A Cost-effectiveness Analysis of AB 32 Measures

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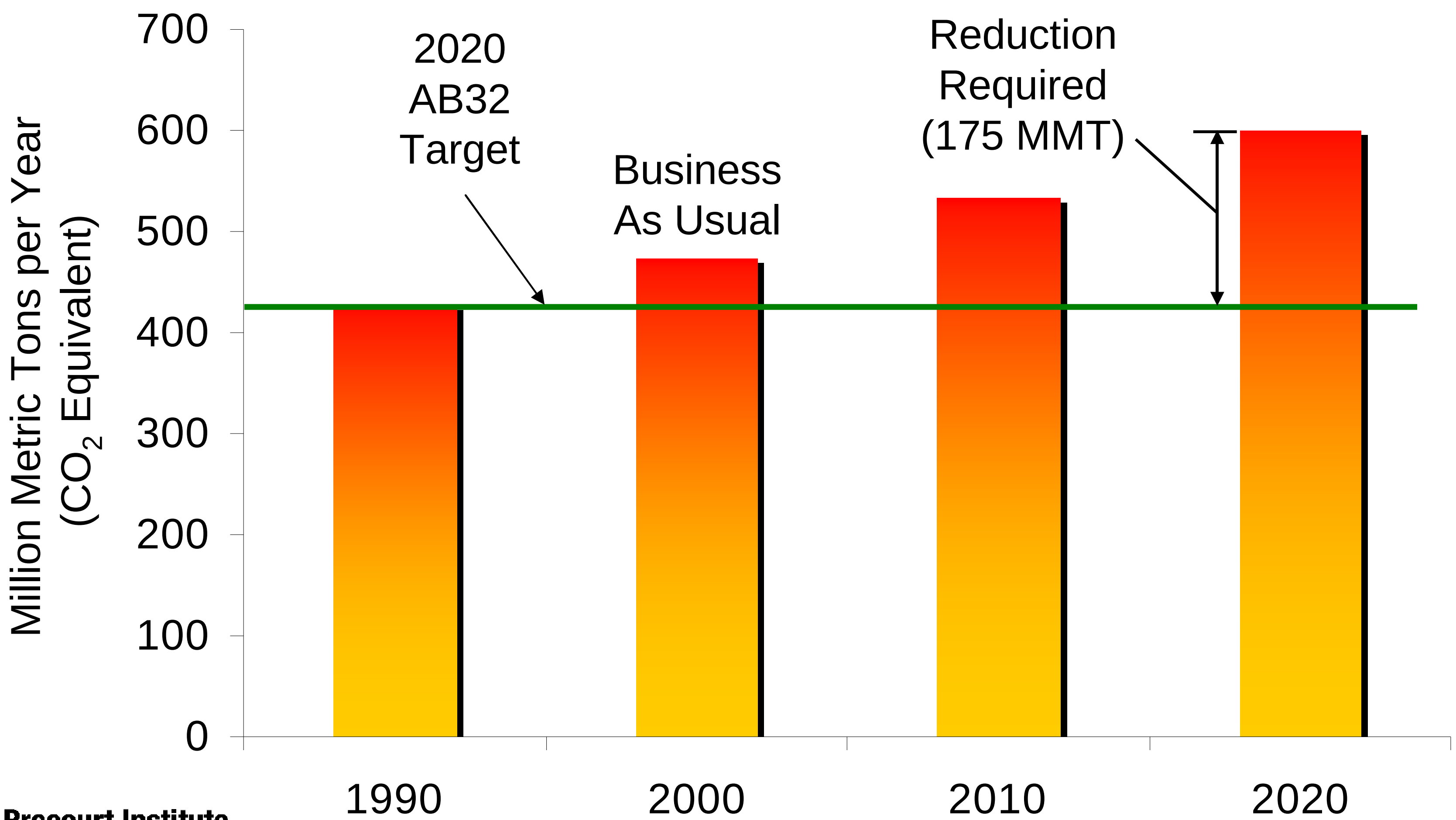
Motivation

The California Global Warming Solutions Act of 2006 (AB32) made California the first state to limit statewide global warming pollution.

Specifically, AB 32 stipulates:

- CARB must monitor statewide greenhouse gas emissions, through mandatory reporting.
- CARB must implement a statewide greenhouse gas emissions policy to ensure that the statewide greenhouse gas emissions are reduced to **1990 levels by 2020**.
- CARB must go further by adopting rules and regulations to achieve “the maximum technologically feasible and **cost-effective** greenhouse gas emission reductions.”

The Challenge



Objectives

We have two objectives:

1. Clarify the concepts of *technologically feasible* and *cost-effective*

2. Examine the cost-effectiveness (in \$/ton CO_2e) of the suite of measures under consideration to meet the 2020 emission reduction targets.

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Technologically Feasible

Technologically feasible *implies that the emission reduction must be possible given the technology that will available at the requisite time of implementation (at the latest 2020).*

This seems to preclude relying on technology forcing rules unless CARB knows with reasonable certainty that the forced-technology will be feasible by 2020.

