ETAAC Energy Sector
Technologies That Will Be Reviewed

1. Carbon Capture and Sequestration
2. Emerging Renewable Technologies
3. Combined Heat and Power / Distributed Generation
4. Advanced Coal Technologies
5. Nuclear Technology
6. Advanced Natural Gas Generation
7. Energy Efficiency
8. Energy Storage
9. Wind
10. Biomass, Landfill and Methane Digester
11. Solar
12. Geothermal
13. Non-Electric Generation Gas Technologies
Progress to Date

1) Energy Sector Meeting, May 10, 2006, Sacramento
   A) Carbon Capture and Sequestration.
      1) Greg H. Rau, UC-Santa Cruz, LLNL
         “The Essential Role of CO₂ Sequestration in Stabilizing Atmospheric CO₂”.
      2) Larry Myer, WESTCARB, CEC, LBNL
         “CO₂ Sequestration Options for Californians”.
   B) Emerging Renewable Technologies
      1) Hal LaFlash, PG&E

2. Input from CEC and Water Quality Control Board on Status of Bioenergy Working Group
ETAAC Energy Sector: Technology Status Outline

1) Technology Description
   Describe the technology and possible applications.

2) Potential to Reduce Greenhouse Gas
   Estimate (in tons) the potential for removing, offsetting or displacing greenhouse gas emissions.

3) Status of Commercialization
   Is the technology commercially available? If not, what is the status of development/ commercialization? How soon will the technology be commercialized?

4) Barriers to Entry
   What are the barriers to entry?
   a) Technology- Are there significant technological barriers?
   b) Financial- Are there cost, financing, or “pay back” hurdles?
   c) Institutional- Are there market or perception challenges?
   d) Regulatory- Are there legal or regulatory barriers to development?

5) Solutions
   Provide any specific policy or other action which can be taken encouraging the commercialization of the technology.
## ETAAC: Template for Technology Summary

<table>
<thead>
<tr>
<th>Technology</th>
<th>Technology Overview</th>
<th>CO₂ Abatement Potential</th>
<th>LCOE in 2007</th>
<th>$/ton of CO₂ Abated</th>
<th>Status/Timing of Commercialization</th>
<th>Barriers to Entry</th>
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**Barriers to Entry**

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Schedule

June
1) Combine Heat and Power
2) Distributed Bioenergy
3) Nuclear

July
1) Advanced Coal
2) Energy Efficiency
3) Energy Storage

August
1) Wind
2) Solar
3) Geothermal

September
1) Biomass, Landfill, Methane Digester
2) Non-Electric Gas Technology
CARBON CAPTURE

AND SEQUESTRATION
Geologic Storage Mechanisms

- Physical, hydrodynamic, trapping
- Dissolution
- Phase trapping
- Mineralization
- Surface adsorption
Primary Storage Options

- Oil and gas reservoirs
  - Storage with Enhanced Oil Recovery (EOR), Enhanced Gas Recovery (EGR)
  - Storage only
- Deep, unminable coal beds
  - Storage with Enhanced Coal Bed Methane (ECBM) recovery
- Saline formations
  - Storage only

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership
Major Geologic Storage Opportunities in California

Gas reservoir capacity: 1.7Gt
Oil reservoir capacity: 3.6Gt
Rosetta Resources CO$_2$ Storage Pilot

- Lead industrial partner: Rosetta Resources
- Validate sequestration potential of California Central Valley sediments
- Test CO$_2$ Storage Enhanced Gas Recovery
- Inject about 2000 tons at about 3400ft depth
- Focus on monitoring

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership
Shasta County Terrestrial Pilot

- Validation of forest growth type for rangelands
- Develop and test fuel management activities; baselines and measurement and monitoring
- Validate emissions reductions from conservation and sustainable forest management practices

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership
Nature’s Chemical CO₂ Capture and Storage:

Nature’s own mechanisms:

Atmospheric CO₂

Photosynthesis
nCO₂ + nH₂O + photons
---→ (CH₂O)n + nO₂

Weathering Reactions

e.g.:
CO₂ + Ca/MgOSiO₂ ---→
Ca/MgCO₃ + SiO₂

CO₂ + H₂O + CaCO₃ ---→
Ca²⁺ + 2HCO₃⁻

Ocean uptake

CO₂ + H₂O + CO₃²⁻ ---→ 2HCO₃⁻
Carbonate Weathering in the Global Carbon Cycle:

Atmospheric CO₂ (7x10²)

fluxes = GT C/yr
(reservoirs = GT C)

1.5
6.3

Continental carbonate weathering

CO₂

HCO₃⁻ (42x10³)

Carbonate minerals (6x10⁷)

0.15

0.05

Organic Carbon (1.5x10⁷)

Fossil fuel (4x10³)

Provided by Greg H. Rau, Institute of Marine Sciences, UCSC
Accelerated Weathering of Limestone (AWL) Reactor:

(Rau and Caldeira, 1999)
Afforestation and Fuel Management are Major Terrestrial Opportunities in California

40 year sequestration potential  40 year marginal costs  Lands suitable for fuel removal

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership
Other Sequestration Alternatives

Bottom Line: Use the chemical reactivity of CO$_2$ for CO$_2$ mitigation.

