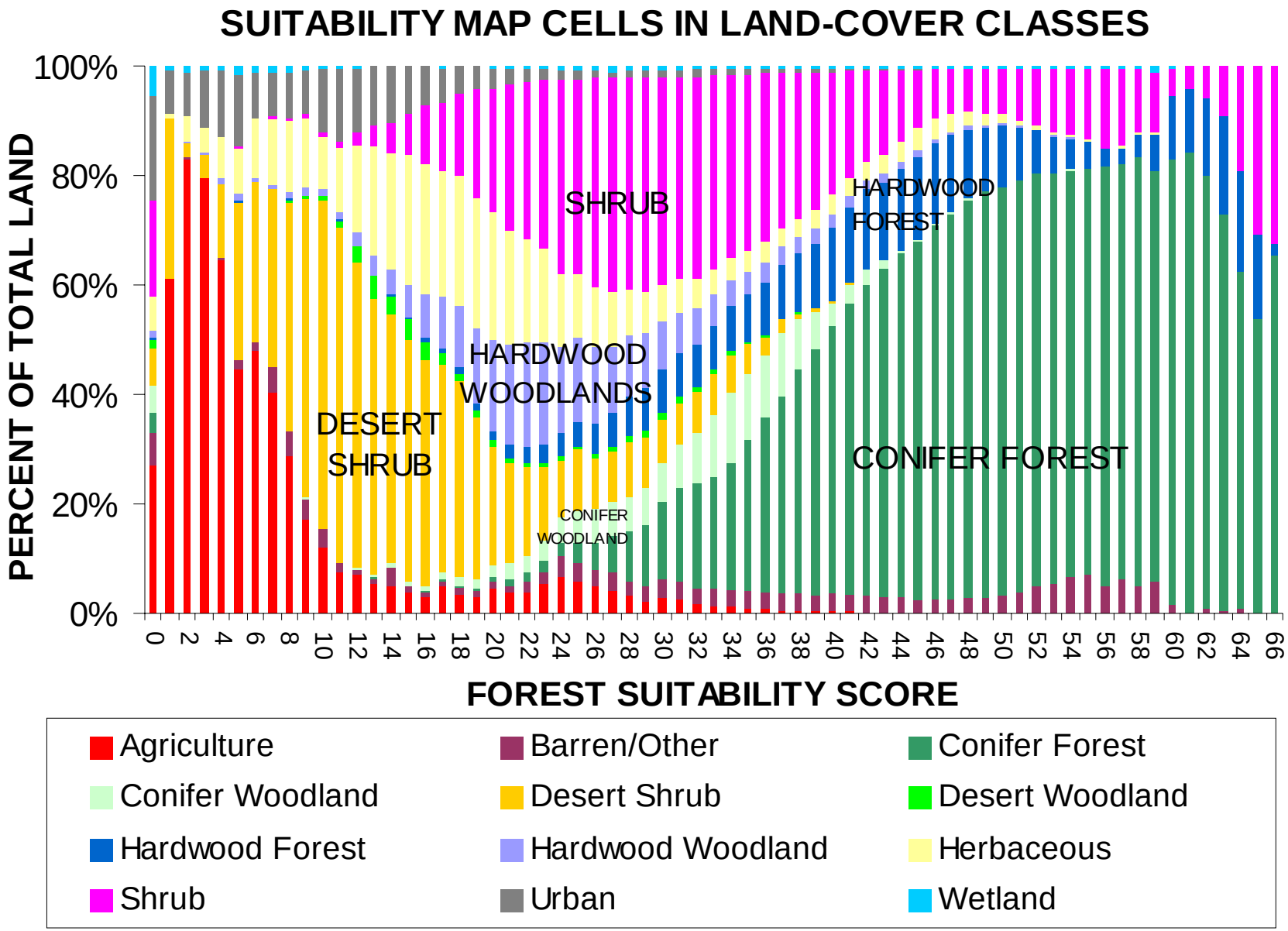


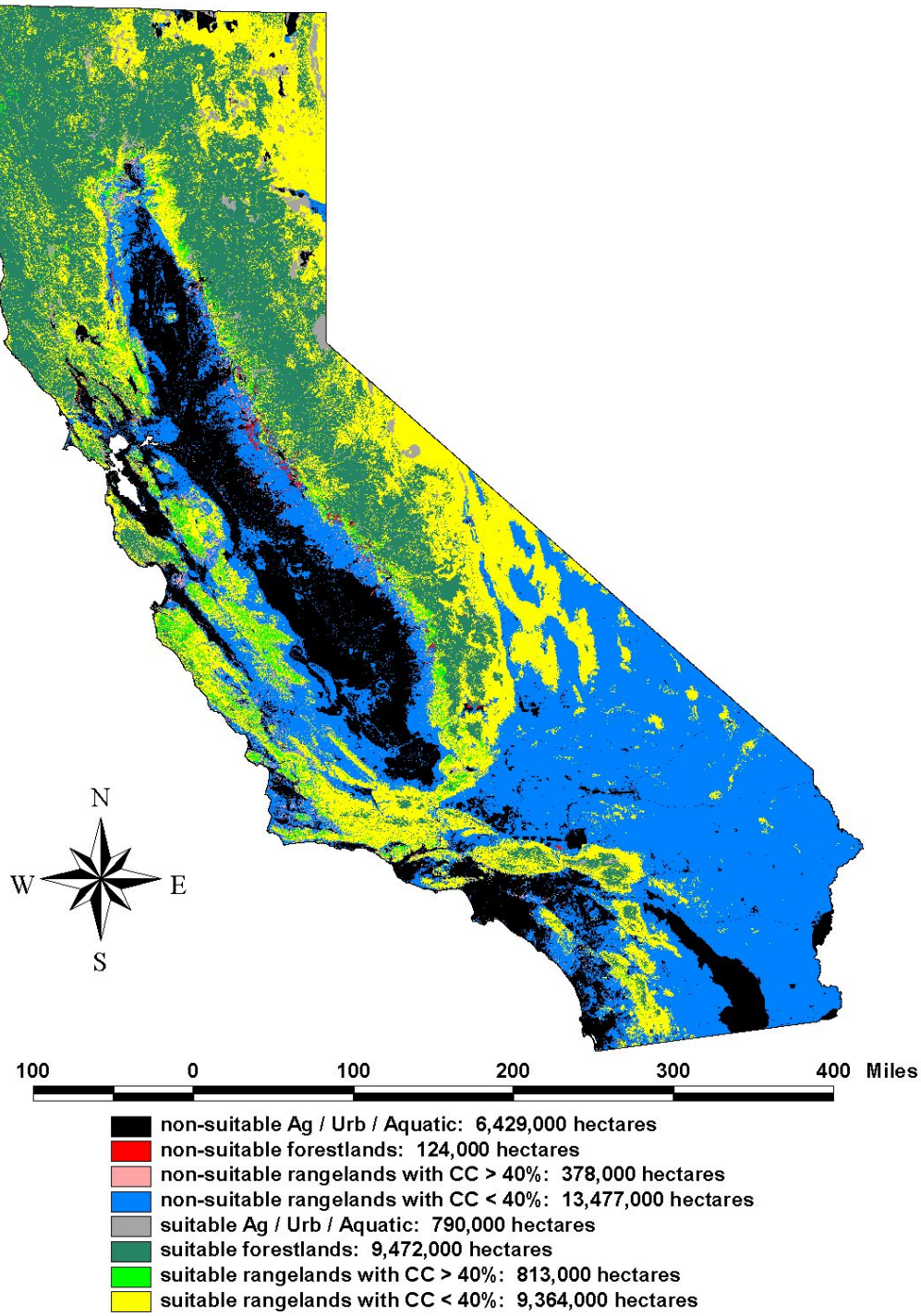
# Area of existing rangelands suitable for forest growth

Overlap of rangeland classes in areas that have the same biophysical characteristics as current forests ~ 23.6 million acres or 9.3 million ha