Cost-effectiveness

A set of greenhouse gas mitigation measures is ***cost-effective*** *under a given target emission reduction if and only if the set of measures together imposes the minimum cost to society (among all feasible measures) of meeting the target emission reduction*

- This is defined in relation to a particular target
- We are referring to the social cost here
- Cost must include ancillary costs/benefits, e.g. non greenhouse gas environmental impacts

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Cost-effectiveness

An <u>individual measure</u> is cost-effective if it is a part of the set of greenhouse gas mitigation measures that minimizes cost to society to meet the specified target

– This can also be rewritten in a more useful way… but it requires two more definitions

Marginal Abatement Cost Curve and Marginal Cost

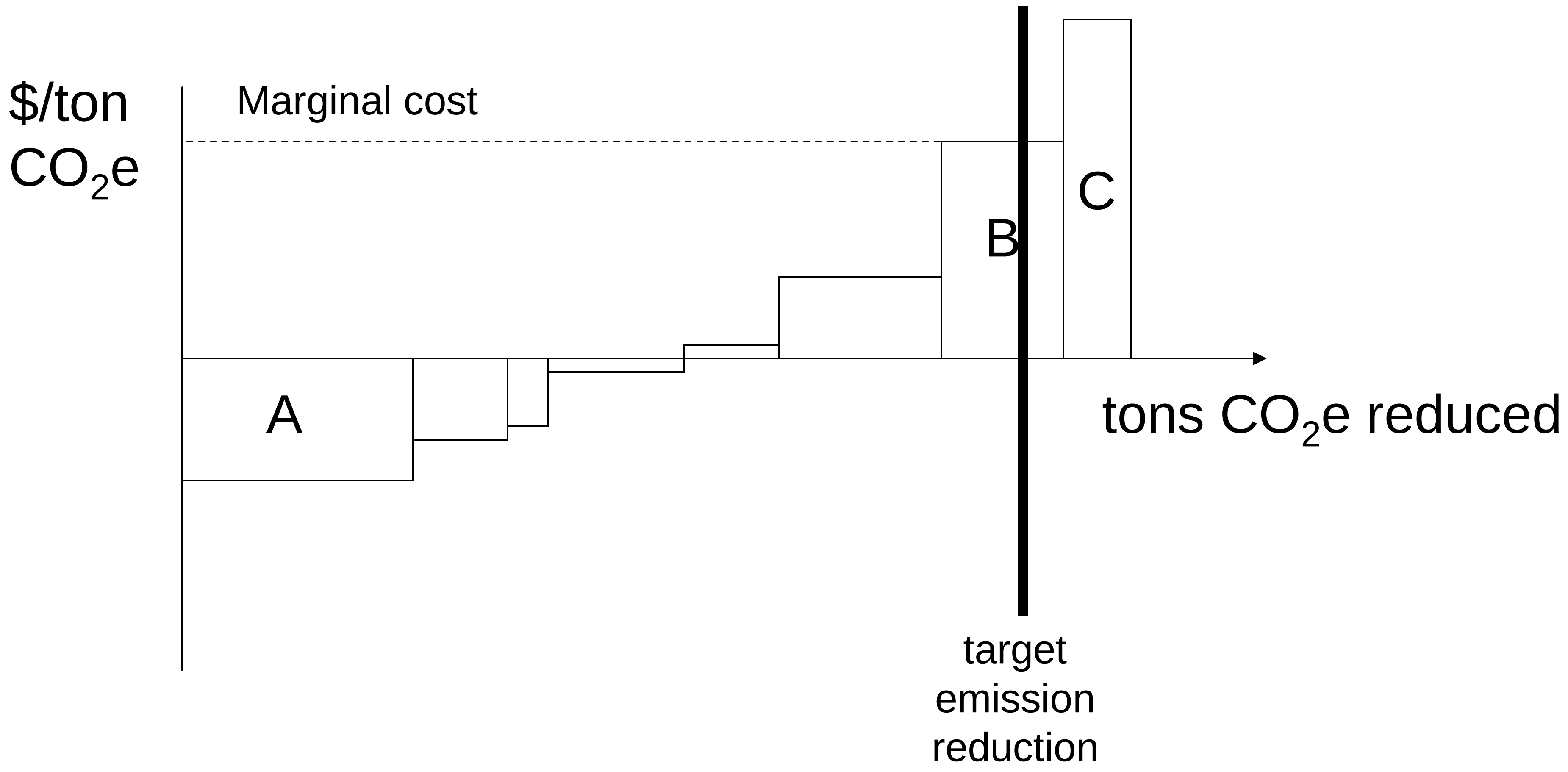
Marginal Abatement Cost (MAC) Curve for GHG emission reductions:

Order all feasible greenhouse gas emission mitigation measures from lowest individual cost to the highest individual cost

Marginal Cost of Emission Reduction:

The MAC curve can be used to estimate how expensive it would be to tighten the target emission reduction further and reduce one more unit of emissions. The cost necessary to reduce one more unit of emissions is known as the marginal cost of emission reduction.