Potential Technologies
- Accelerated weathering of limestone reactor
- Combined CO$_2$ and kiln dust mitigation
- CO$_2$ sequestration using H$_2$O co-produced with oil
- Iron / CO$_2$ fuel cells
Carbon Sequestration

Marginal Cost Curve for California, Current Conditions

Source: H. Herzog, MIT via West Coast Regional Carbon Sequestration Partnership
EMERGING RENEWABLES (EXAMPLES)
Concentrating Photovoltaic

Operation: Light reflects off tracking mirrors to fixed overhead panel. The concentrated light is converted to electricity by photovoltaic cells. ~200watts/unit

Key Advantage: Modular design and direct solar-to-electric conversion. No working fluids.

Key Challenge: Getting the power cost down via efficiency improvement, technology development and manufacturing to scale.
Concentrating Thermal Trough

**Operation:** Elliptical Mirror concentrates sunlight to heat oil traveling through tube. Hot oil used to generate steam and operate a turbine connected to generator.

**Key Advantage:** Technology is proven and has large-scale operating history. Potential to dispatch with natural gas.

**Key Challenge:** Core Technology is 20+ years old and has limited improvement potential. Design is very capital intensive. CLFR less expensive.
Concentrating Thermal Tower

**Operation**: Mirrors focus sunlight on a central tower, where water is heated to generate steam. Steam is used to spin a turbine connected to generator.

**Key Advantage**: Higher efficiency, simpler design, lower installation cost. Dispatchable with gas-fired boiler.

**Key Challenge**: No long-term operating history. Original version 20 years ago, new versions under development or construction.
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<th>Tower</th>
<th>CPV</th>
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<tbody>
<tr>
<td><strong>Technology Maturity</strong></td>
<td>High – in production</td>
<td>Medium – working prototypes</td>
<td>Low – R&amp;D needed</td>
<td>Low – still in R&amp;D</td>
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<tr>
<td><strong>Working Fluid</strong></td>
<td>Synthetic Oil, water for steam</td>
<td>Hydrogen Gas</td>
<td>Water/steam</td>
<td>None</td>
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<tr>
<td><strong>Energy Conversion</strong></td>
<td>Steam Turbine</td>
<td>Reciprocating Engine</td>
<td>Steam Turbine</td>
<td>Direct solar to electric conversion</td>
</tr>
<tr>
<td><strong>Dispatchable</strong></td>
<td>Yes, if designed to (currently solar-only)</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Time to Market</strong></td>
<td>2010+</td>
<td>2011+</td>
<td>2010+</td>
<td>2007+</td>
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<tr>
<td><strong>Technology Risk</strong></td>
<td>Low, working in field</td>
<td>Medium, risk on scaling up</td>
<td>High, still in R&amp;D</td>
<td>High, still in R&amp;D</td>
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<tr>
<td><strong>Price per MWh</strong></td>
<td>~$100-120/MWh</td>
<td>~$80-90/MWh</td>
<td>~ 100-120/MWh</td>
<td>~$200/MWh+</td>
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</table>
Overview – Wave Technologies

Ocean Power Delivery Pelamis

AquaEnergy AquaBuOY

Ocean Power Technology PowerBuoy™

OPD Pelamis Wave Plant ('Farm')

UK Wave Hub

Wavebob

Devices and technologies pictured for illustration / discussion only
Does not reflect or imply any PG&E preference
Potential California Wave Power Generation

- **Selection criteria for initial sites**
  - Grid interconnection
  - Wave resource
  - Port infrastructure (deepwater ports shown in green)
  - Local support

- **PG&E filed two FERC preliminary permit applications (40MW each)**
  - Humboldt County (Eureka)
  - Mendocino County (Fort Bragg)

- **Wave power plant**
  - Multiple wave energy conversion devices arranged in an array
  - Leading devices float on surface of water
  - 0.5-10 miles offshore
  - Connected to land via subsea cable
Tidal Power Turbines

Verdant Power Turbine – East River Project

Installation Illustration

MCT Seaflow- SeaGen Turbines – UK Installation

Devices and technologies pictured for illustration / discussion only
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USGS Bathymetry Map of SF Bay

Maximum depth = 377 feet

Conclusions

- There are a significant number of technologies which may produce energy that displaces carbon dioxide emissions or captures and sequesters carbon.
- Further investigation is warranted on carbon capture and sequestration.
- Carbon capture and sequestration will raise regulatory and liability issues.
- Emerging renewable technologies are under RD&D, utilizing a number of different renewable resources.
- Long-term commercialization of emerging renewable technologies is highly dependent on technological advances, cost reductions, and addressing environmental issues.
Sample CO₂ Abatement Supply Curves for California

Source: Nicholas Institute analysis using the NEMS model, February 2007