# What type of forests are suitable?

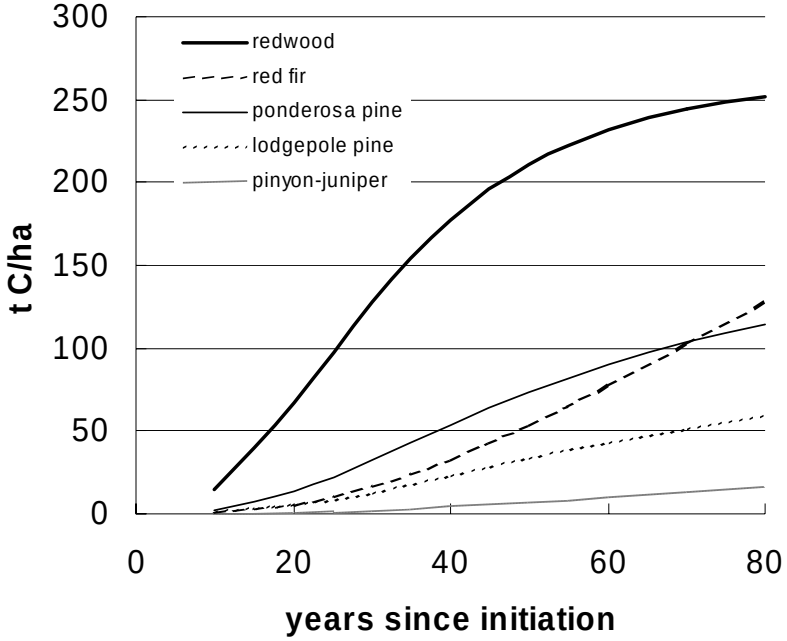


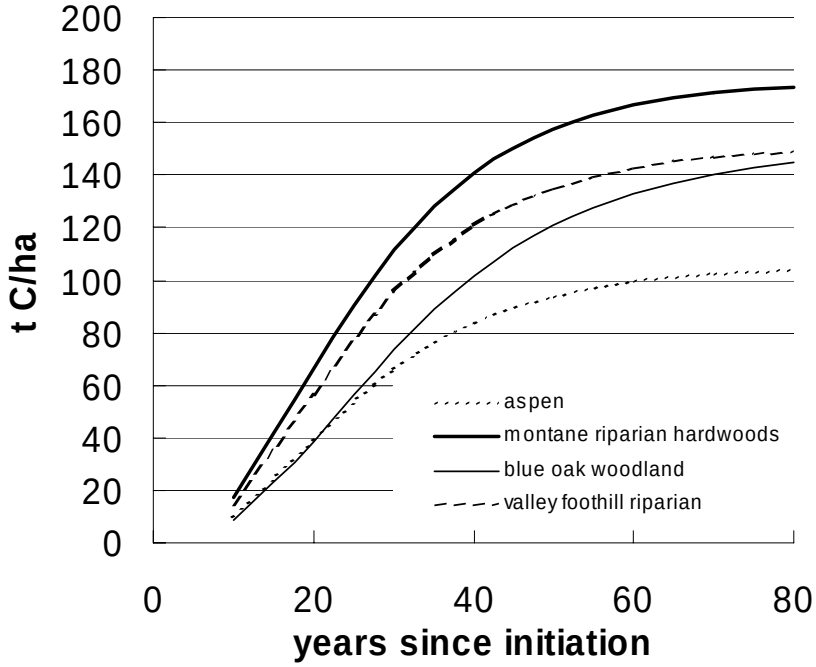



# Map of rangeland areas (in yellow) suitable for afforestation

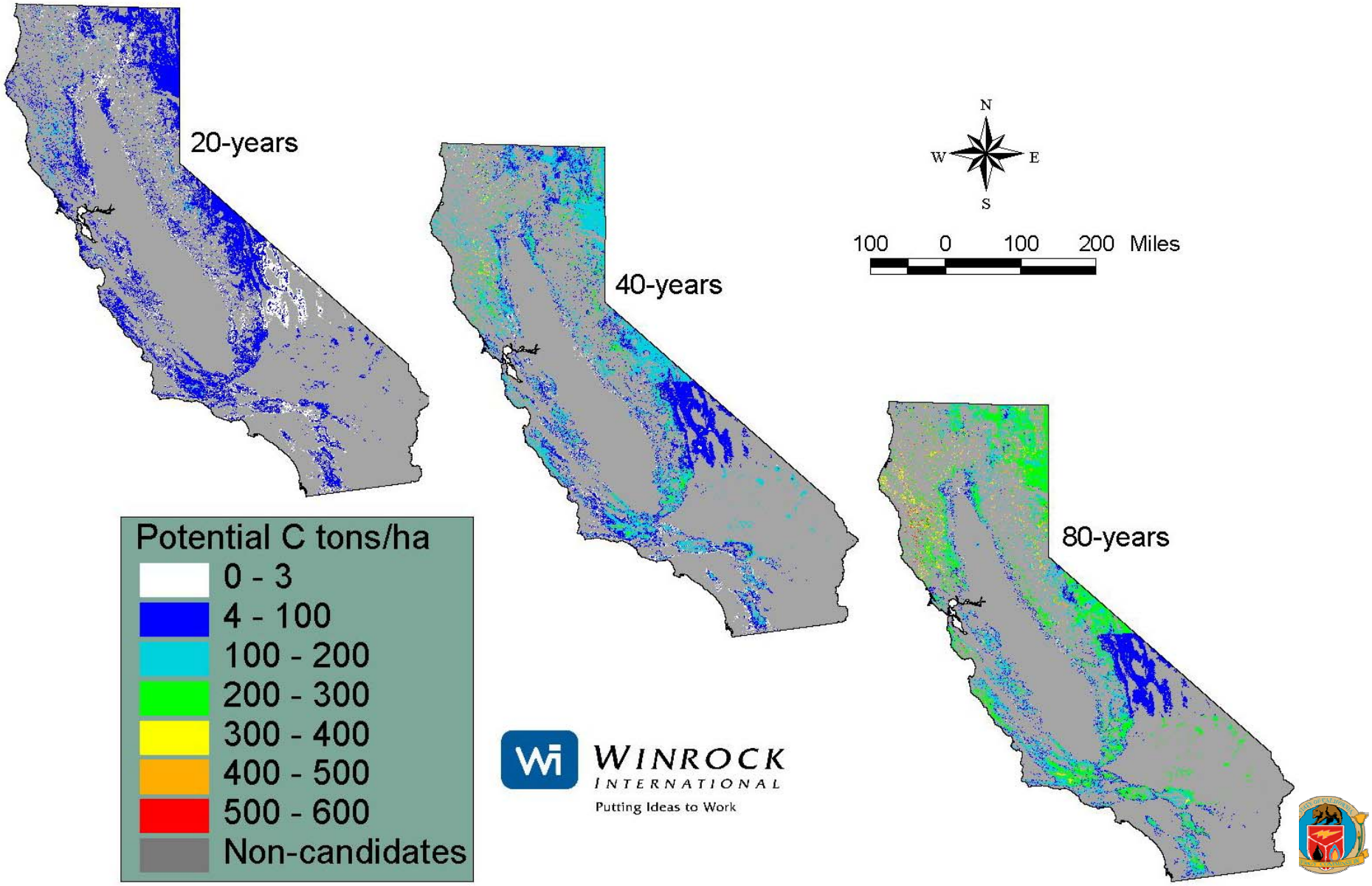
- *Represent about 24 million acres or 23% of State area*

# Potential biomass-carbon accumulation in conifer and hardwood forests



# Net carbon accumulation applied to potential woody-species distributions over three time periods



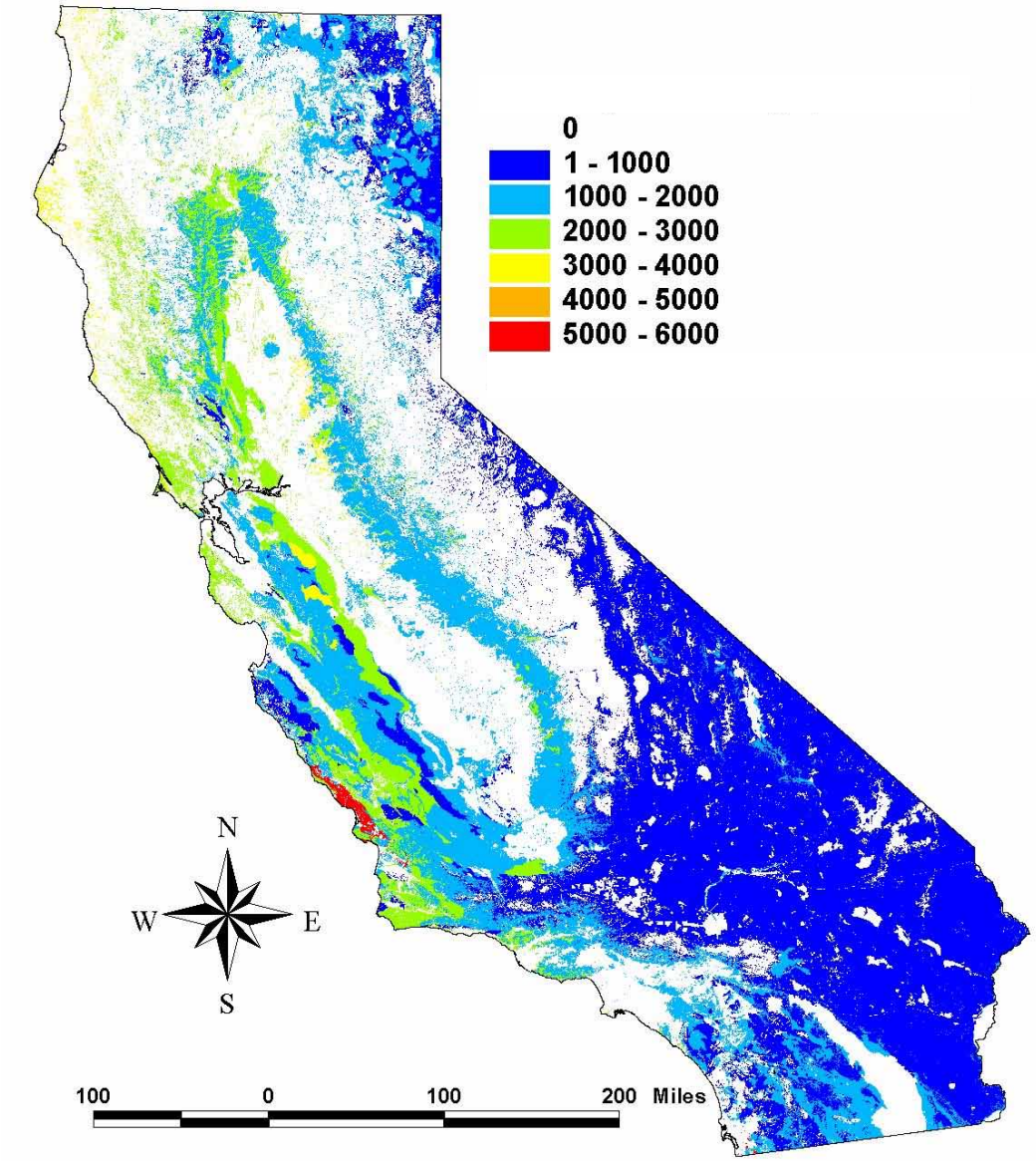
# Opportunity Cost

- Using the same biophysical factors, a model was used to extrapolate STATSGO forage productivity data samples to a state-wide coverage.

  ***Product = map forage production***

- Economic analysis of forage value derived from national databases and field interviews
  - Mean annual profit/cow
  - Number of cows supported based strongly on forage production (1 animal unit month for CA = 791 lbs)

# Estimated forage productivity across rangeland classes (lbs per acre per year)

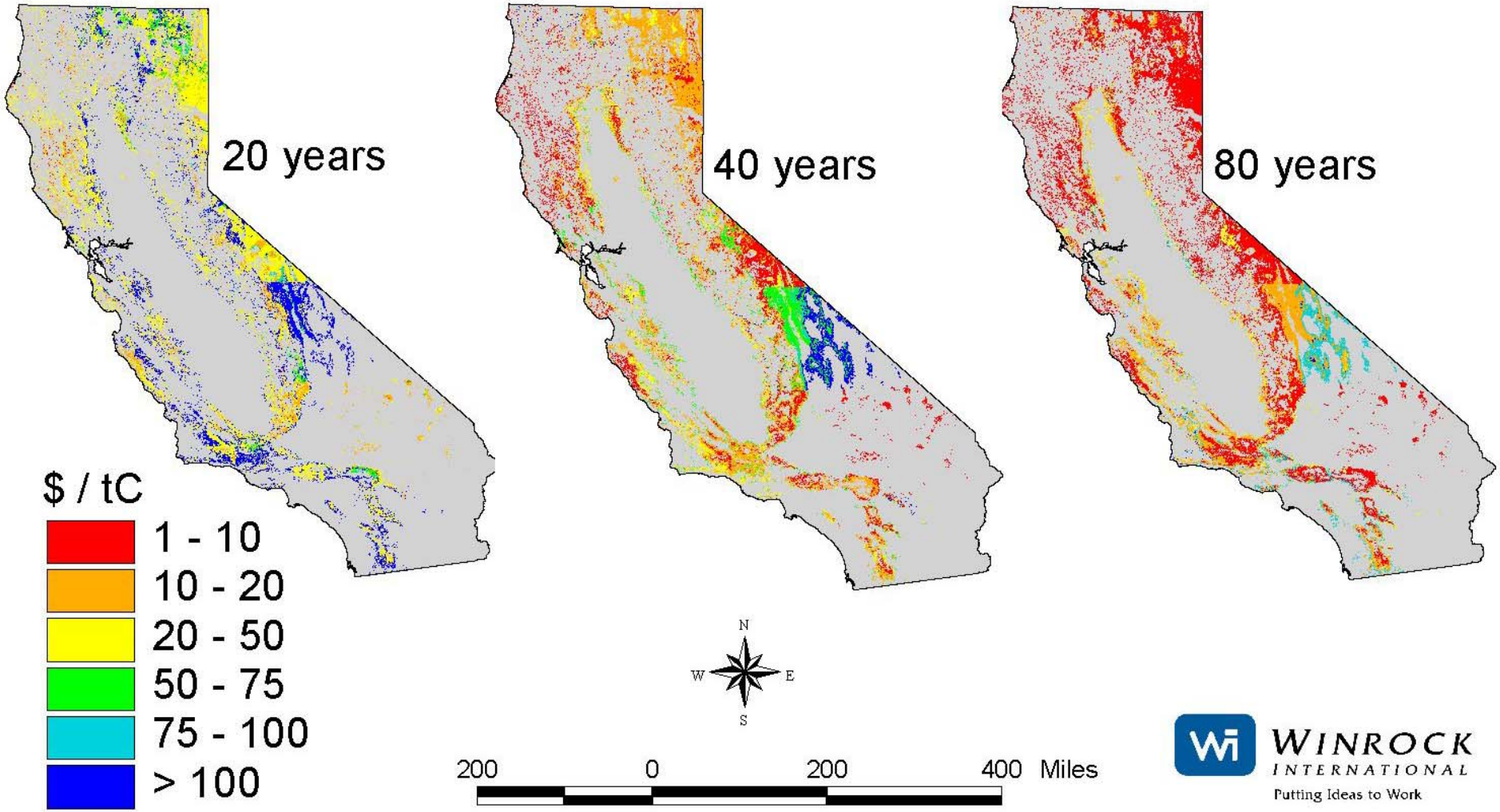



This map used to estimate number of cows per acre based on need for 9,492 lbs of forage per year for range-fed cattle and opportunity cost based on profitability per cow

