Carbon Emission Reduction Opportunities in California Transportation

CARB Chair's Seminar
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Background

- E3 is modeling electricity sector for CPUC
  - Wanted to explore possibility of cross-sector trading with transportation
- My work
  - 4 person-months / Masters Project
  - Surprising results
- Synthesis of existing data
- Selection and combination of options into coherent supply curves

Goals for Today

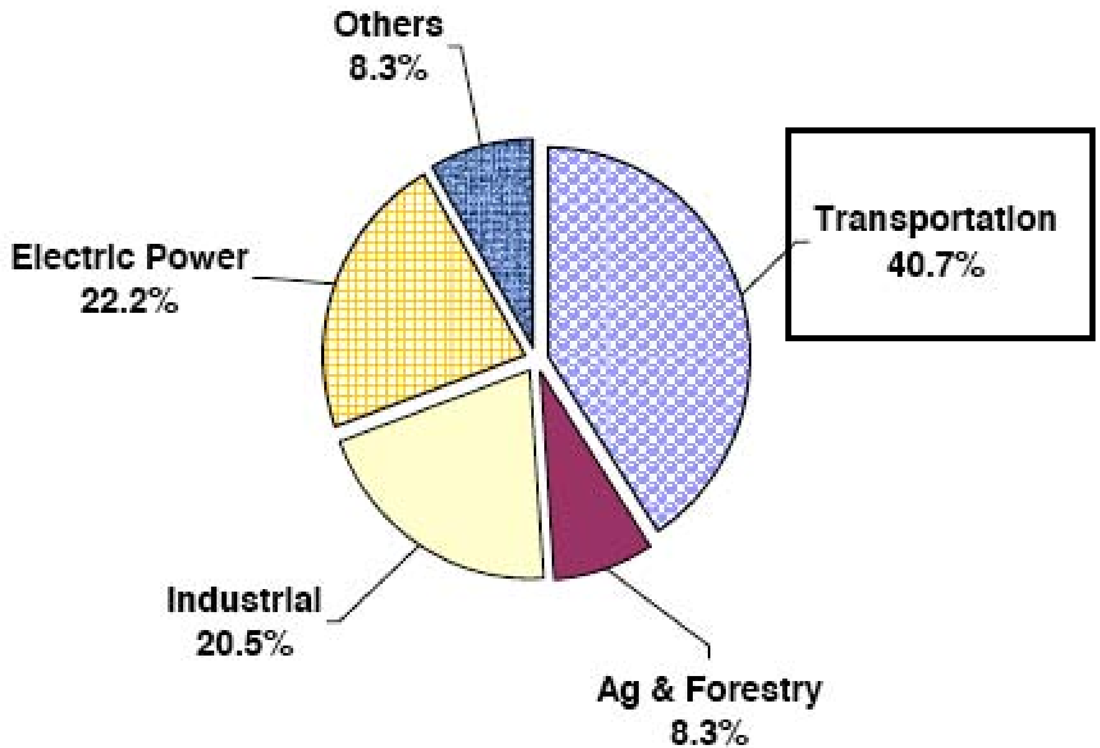
- Introduction
  - AB 32 Context
  - Approach
- Technology Options
  - Sources, Assumptions, & Results
- Supply Curves: MMT CO_2 & $ / tonne
- Discussion
  - What does this mean for AB 32?
- Please hold questions and comments until the end of the talk.