Marginal Abatement Cost Curve and Marginal Cost



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Cost-effectiveness

*An individual measure is **cost-effective** under a given target emission reduction if and only if it costs no more than the marginal cost associated with the target emission reduction.*

Alternative Concepts

Economic Efficiency

- *May be useful for setting the target*
- *Less useful once target is set*

Zero Cost and Negative Cost Measures

- ***Not*** *the same as cost-effective*
- *Likely implies fewer emission reductions*

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Measures vs Instruments

- I will use “measures” to mean the physical or process change to be undertaken, e.g. adoption of plug-in hybrid vehicles.
- I will use “instrument” to mean system to motivate the measures, e.g. minimum sales mandate or cap-and-trade system
- Whether some cost-effective measures can be implemented may depend on the instrument used.
- I will not focus on the instruments today.

Uncertainty

Costs and quantities for many measures are highly uncertain

- *Limits to inherent knowledge*
- *Incomplete analysis*
- *Role of other constraints, e.g. equity*

Whether relatively high cost individual measures are ***cost-effective*** *depends on uncertainty in their costs and in quantity achievable of lower cost measures.*

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Uncertainty

Information will change over time, with new analysis, technology changes, and political changes.

Maximum marginal cost will change over time.

Implies need for scoping plan to be a "living document".

Implies need for robust, flexible instruments

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Our Methodology

- Meta-Analysis
  - Sources: ITRON, E3 Calculator, CAT, McKinsey
  - Own analysis
- Identify and focus efforts on large measures
- Refine estimates around the 2020 target of 175MMT
- Review and integrate available reports with a common baseline and assumptions
- Improve transparency
- Identify areas where more research is necessary
- Contribute to a ongoing and iterative process of improvement