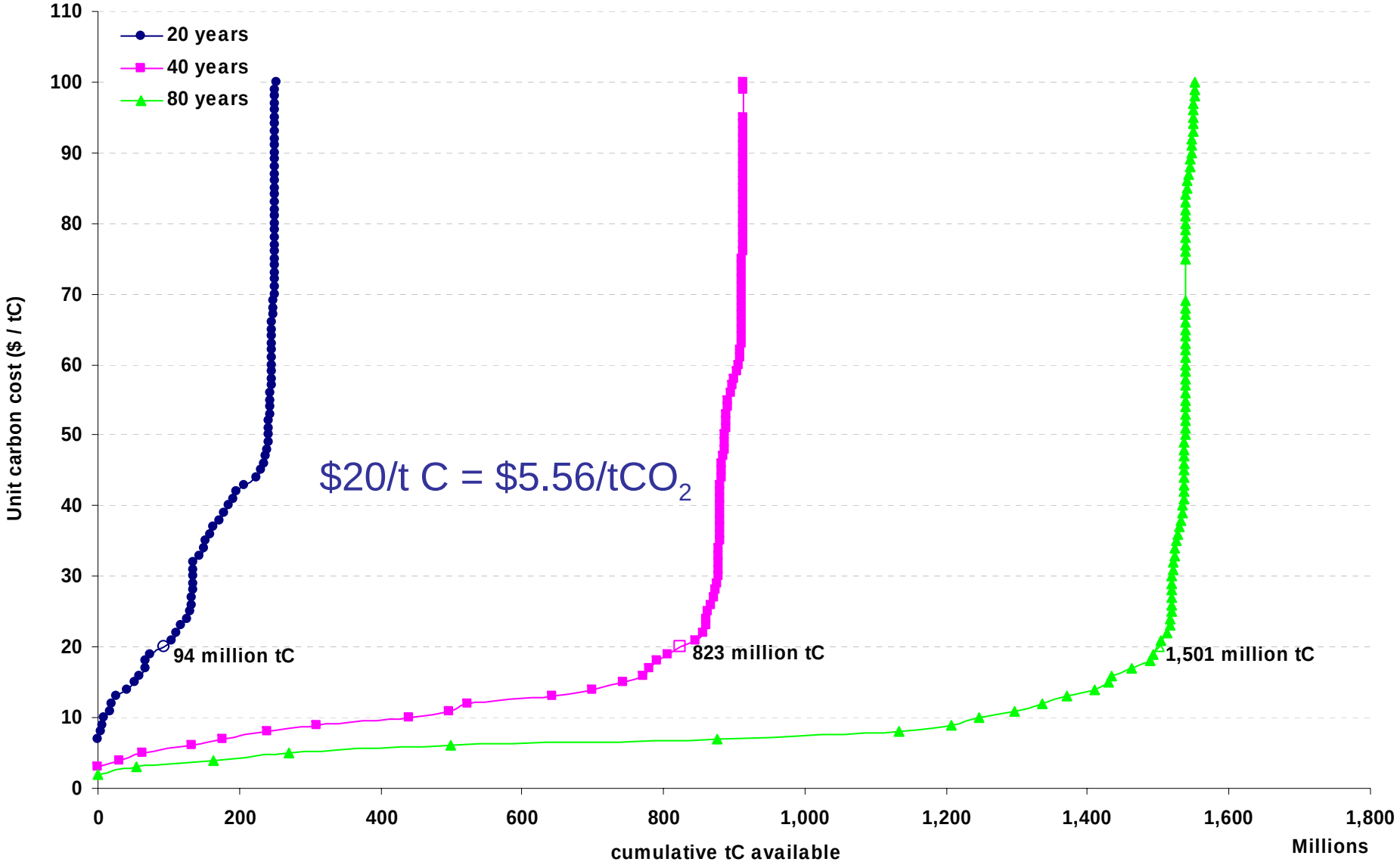
# Cost of Carbon Sequestration

- Total cost, as net present value over life of duration of activity = opportunity cost + conversion cost + measuring&monitoring cost + maintenance cost
  - Conversion costs—one time cost for planting trees (about $450/ha)
  - Measuring and monitoring costs over life of activity (about $2.5/ha annually)
  - Maintenance costs—replanting, fencing, chemical additions (about $20/ha annually for 5 years)

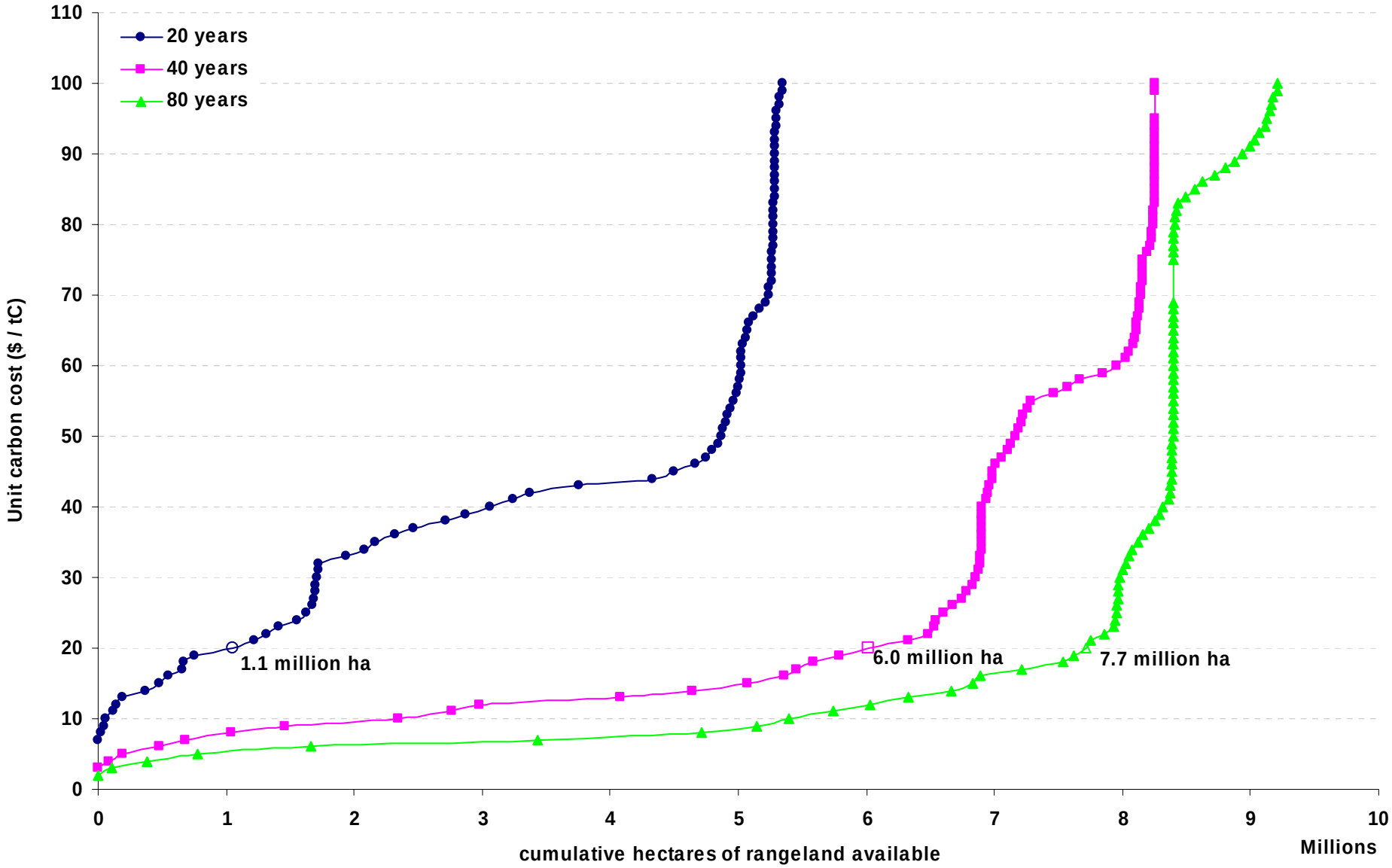
# Cost of carbon sequestration through afforestation of California rangelands



# Carbon supply curves for afforestation activities for 20, 40 and 80 years

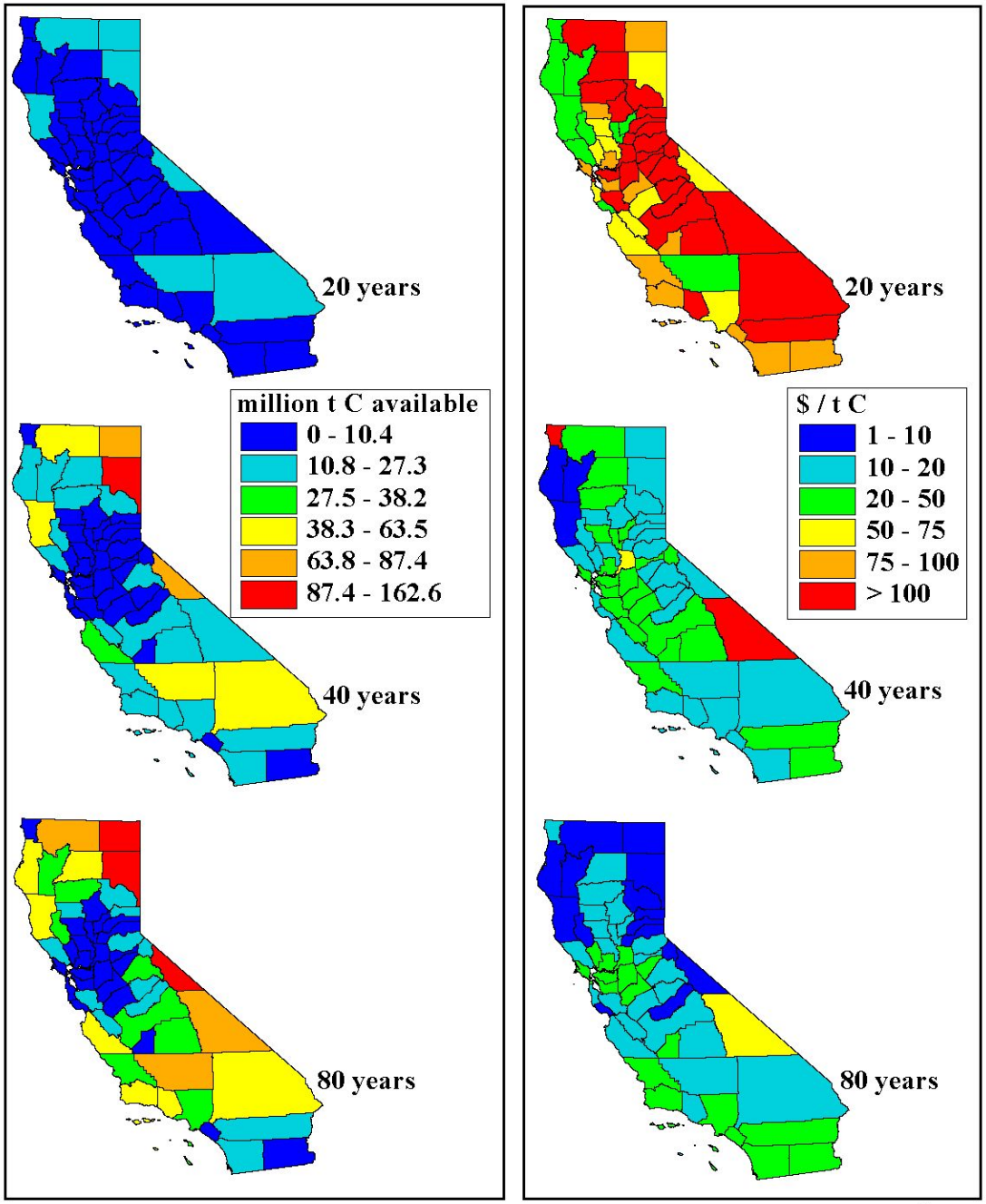


# Area of rangelands for afforestation activities at different price points



# Quantity of $CO_2$ and area of rangeland for cost of up to \$5.5/t $CO_2$(\$20/t C)

| Life of Activity | Carbon Supplied (million tons $CO_2$) | Rangeland (million ac) | Percentage of Suitable Rangeland |
|---|---|---|---|
| 20 | 338 | 2.72 | 14% |
| 40 | 3,018 | 14.8 | 68% |
| 80 | 5,504 | 19.0 | 83% |