50 minute talk

Plenty of question time following the main presentation

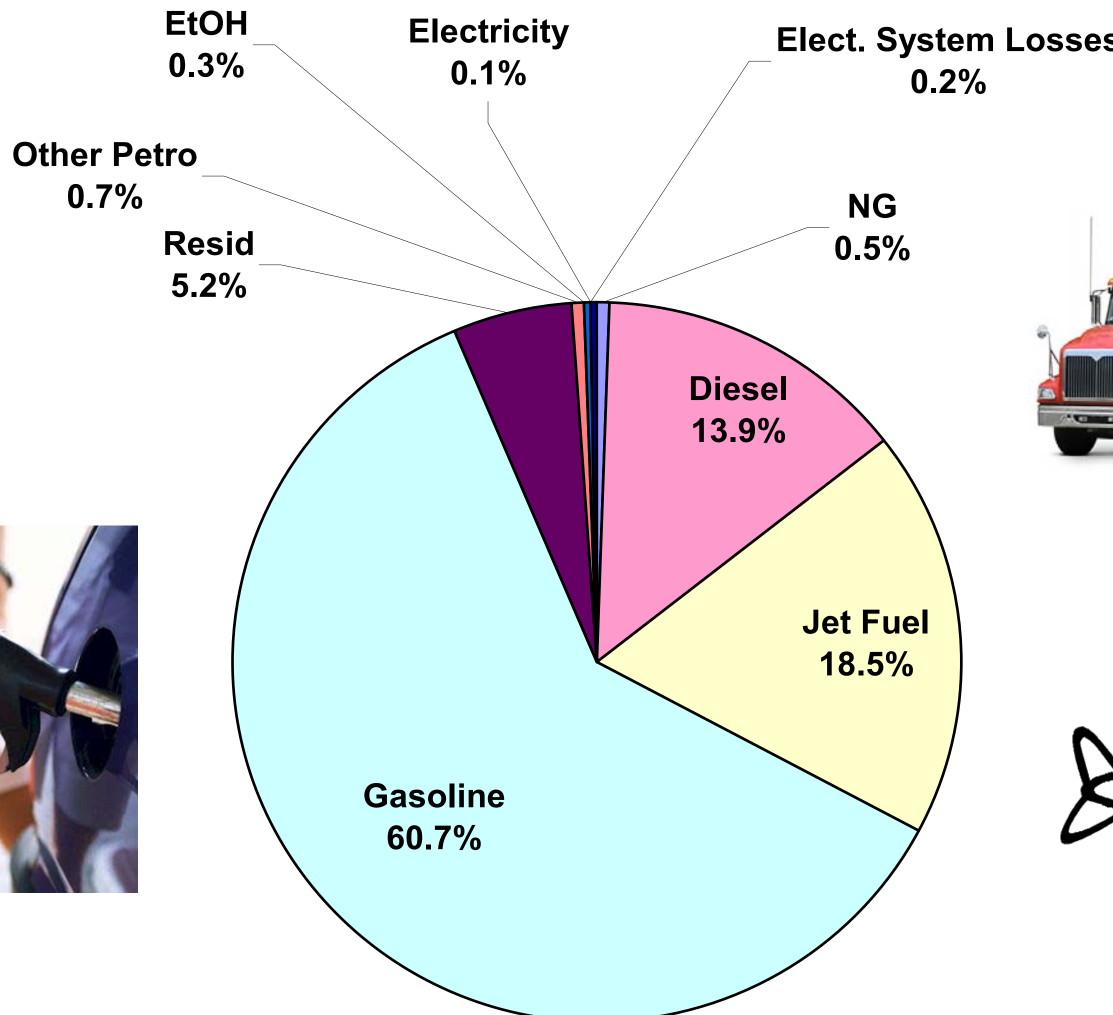
Context

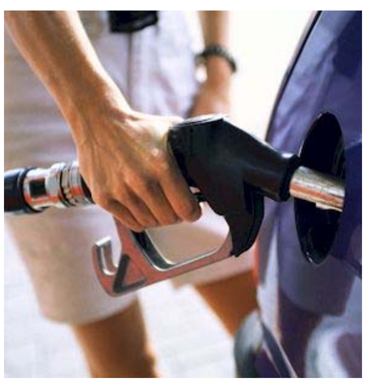
Figure 3 -- Sources of California's 2004 GHG Emissions (By End-Use Sector)
(Includes electricity imports and excludes international bunker fuels)