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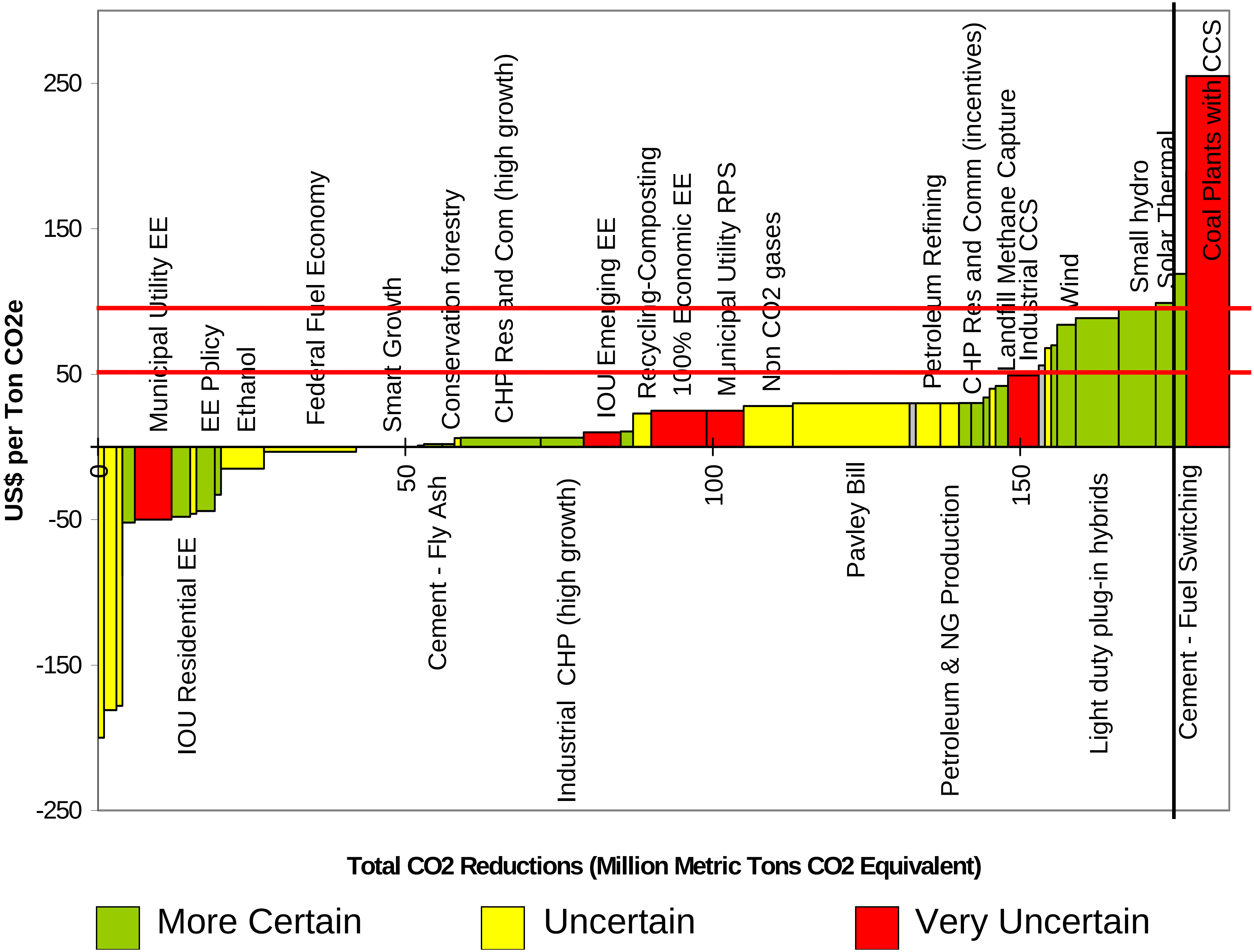
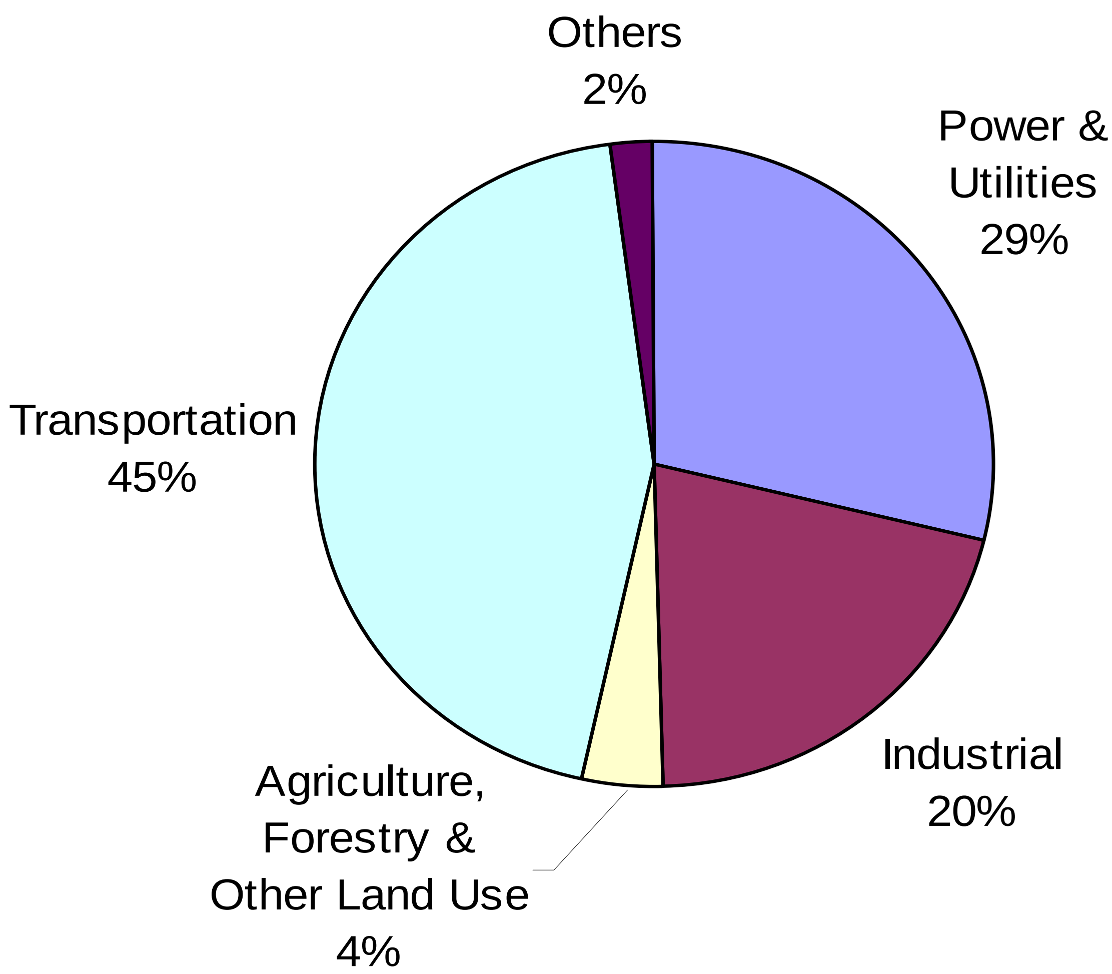


US$ per Ton CO2e
250
150
50
-50
-150
-250
0
50
100
150
Municipal Utility EE
EE Policy
Ethanol
Federal Fuel Economy
Smart Growth
Conservation forestry
CHP Res and Com (high growth)
IOU Emerging EE
Recycling-Composting
100% Economic EE
Municipal Utility RPS
Non CO2 gases
Petroleum Refining
CHP Res and Comm (incentives)
Landfill Methane Capture
Industrial CCS
Wind
Small hydro
Solar Thermal
Coal Plants with CCS
IOU Residential EE
Cement - Fly Ash
Industrial CHP (high growth)
Pavley Bill
Petroleum & NG Production
Light duty plug-in hybrids
Cement - Fuel Switching
Total CO2 Reductions (Million Metric Tons CO2 Equivalent)
More Certain
Uncertain
Very Uncertain