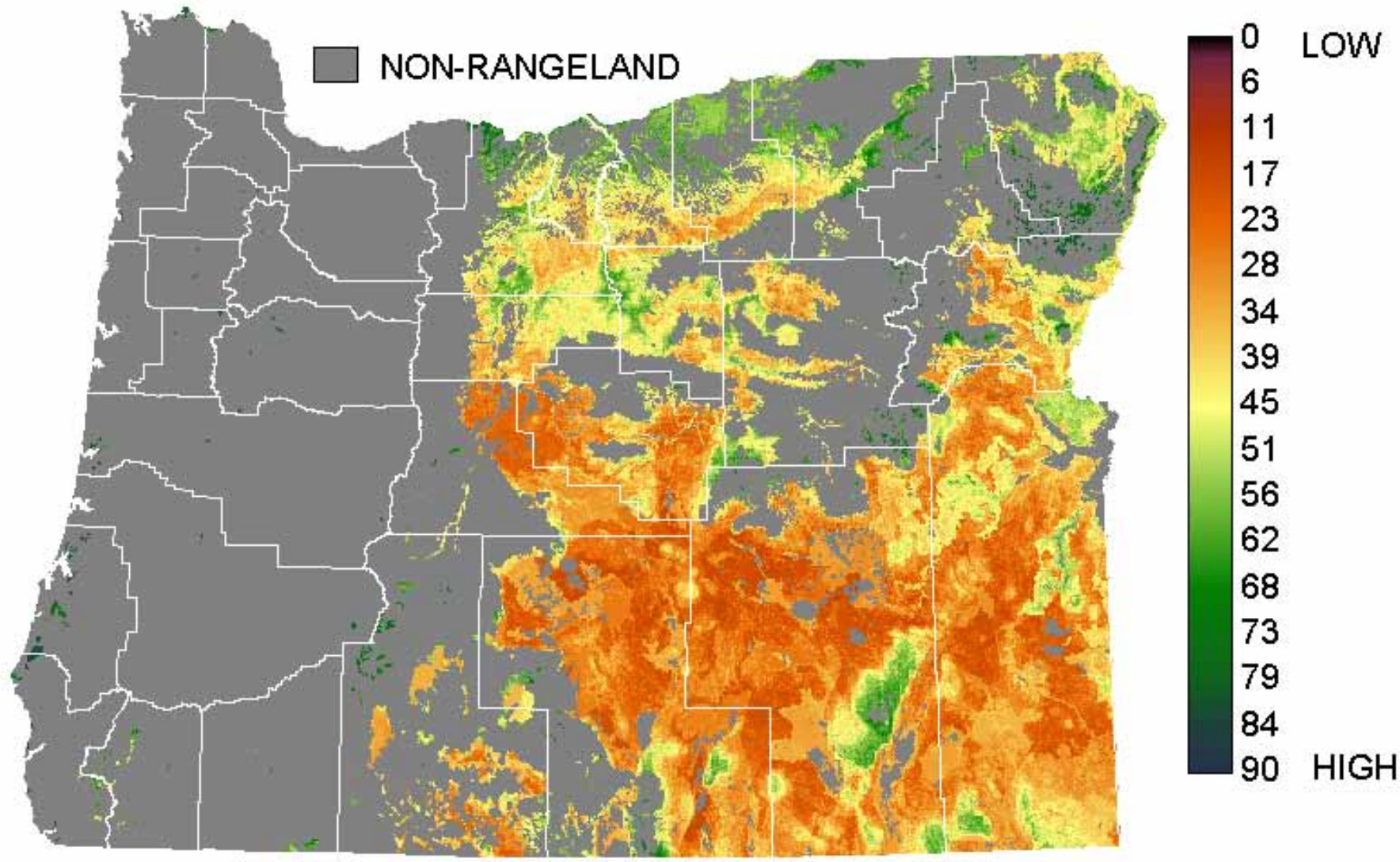

200 0 200 400 Miles

N

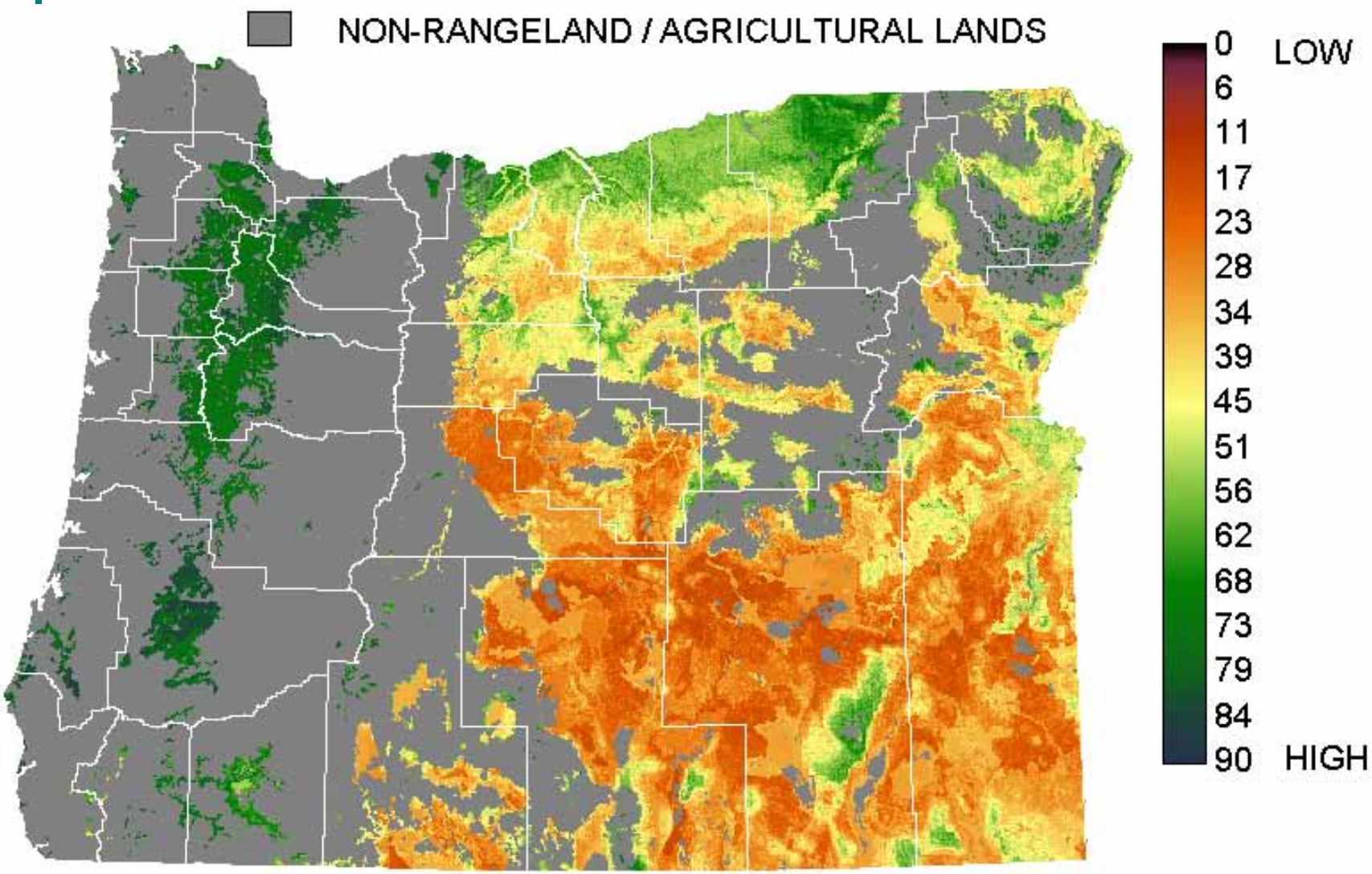
# Total carbon sequestered by afforestation of rangelands and area-weighted average cost $/t C and after 20, 40 and 80 years

To convert to $/ metric t CO2, divide by 3.6

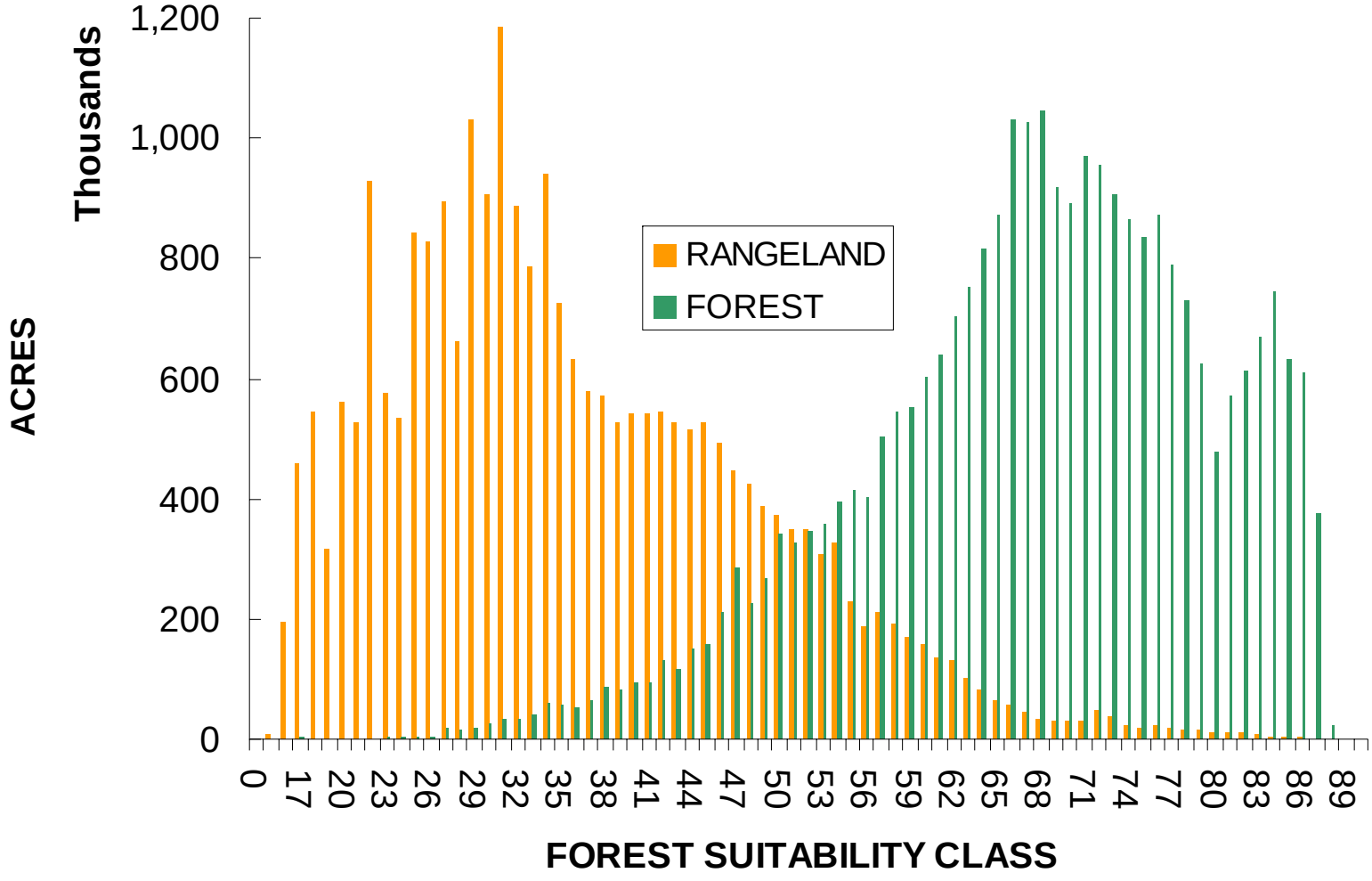
# Oregon Grazing Lands Suitable for Afforestation



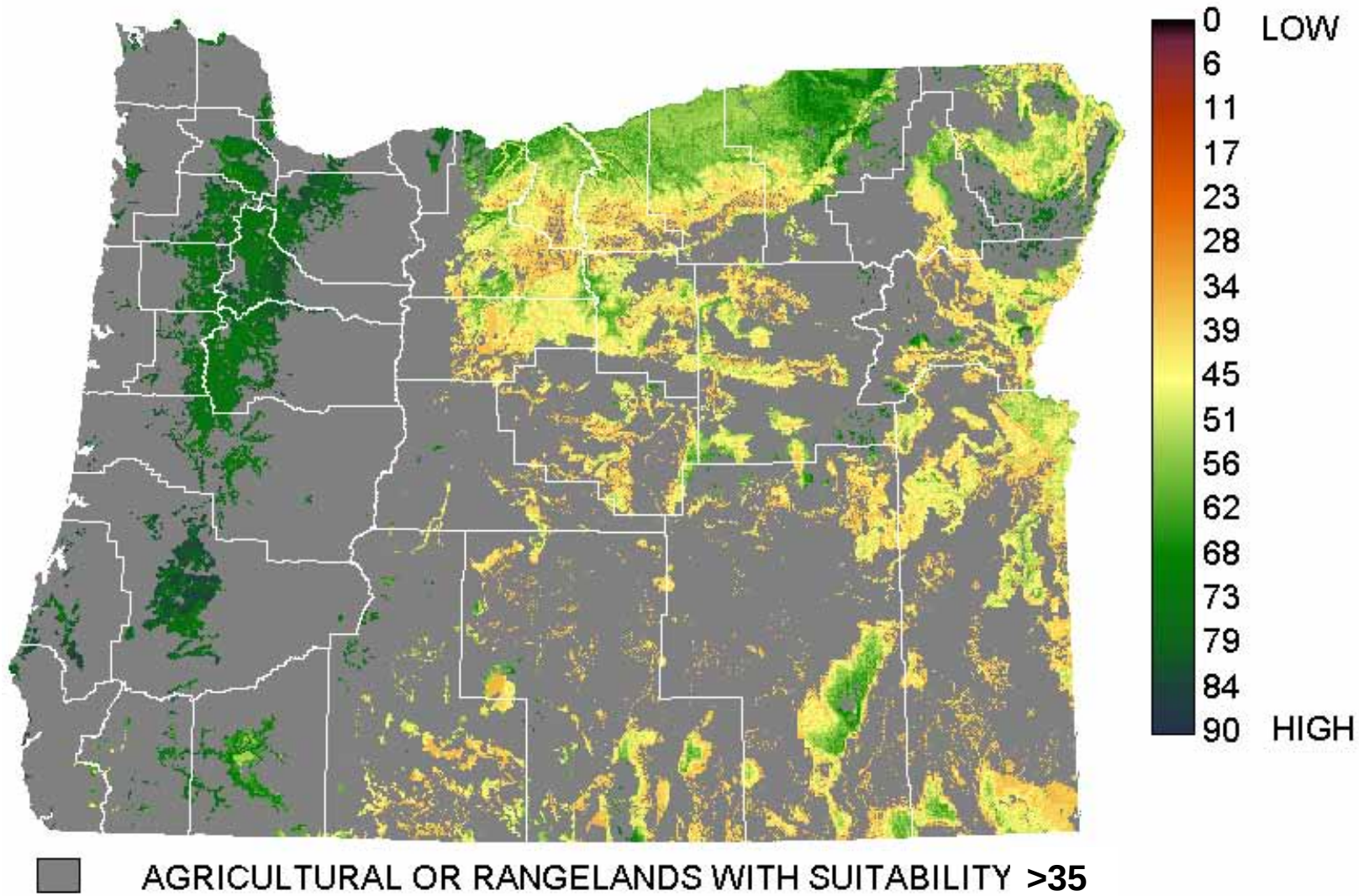
# Oregon Agricultural and Grazing Lands Suitable for Afforestation