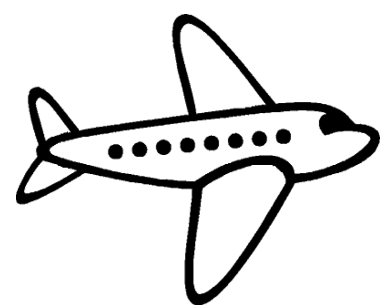


Source: California Energy Commission, Greenhouse Gas Inventory, Dec. 2006

CA Transportation Energy Consumption, 2001

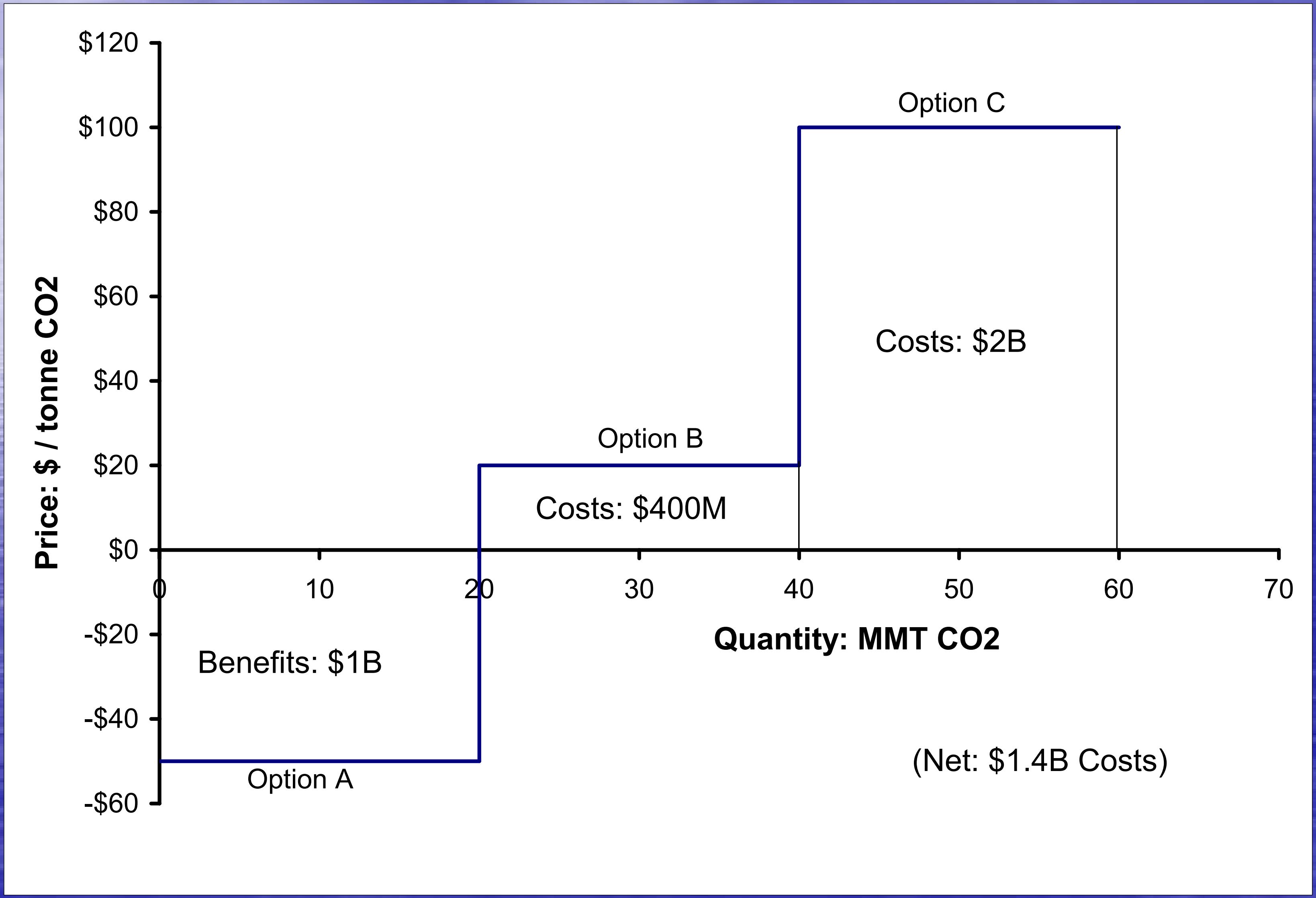






Source: BTS

What is a supply curve?



Research Goals

1) Determine technology options with price & quantity of possible GHG reductions
2) Stack from low cost to high cost, eliminate overlap, & combine into supply curve
3) Assess the potential in the transportation sector: are low-cost options available after Pavley & the LCFS?