Emission Sources 2004



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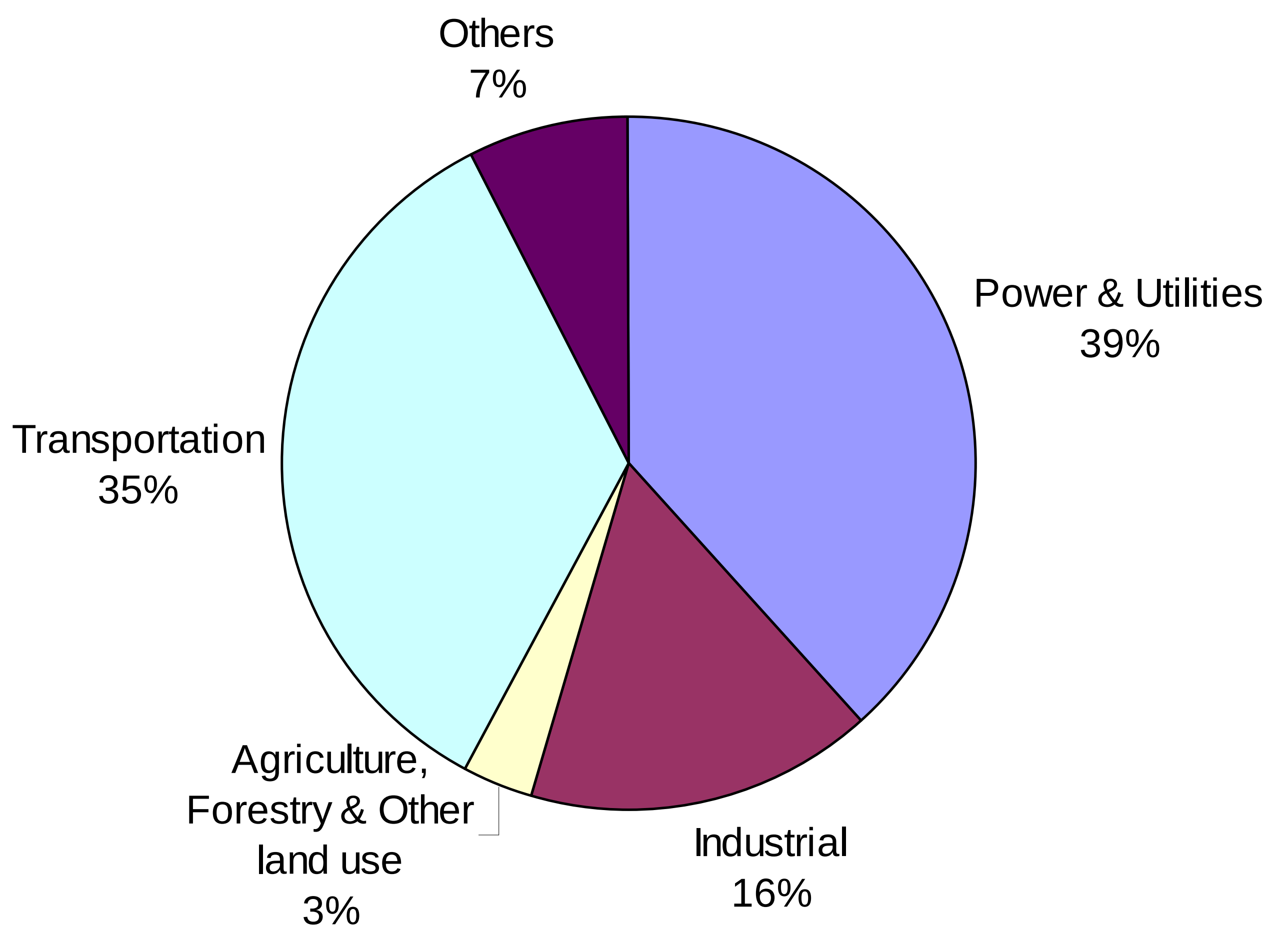
Our 2020 Emission Reduction Measures



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What Is Bottom Line?

- Some measures will not be implemented absent economic instruments such as carbon price or cap-and-trade system
- Much uncertainty about prices
- Suggest implement all with cost below $50/tonne
- More fully analyze those with estimated cost below $100/tonne
- Put on hold any with higher cost.