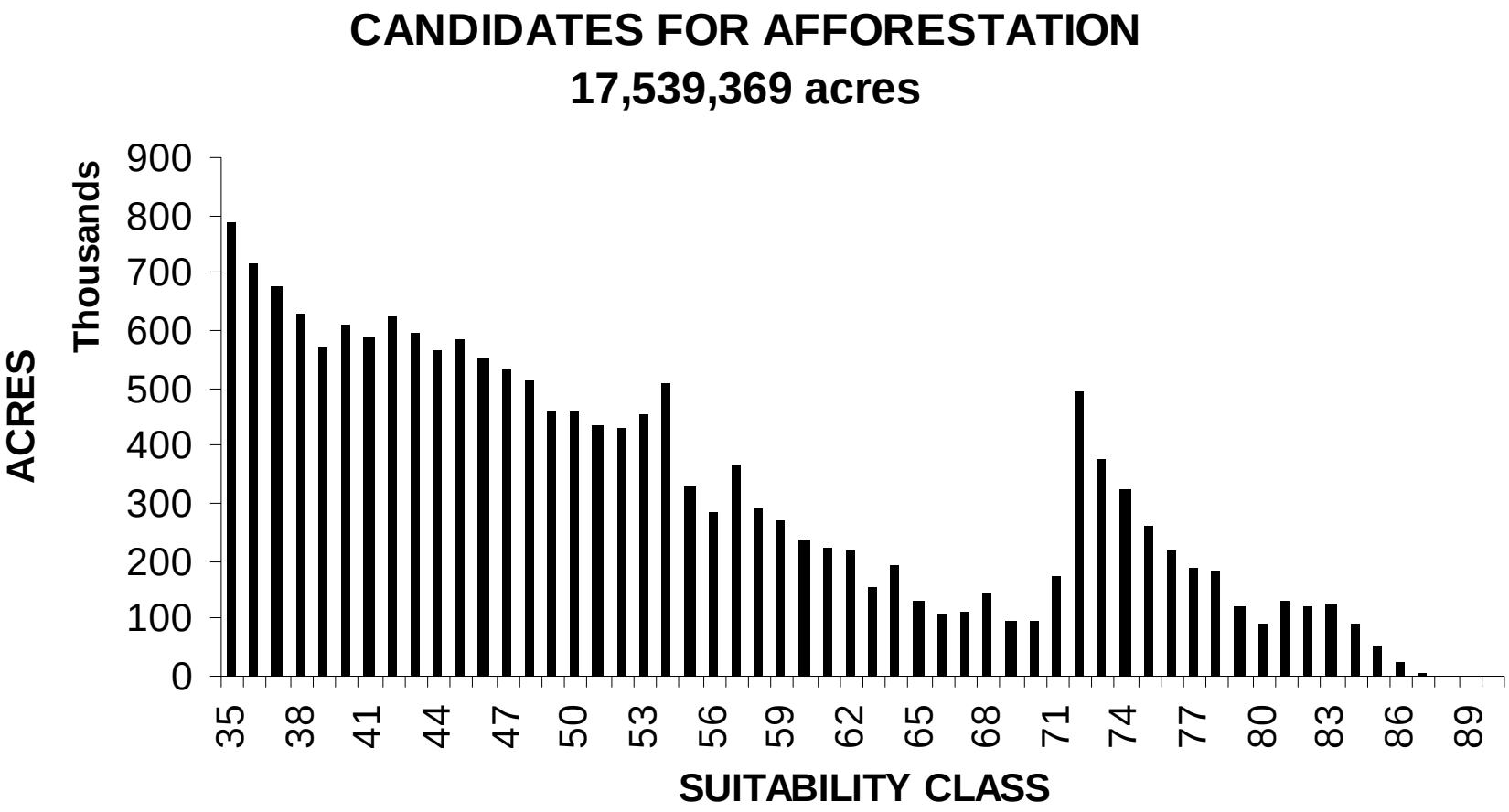
# Oregon Suitability for Forest versus Rangeland



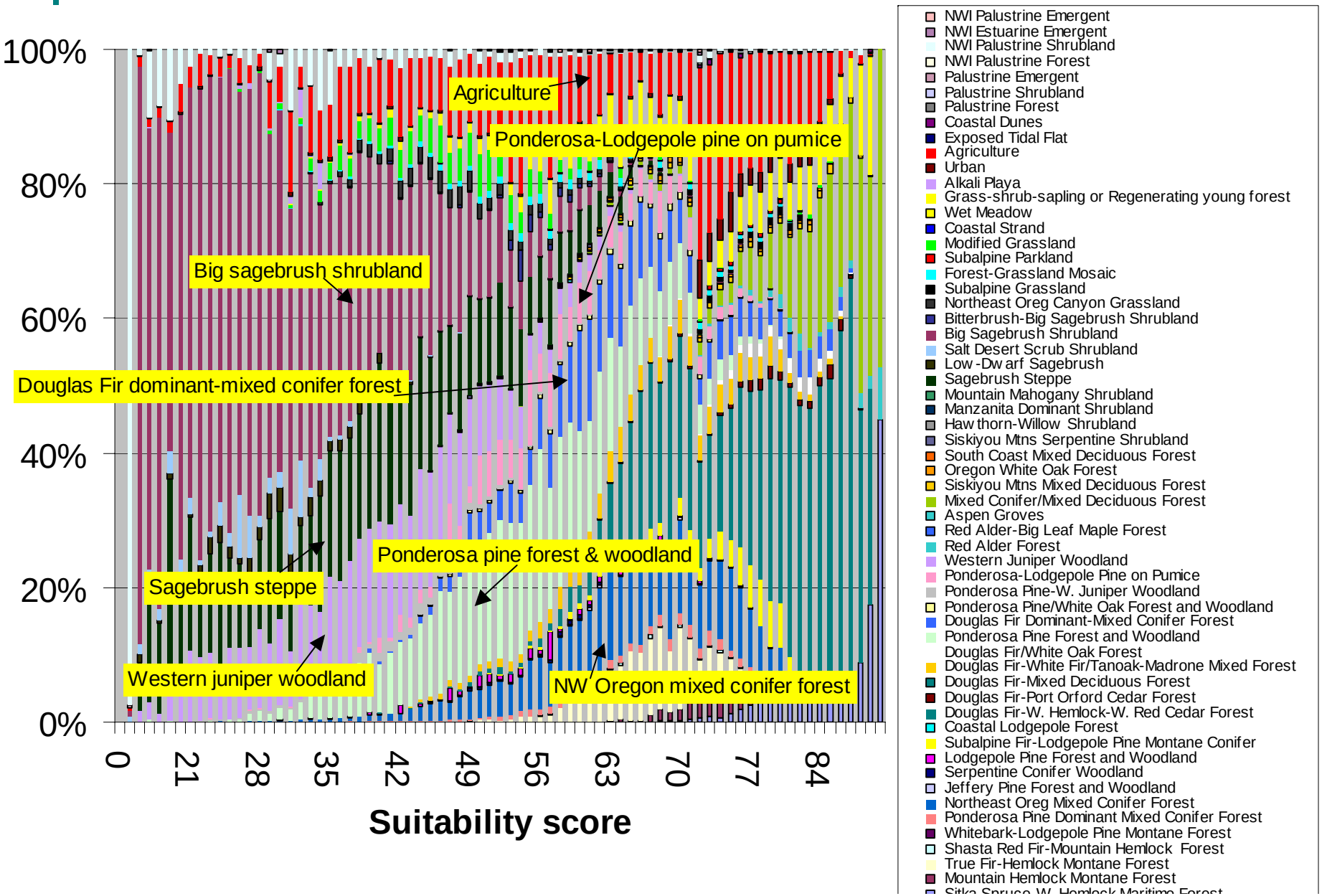
# Suitability Greater Than 35



# Oregon Potential Afforestation Area



# Species Mix for Various Suitability Scores

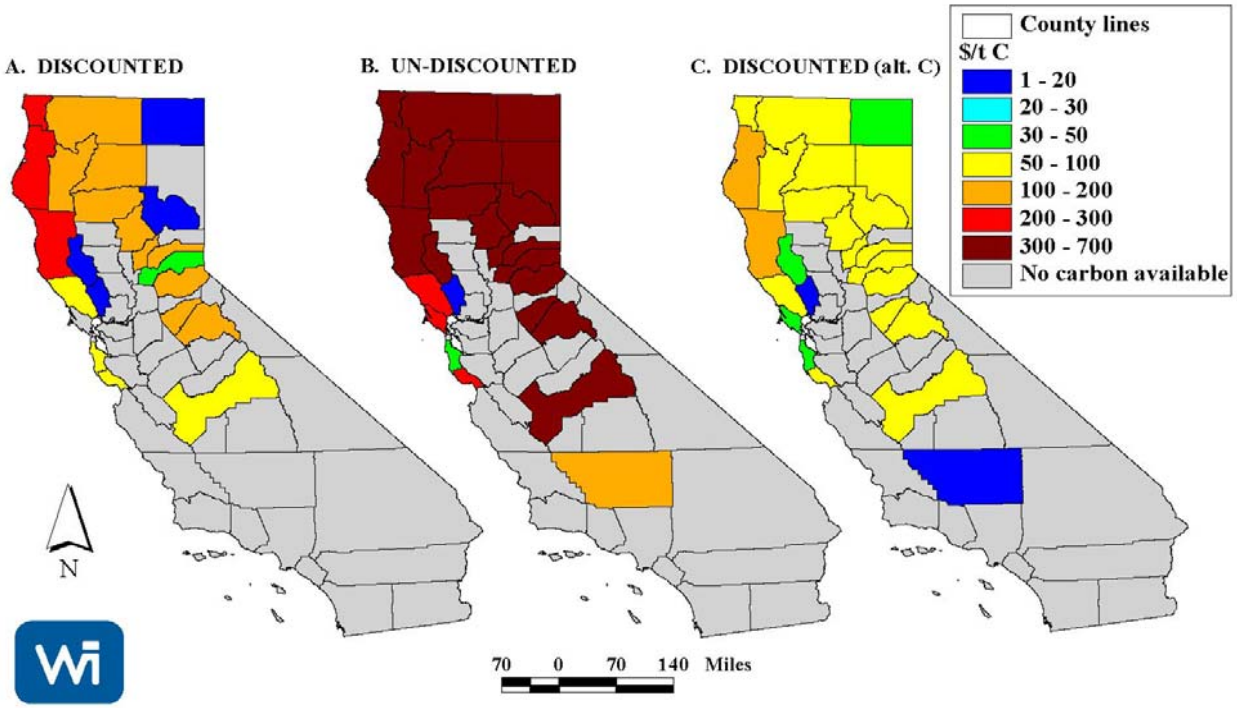


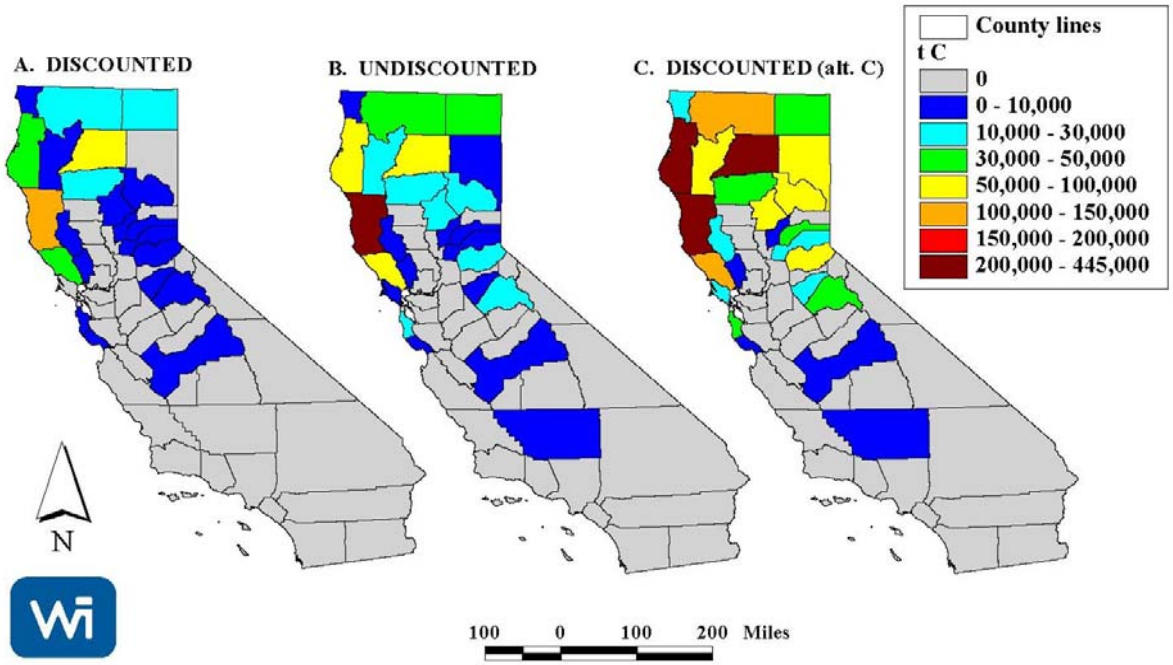
westcarb.org
West Coast Regional Carbon Sequestration Partnership