Methods

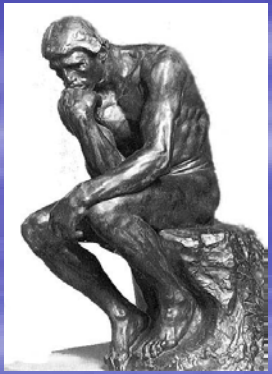
- Literature Review
  - CA-specific data & forecasts when possible
- Spreadsheet Model
  - First examine technologies separately, then integrate into supply curves
- 2010, 2020, & 2030
- Baselines: BAU & existing GHG standard (Pavley + LCFS)

Methods, Cont’d

- Direct economic costs (conservative), ignoring:
  - Taxes
  - Macroeconomic benefits
  - Externalities

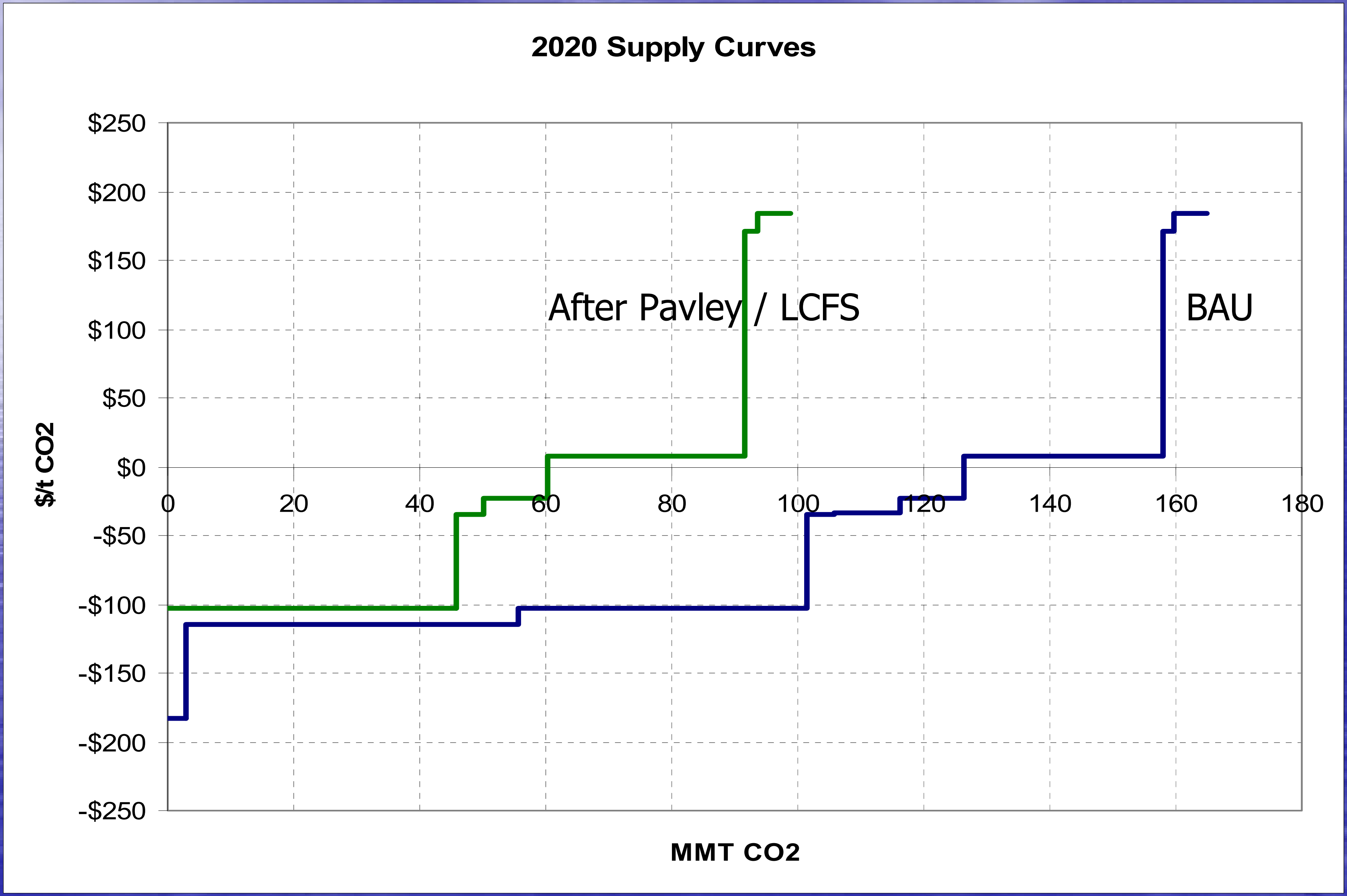
- No transaction / implementation costs
- Use underlying data
- Avoid speculative technologies