A Few Comments on Measures

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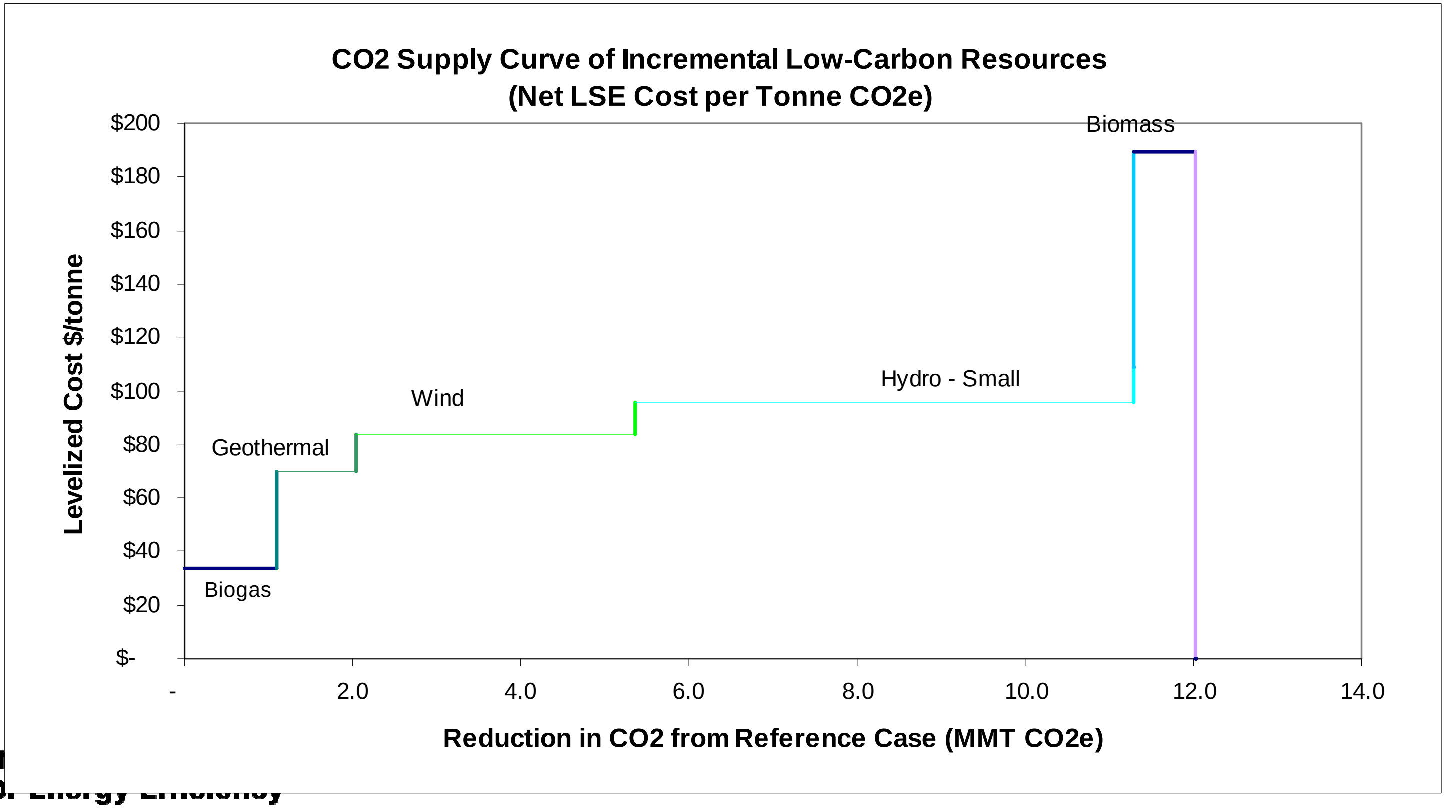
Renewable Power – Insights

- All renewable resources were taken from E3's most recent GHG calculator that models the power sector. We used the case with 20% RPS in the baseline and up to $160/tonne CO2e to build the RE supply curve.
- One of the major takeaways is that after 20% RPS, the renewable options are not cheap



Rooftop Solar PV

- Social cost much less than private cost
  - Learning by doing in balance of system
  - Estimate as Minus $89/tonne of CO_2
- Carbon dioxide reduction is tiny
  - 0.5 mm tonnes by 2020

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Energy Efficiency Measures

- Negative cost energy efficiency savings are available
- Helpful to have scenarios with an explicit carbon cost criterion, not just utility profitability (TRC) in models such as ASSET (ITRON)
- 5.5 MMT of economic potential can be achieved at negative costs but additional 9MMT available at 100% penetration of economic potential would most likely have positive costs
- Next steps
  - Refine cost estimates and baseline assumptions
  - Use a cost per ton carbon saved criteria to estimate EE savings from ITRON model (ASSET).

Transportation: Insights

- Abatement cost for transportation measures should continually be revisited if projected oil prices continue to rise
  - Incentivizing PHEVs has a prohibitively high cost in past studies but could lower significantly
  - Transportation measures could "leap-frog" non-transportation measures becoming lower cost
- How value consumer welfare?
  - If consumers value fuel savings for 3 years
    - Federal standards: - \$3 /ton $CO_{2;}$ Pavley: \$30/ton CO_2
  - If consumers value fuel savings over 14 years
    - Federal standards: - \$323/ton CO_2;Pavley: - \$298/ton CO_2

AS2

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Slide 26

AS2 I'm trying to say that measures like PHEVs could easily drop in cost if oil price goes up compared to similar high cost measures like Wind Power. I'm assuming the wind power measure will not become much cheaper with high oil prices. Currently PHEVs are more expensive than wind. If oil prices rise again, the PHEV measure could become cheaper than wind, thus the PHEV measure would jump ahead of Wind in Cost effectiveness.

Amul Sathe, 6/1/2008

Non-CO2 Gases: Insights

- Potential for emission reductions for Non-CO2 gases are significant.
- The present estimates are based on the CAT analysis (2006).
- Costs estimates for High-GWP would need further analysis to reflect the true social cost of the measures.