# *Forests*

# Four alternatives analyzed:

- Estimates were derived for 20 year and/or permanent contract periods:
  - ✓ (1) allowing timber to age, i.e. lengthening rotation time;
  - ✓ (2) increasing the riparian buffer zone by an additional 200 feet;
  - – (3) changing traditional clear cuts to group selection cuts—*little to no increase in carbon sequestration;*
  - ➢ (4) forest fuel reduction to reduce hazard of catastrophic fires, and subsequent use of biomass in power plants

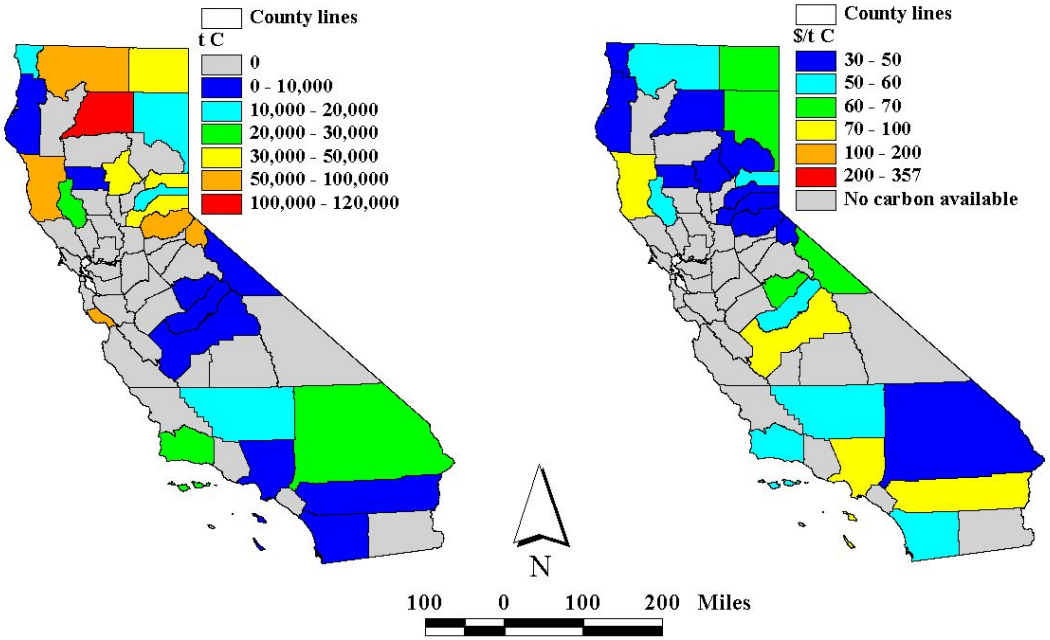


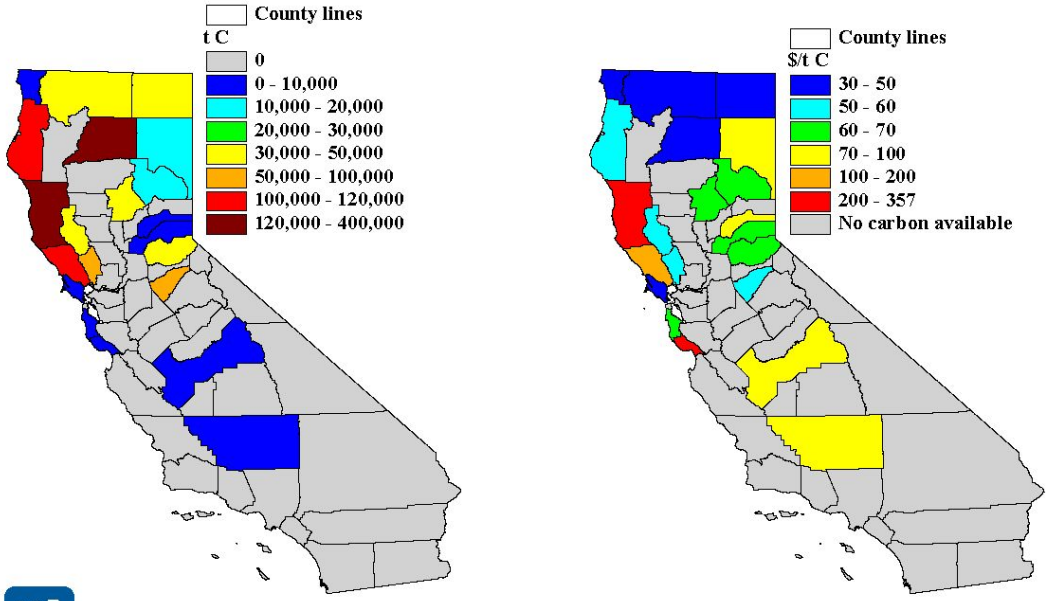

# Alternative 1: County level costs and quantities of carbon for lengthening the forest rotation time by 5 years

The two methods of discounting carbon (A. and C.) are related to how the emissions from the initial harvest are counted.

## A. PUBLIC LANDS




## B. PRIVATE LANDS

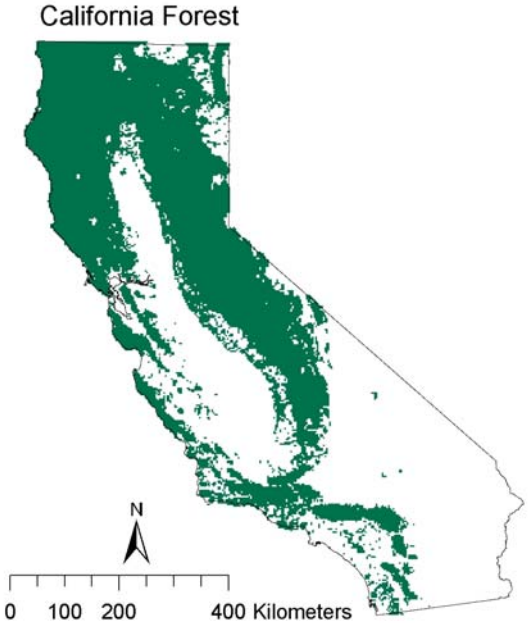


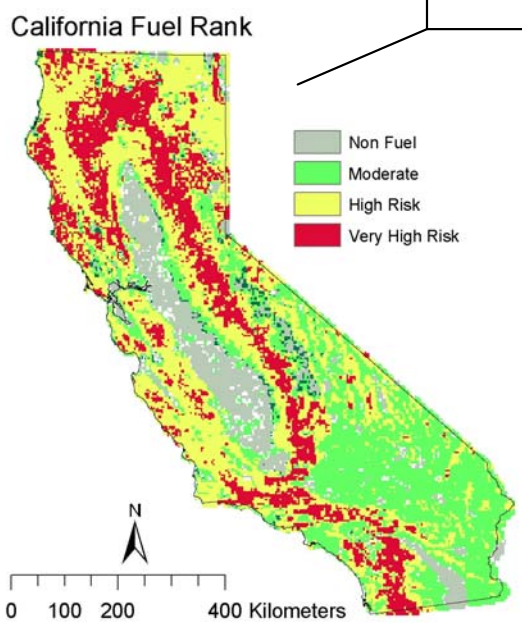

# Alternative 2: County level quantity of carbon and cost by extending riparian buffers 100 feet on both sides of perennial streams on public and private lands.

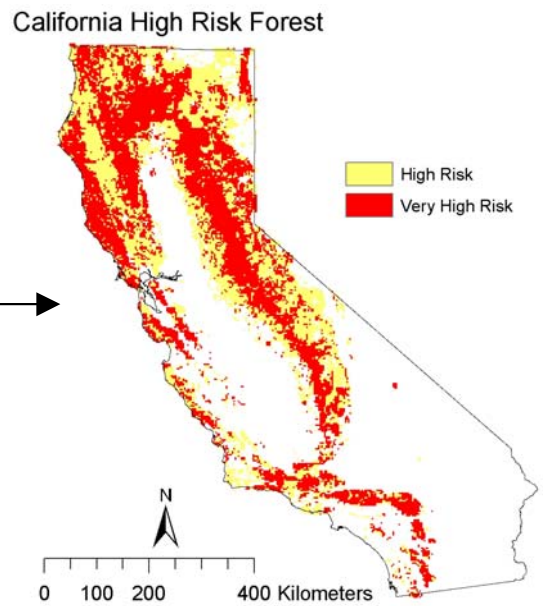
# Alternative 3: forest fuel reduction

- Estimate the areas and carbon stocks of forests suitable for fuel reduction to reduce their fire risk and their location relative to existing power plants
- Develops a “Suitability for Potential Fuel Reduction (SPFR)” score for high fire risk forests based on slope, distance to biomass plants, and distance from roads
- SPFR scores rank areas feasible for transporting the removed fuels to biomass power generating plants

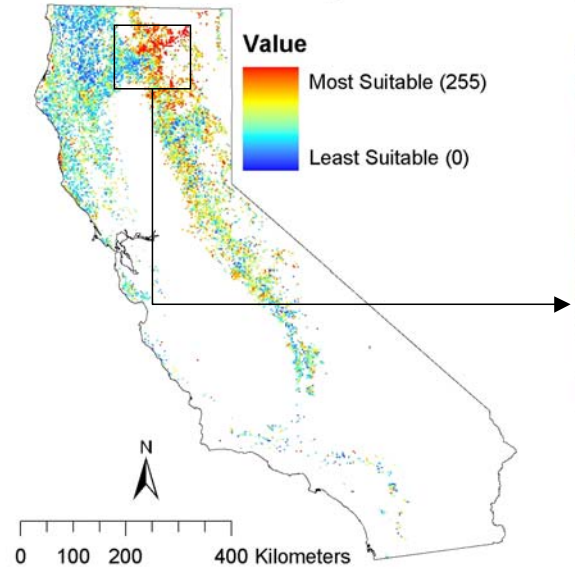
# Distribution of California's forests at high and very high risk for catastrophic fire



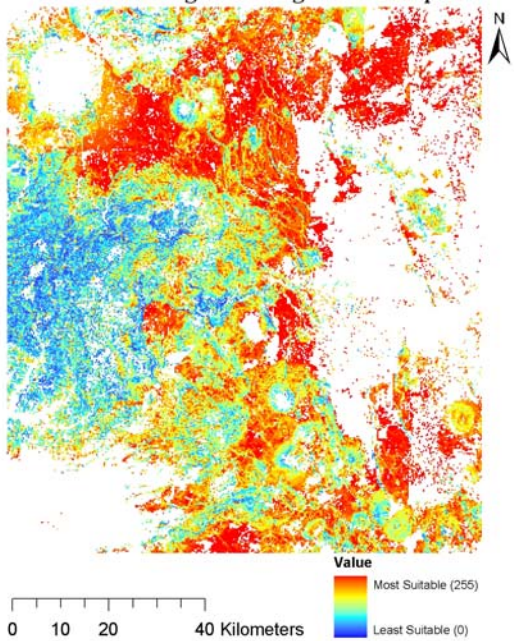



Factor Image for Suitable Slopes

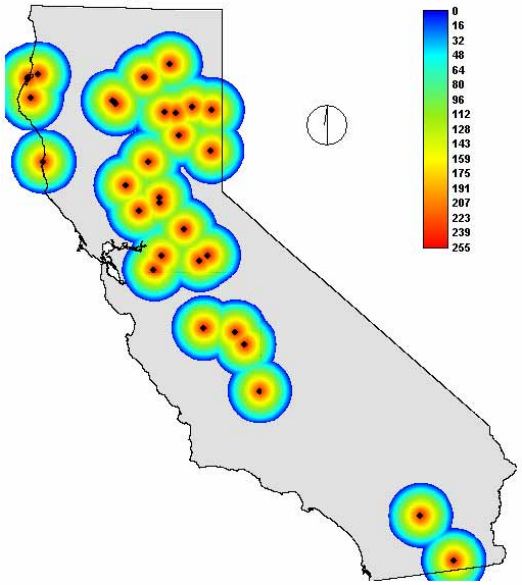



Windowed Image Detailing Suitable Slopes

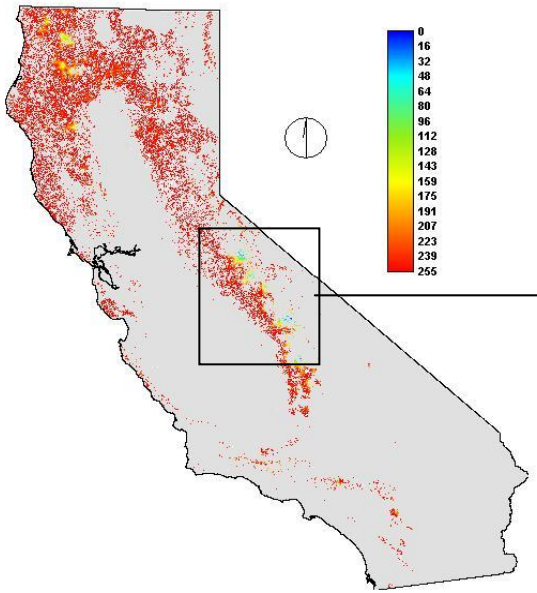



**Factors used to develop index of suitability for fuel reduction**

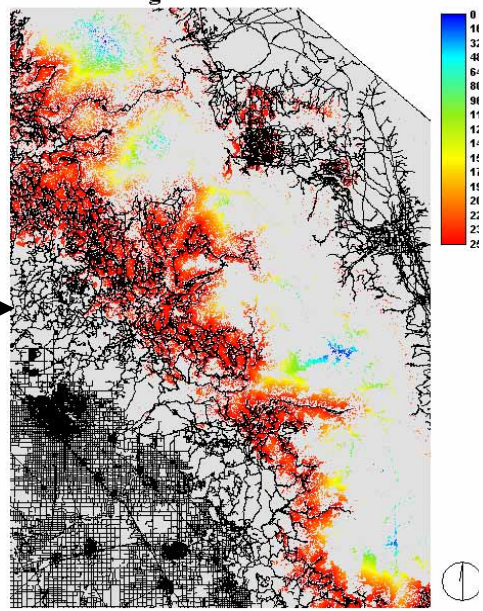
Factor image for distance from biomass plants