Backup Slides on Methods

Energy Efficiency Overview

- ITRON Energy Efficiency Potential Study
  - covers 4 IOUs, has an extensive database of efficiency programs and measures

- Scenarios Available:
  - Base (current) Incentive Levels
  - Full Incentive Level, covering complete incremental costs to consumer

- Criteria used to apply measure:
  - TRC Ratio: Profitable for utility
  - NOT identical to negative costs per tonne CO2 reduction

- Baseline assumptions
  - Natural market forces
  - increasing awareness/willingness
  - utility incentives not available

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Energy Efficiency

- The estimate of 2.6MMT and -$46 came from the mid projection for energy efficiency policy in the E3 model.
- The estimates come from the Huffman Policy and improvements in Title 24 Standards.

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Energy Efficiency Results

Quantity

- **5.5 MMT**: Full Incentives + Restricted Consumer Adoption (market potential)
- **+ 9 MMT**: Full Incentives + 100% Consumer Adoption (economic potential)
- Total potential: Sum of Market + Economic Potential
- Includes economic efficiency measures: incremental costs < benefits to utility

Costs

- Negative costs to achieve market potential
- Positive costs to achieve ALL additional economic potential (high program costs)
- E3 estimates to reach about 5.5 MMT: -$46 dollars per tonne

Question: How much of the additional 9 MMT can we achieve at 'reasonable costs'

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Results (By Sector and Type)

	Total CO2 saved (MMT)
Aggregate	5.55

Residential	2.48
Commercial	1.75
Industrial	1.32
	5.55

Industrial	1.32
Lighting (Res + Com)	2.14
HVAC (Res + Com)	0.76
WH (Res + Com)	0.28
All other Residential	0.37
All other Commerical	0.69
	5.55

Key Takeaways

- Negative cost energy efficiency savings are available
- Helpful to have scenarios with an explicit carbon cost criterion, not just utility profitability (TRC) in models such as ASSET (ITRON)
- Savings reported include only IOU efficiency:
  - Additional savings from federal and state standards and regulation (estimated in E3 model)
  - Municipal Utility Savings Potential?
- Next steps
  - Refine cost estimates and baseline assumptions
  - Use a cost per ton carbon saved criteria to estimate EE savings from ITRON model (ASSET).

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Light-Duty Vehicle Emission/Fuel Economy Standards Estimates

- Emission reductions (assuming no leakage)
  - Federal Fuel Economy Standards: 15 $MMTCO_2$
  - Pavley Emission Standards: 18.6 $MMTCO_2$ (additional)
  - Total reductions: 33.7 $MMTCO_2$
  - CARB estimates 18.8, 12.9, and 31.7 respectively
- Cost-effectiveness
  - If consumers value fuel savings for 3 years
    - Federal standards: \$-3.39/ton CO_2
    - Pavley: \$30/ton CO_2
  - If consumers value fuel savings over 14 years
    - Federal standards: \$-323/ton CO_2
    - Pavley: \$-298/ton CO_2 (CARB estimate: \$-135/ton CO_2)

Heavy-Duty Vehicle Smartway and Hybrid Estimates

- Emission reductions (assumes only CA registered)
  - –Smartway drag reductions: 1.25 $MMTCO_2$
  - –Hybrid trucks: 1 $MMTCO_2$ (additional)
  - –CARB estimates 1.3 and 0.5 respectively
- Cost-effectiveness
  - –Assuming full vehicle lifetime (10 years)
  - –Gas: $3.50/gallon -Diesel: $4.00/gallon
    - Smartway: $-180/ton CO_2
    - Hybrid trucks: $70/ton CO_2
- Coverage
  - This includes class 8 and parcel trucks; CARB only considered parcel trucks for hybrids

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Next steps for fuel economy modeling

- Remaining work:
  - May be small amount of double counting with ethanol vehicles will be taken out of this number before the final report
  - Still looking for better estimates of the number of vehicles of different types (e.g., compact, midsized, large) to get a more accurate weighted average cost-effectiveness (with NRC estimates).
    - Not likely to change much
  - More fine-tuning and verification with VISION

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Ethanol Modeling

- 7.4 MMt abatement at (-15.40) $/ton
- Increase ethanol blending in gasoline from 5.7% to 10%
- Double the BAU amount of Flex Fuel Vehicles (FFV) on the road in 2020
- Utilization of E85 by FFVs increases from 5% to 50% of VMT in 2020[1]
- Emissions factors taken from the 2007 LCFS study by Dr. Farrell and Dr. Sperling (adaptation of the GREET model)
- GREET model still faces scrutiny regarding its modeling of land use

[1] Under BAU, FFVs only use E85 for 5% of their miles traveled, the remaining 95% of the time they are fueled using only gasoline which provides no GHG reduction.