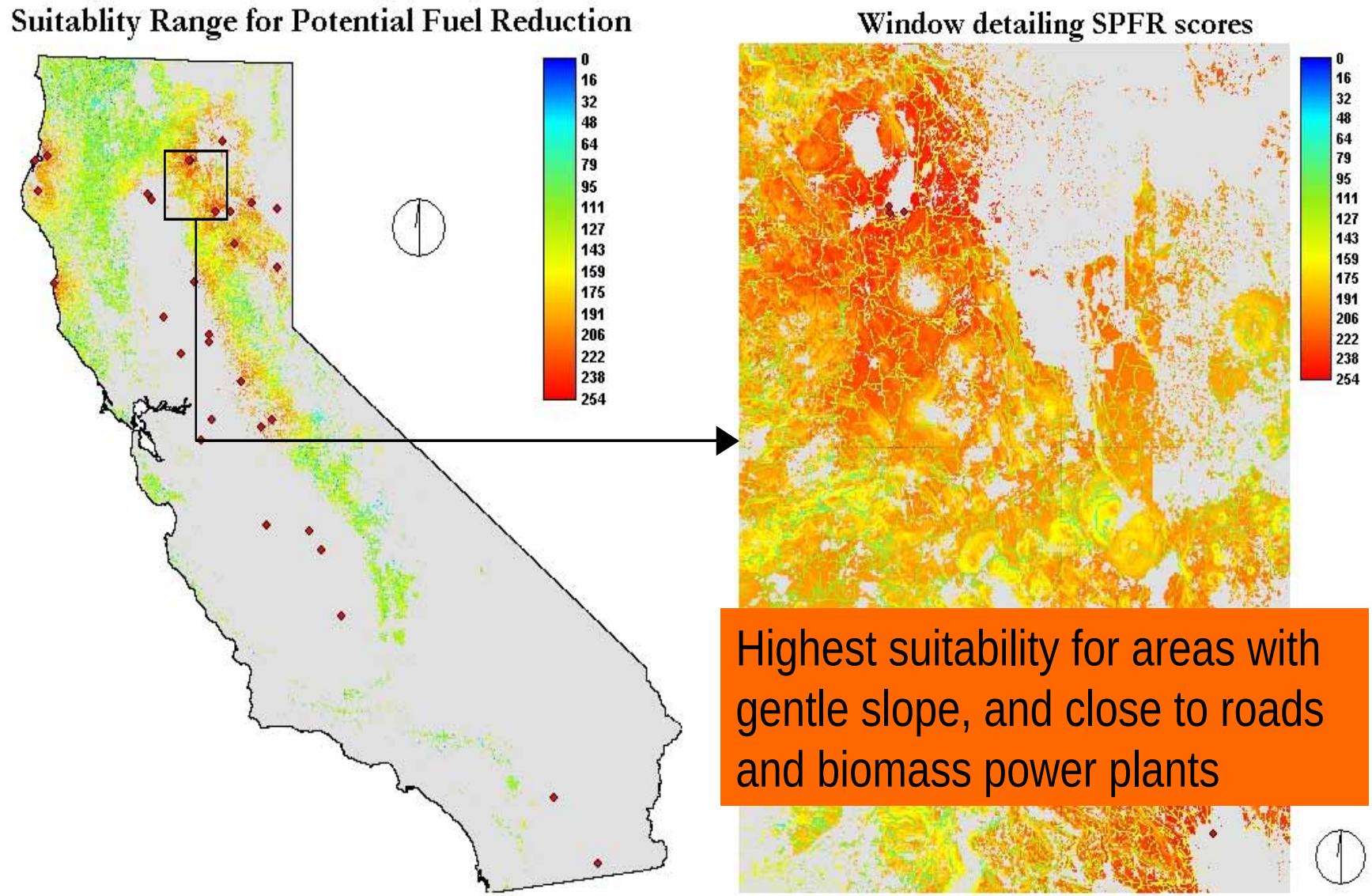

Factor image for distance from roads




Zoomed image for distance from roads

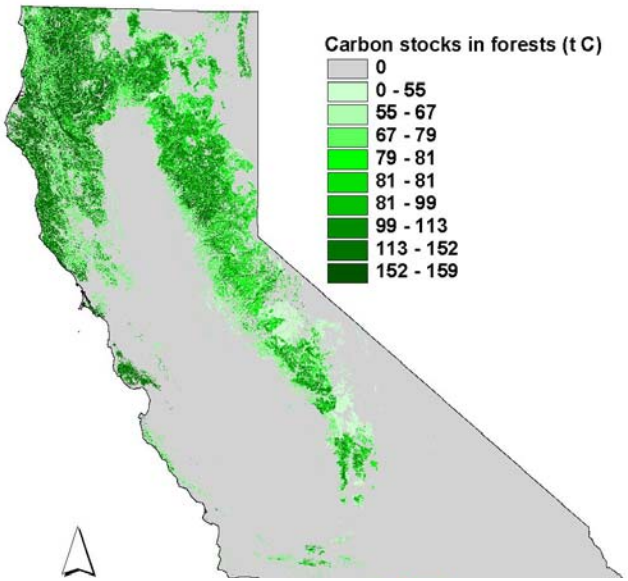


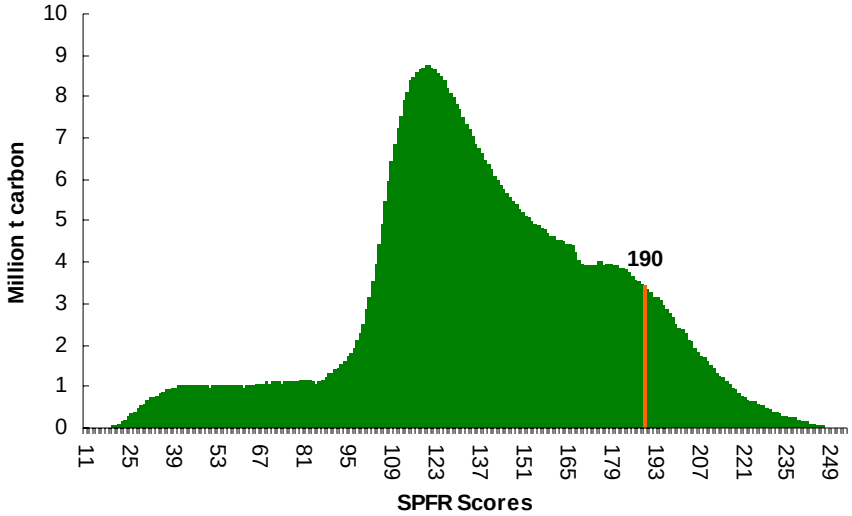
# Map of suitability scores for potential fuel reduction for California forests



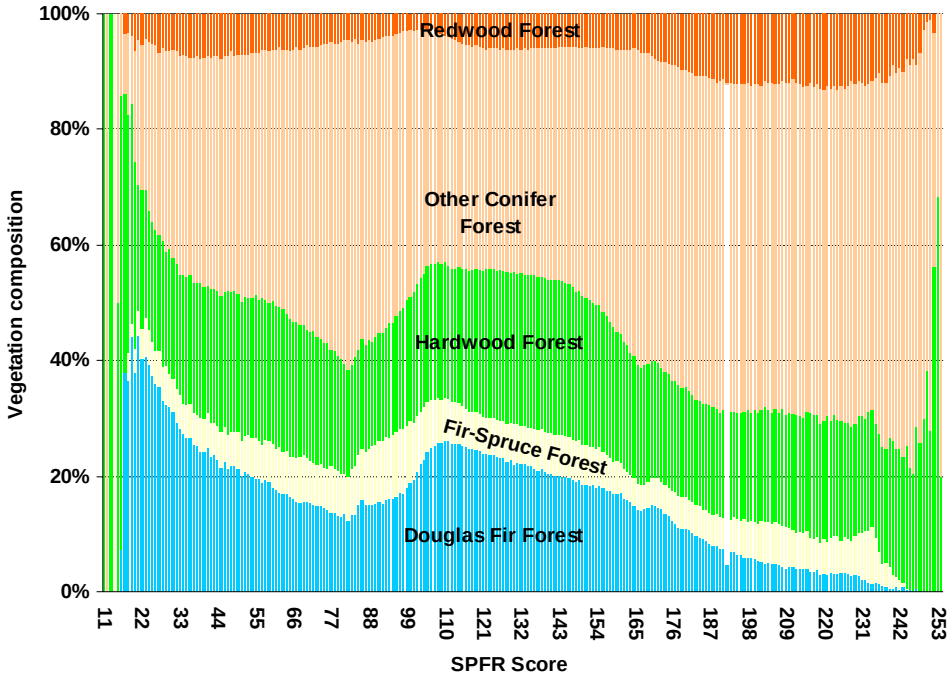

Highest suitability for areas with gentle slope, and close to roads and biomass power plants

# Carbon stocks in forests exposed to fire




Carbon stocks by SPFR classes for forests at high and very high risk for fire




Forest composition of the SPFR classes for areas at high and very high risk for fire.

# Potential Carbon Emissions from Fire

- Cumulative carbon stocks in forests at high and very high risk for fire with SPFR classes higher than the top 25% (score of 190) = 74.2 million t covering an area of approximately 775,000 hectares
- The estimated net emissions from these forests if they burned could be as much as 22 million t C (range for different forest classes =25-51 t C/ha)

# Project Example: Fire Management

- Remove fuel load from forests to reduce carbon emissions from fire
- Transport fuel to power plant
  - Account for emissions from transport

# Improve Understanding of Sequestration Benefits from Improved Fire Management

Source: Dr. Sam Sandberg, USDA Forest Service PacificWildland Fire Sciences Laboratory

- Change GHG emissions from combustion
- Reduce loss of carbon stocks from large trees
- Reduce loss of carbon stocks from duff
- Maintain carbon accumulation rates during recovery
- Avoid ecosystem-changing fires

# What changes can be made in fuels and fire management to reduce net GHG emissions?

- Continuous fuel management to keep fuel loads below prescribed levels
- Substitution of low severity prescribed fire for high severity wildland fire
- Substitution of low severity wildland fire for high severity wildland fire

Source: Dr. Sam Sandberg, USDA Forest Service PacificWildland Fire Sciences Laboratory

# Removing Fuel from the Forest

- Typical forest thinning operation requires about $1 Million investment
  - 2 or more shears
  - 2 skidders
  - Chipper
  - Road maintenance equip.
  - Maintenance truck
  - 6 or more employee

Source: Steve Jolley, Wheelabrator Shasta

# Production Rate from Thinning Operations

Source: Steve Jolley, Wheelabrator Shasta

- Production expectation for one operation:
  - Approximately 12-16 loads per day
  - Equals 150-200 BDT per day
  - Cost into the chip van about $30/BDT
- Transportation costs additional
  - Based on $55-$60/hr.
  - Delivered price is $39-$45/BDT

# How Far Can Fuel Be Transported?

- Factors affecting transport costs:
  - Transport type
  - Fuel type and density
  - Distance from the plant
  - Season (affects availability of trucks)
  - Backhaul opportunities