Plug-in Hybrid Electric Vehicles

- Emissions reduction
  - 6.68 MMT CO_2e in 2020
  - $88.61 / Mt CO_2e
- Reductions potential is non-overlapping with fuel efficiency standards
- Incorporated learning by doing to account for changing technology costs
- Cost to state based on incentive structure similar to CA Million Solar Roofs model
- Compared with NREL numbers, costs are similar
- PHEV cost curve is being integrated with other transportation elements into common transportation model
- Drew data from PNNL, NREL, NESCCAF, other sources

Renewable Power

- All renewable resources were taken from E3's most recent GHG calculator that models the power sector. We used the case with 20% RPS in the baseline and up to $160/tonne CO2e to build the RE supply curve.
- One of the major takeaways is that after 20% RPS, the renewable options are not cheap
- Wind – 3.3 MMT, $84/tonne
- Biogas – 1MMT, $34/tonne
- Biomass – .7MMT, $190/tonne
- Small Hydro – 6MMT, $96/tonne
- Geothermal – 1MMT, $70/tonne

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IGCC with Carbon Capture and Sequestration

- E3's output resource mix does not include CCS because of high costs.
- If reduction measures costing less than \$250/tonneCO2 are insufficient for AB-32's target, CCS could be considered.
  - Costs come from E3's inputs, and corroborating literature
- Potential of 6.5MMtonnes if all electricity growth after 2015 is IGCC w/CCS;
- But satisfying electricity demand with more cost-effective renewable resources and efficiency measures reduces CCS potential.

Non-CO2 Gases

Measures	Emission Reductions	Costs ($/MMTCO2eq)	Uncertainty/ Caveats
Landfill Gases: Capture and Destruction	2.3	42	Baseline emissions from landfills are uncertain. Methodology in development.
Recycling and Composting	3	23	Estimates are mostly a placeholder.
Landfill Gases to Energy Systems	1	34	Costs for electricity generation from biogas has been estimated as an aggregate. Estimates are for electricity generation in addition to the RPS requirement (20%).
Manure Management (Electricity Generation)			
High-GWP gases: refrigeration systems	8.5	28	Costs are highly uncertain. Further emission reductions from stationary refrigeration systems are possible.
Total	14.8		

Non-CO2 Gases: Discussions and Future Research

- Potential for emission reductions for Non-CO2 gases are significant.
- The present estimates are based on the CAT analysis (2006).
- Estimates for electricity generation from biogas is based on E3 calculator. The quantity appears to be in the low range of possible estimates.
- Costs estimates for High-GWP would need further analysis to reflect the true social cost of the measures.
- Recycling is an important unknown.

Cement

- Fuel Switching: 100% natural gas for heat (2.2 MMT or 14% reduction)
  - Cost $119/MT – Expensive
- Pozzolans: substitute 25% of all cement with fly ash (2.4 MMT reduction)
  - Cost $0/MT – But usable fly ash expected to decline
- Efficiency: increase the efficiency of plants (0.8 MMT reduction)
  - Cost ($33)/MT – But how efficient are CA plants today?
- Biggest question: Leakage
  - Increased imports from: China, Taiwan, Thailand

Combined Heat and Power

- Divided into industrial sector and residential and commercial sector
  - Each sector divided into two growth scenarios
    - Relying on increased incentives only
      - Extension of Self Generation Incentive Program (SGIP)
      - Production tax credit extension
    - Aggressive expansion through full set of policy options
      - Further expands incentives and production tax credits
      - Provides avoided cost of transmission and distribution to distributed generators
      - Includes changing regulatory processes
      - Increased funding for R&D
  - Two scenarios are non-overlapping
  - Based on data from EPRI / CEC

Combined Heat and Power

- Industrial
  - Incentives only
    - 1.26 MMT CO_2e
    - $30 / MT CO_2e
  - Aggressive expansion
    - 7.13 MMT CO_2e
    - $6 / MT CO_2e
- Residential and Commercial
  - Incentives only
    - 2.3 MMT CO_2e
    - $30 / MT CO_2e
  - Aggressive expansion
    - 12.8 MMT CO_2e
    - $6 / MT CO_2e

Smart Growth Planning

- Offers significant potential for reducing emissions in addition to other benefits
- Emission reductions and costs hard to estimate
  - Most current models not suited for land use change
  - Inherent complexities in predicting development patterns
  - Possible costs and their magnitudes difficult to enumerate and estimate
- Reduction amount of 7.06 MMT estimated using the smart growth scenarios of four major regions
- Cost likely to be negative – high uncertainty
- An additional 2.82 MMT (total 9.88MMT) is from other transportation related measures listed in CAT 2007 analysis

GHG Mitigation in Agricultural Soils

- Data used: CEC study (and census) that estimates potential in 10 counties and supply curve for Yolo county
- Strategies considered: reduced tillage, manure application, and winter cover cropping
- 1.05 MMT of emission reduction @ $6 per MT
- Concerns:
  - Extrapolation of costs and emissions from only a subset of CA counties and for only six chosen crops
  - High uncertainty and non-permanence of emissions' reduction
  - Further research needed on N2O emissions

Forestry

- Estimates based on CAT analysis (2007)

Measure	Emissions Reduction	Cost ($/ MT)
Afforestation/ Reforestation	1.98	10.6
Conservation forest management	2.35 MMT	2
Forest Conservation	0.4 MMT	37.5

- Concerns:
  - Significant double counting in excluded measures
  - Uncertainty and permanence issues
  - Other measures being added and estimates being revised by number of groups

Petroleum Refining & Production

- Emissions in 2004:
  - 35 MMT from refining
  - 12 MMT from production
- Estimates for potential reductions (4.4 MMT and 3 MMT) based on CARB's workshop presentations
- Cost numbers ($30/ MT of CO2eq) are placeholders
- No publicly available data: data for analysis being sought

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