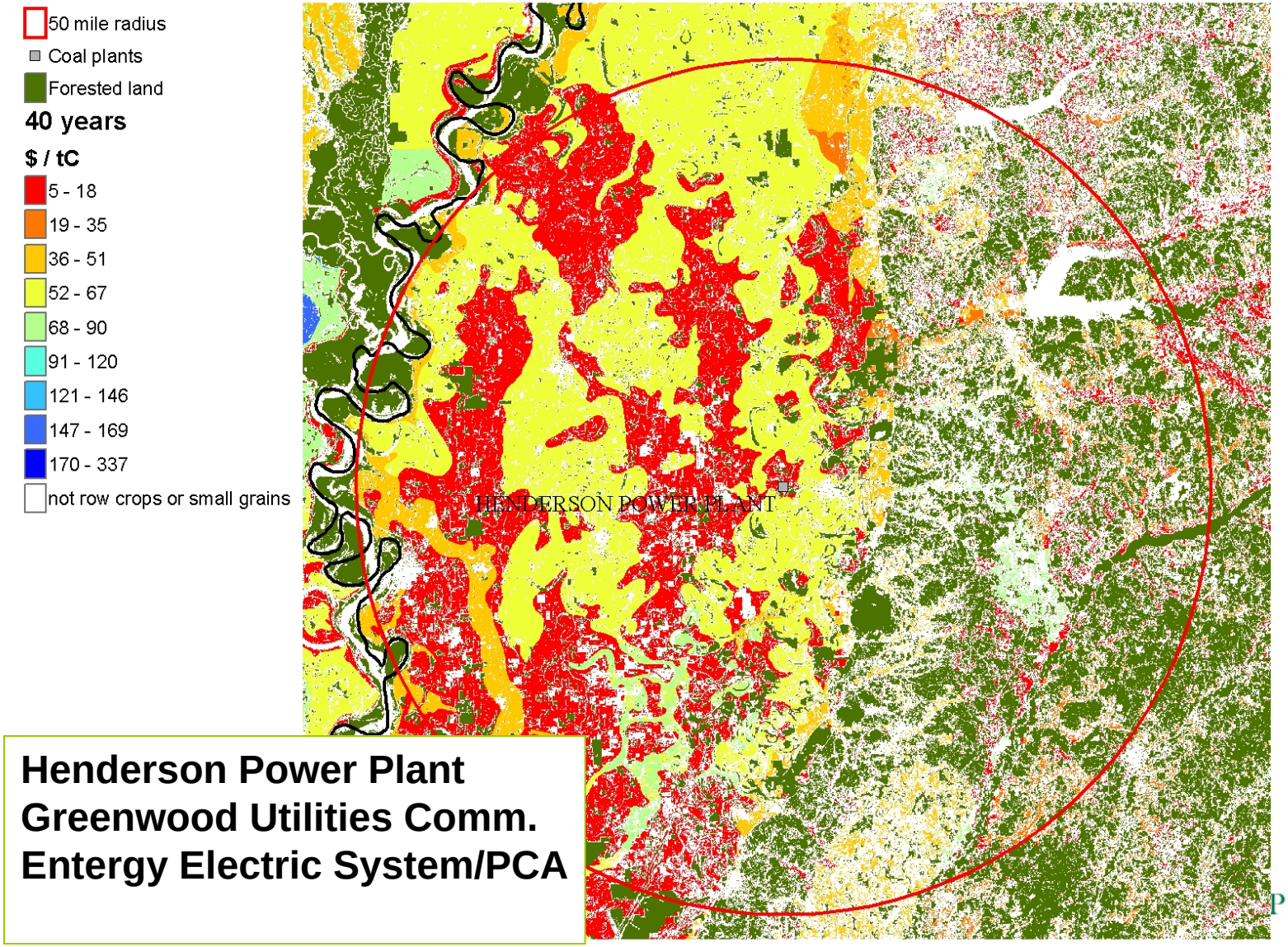
Source: Steve Jolley, Wheelabrator Shasta

# Fuel Use at Biomass Energy Plants

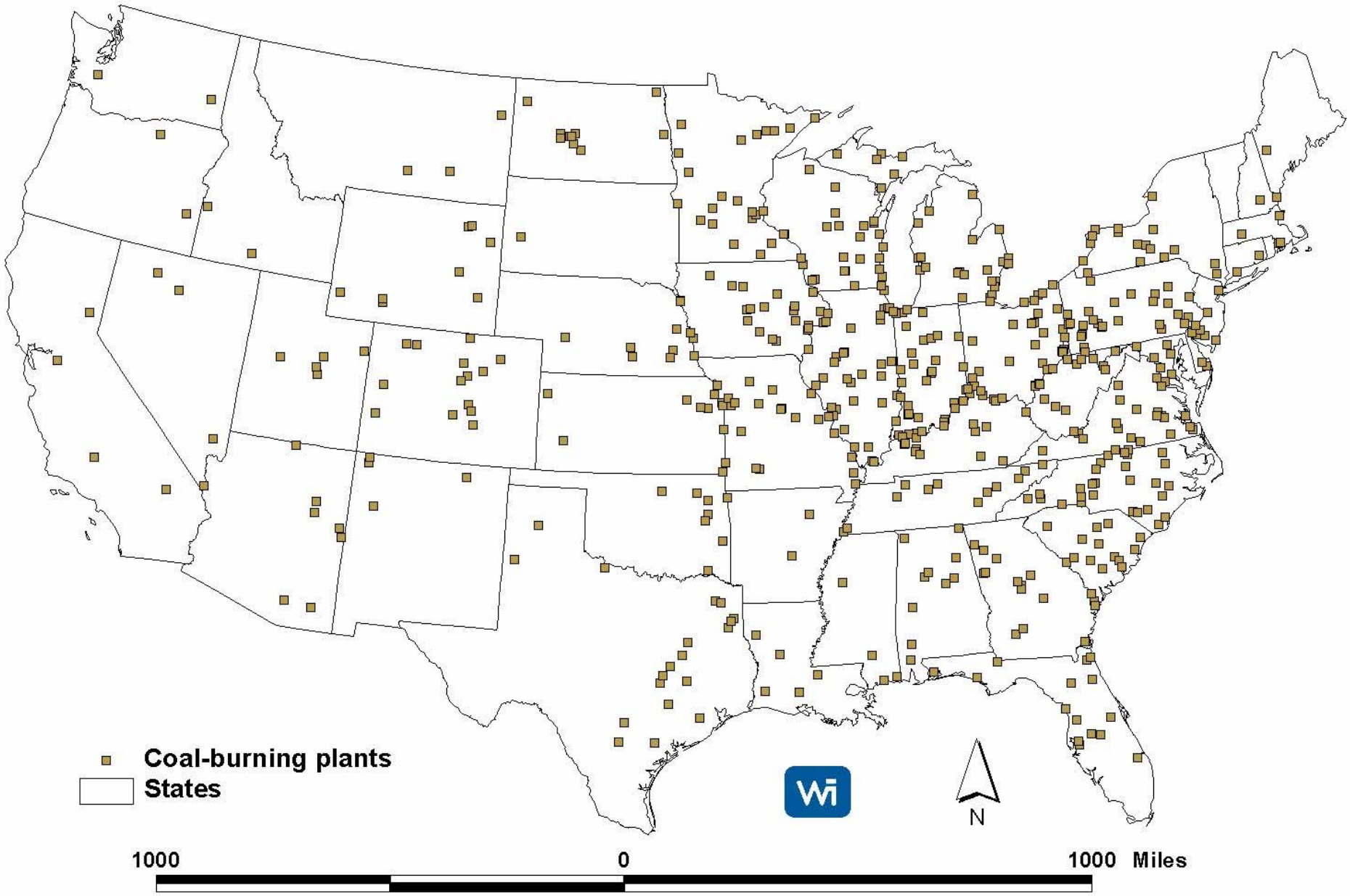
| Plant | CapacityFactor % | MW | GWh/yr | Kcal/ kWh | Estimated Tons/yr |
|---|---|---|---|---|---|
| Shasta-CA | 96 | 50 | 418 | 4,335 | 846,000 |
| Stratton-MA | 90 | 45 | 353 | 3,402 | 561,000 |
| Kettle Falls-WA | 82 | 46 | 327 | 3,554 | 542,000 |
| Grayling-MI | 63 | 36 | 200 | 3,428 | 320,000 |
| McNeil-VT | 35 | 50 | 155 | 3,528 | 255,000 |
| Bay Front-WI | 82 | 30 | 164 | 3,276 | 251,000 |
| Multitrade-VA | 19 | 79 | 133 | 3,528 | 219,000 |
| Camas –WA | 65 | 17 | 97 | 4,284 | 194,000 |
| El Nido*-CA | 60 | 10 | 53 | 5,040 | 125,000 |

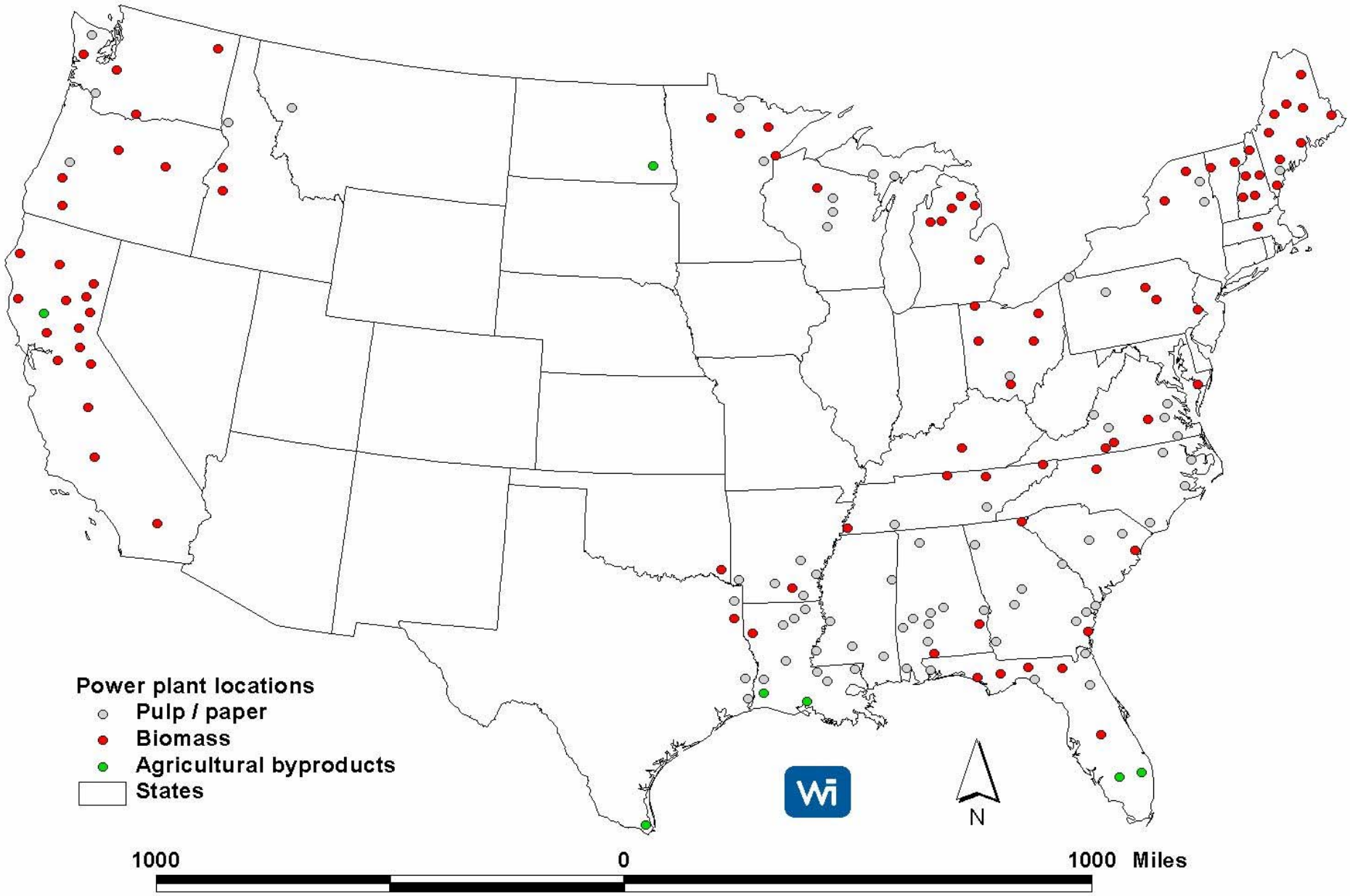
Source -- Morris, G (2000) “Biomass Energy Production in California: The Case for a Biomass Policy Initiative”, NREL/SR-570-28805.

# Define Project Area




**Henderson Power Plant**
**Greenwood Utilities Comm.**
**Entergy Electric System/PCA**


Coal-burning plants
States
N
1000
0
1000 Miles


Power plant locations
Pulp / paper
Biomass
Agricultural byproducts
States
N
1000
0
1000 Miles

# Example: Data Needed for Next Steps in Project Evaluaion

- Refine fire baseline
- Review and collect field data on effect of fires on carbon stocks,
- Review pattern of recovery of carbon stocks after fire,
- Review available data and experience for gathering and transportation of fuel forest thinnings,
- Develop site selection criteria.