Analytical Challenges



- Predictions are uncertain
  - Fuel prices (particularly gasoline)
  - New technology prices & performance
  - Rate of new technology uptake
- Economics sometimes very sensitive to uncertainties
- Integration of separate options into coherent supply curves

Preview of Results



Key Sources

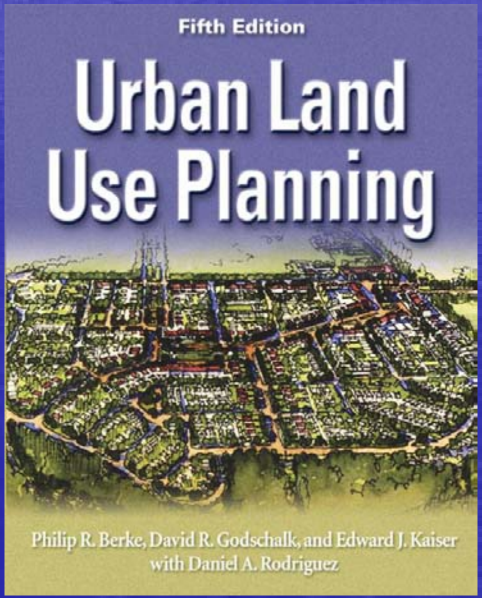
- K.G. Duleep's LDV Analysis for EEA (2006)
- CEC Transportation Forecasts (2007) & Petroleum Reduction Options Study (2005)
- LCFS Technical Analysis (2007)
- CARB ZEV Report (2007)
- IEA Global Biofuels Analysis (2004)
- ANL's VISION Model
- Chris Saricks' Truck Efficiency Analysis for ANL (2003)

Technology Options

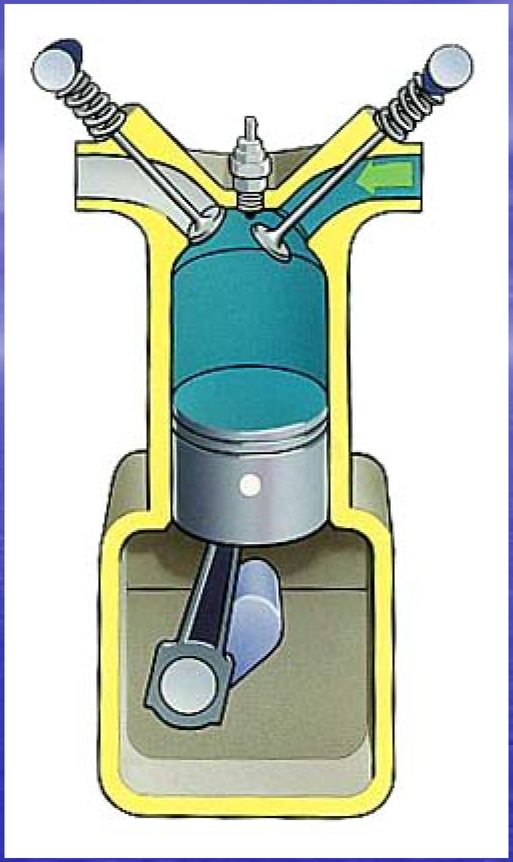
- Light-duty vehicles (LDVs)
  - Incremental fuel efficiency
  - Hybrids
  - Plug-in hybrids
  - Alternative hydrocarbon fuels
    - Natural Gas
    - Biofuel
- Heavy-duty vehicles (HDVs)
  - Truck fuel efficiency

Other Options (not in this talk)

- Transit / freight efficiency improvements
- Urban planning, driving discouragement policies
- Not included in analysis:
  - Hydrogen cars
  - Advanced biofuels
  - Size & performance reductions
  - Pure electric vehicles



Switchgrass



Light-Duty Vehicles: Incremental Fuel Efficiency

LDV Incremental Fuel Efficiency

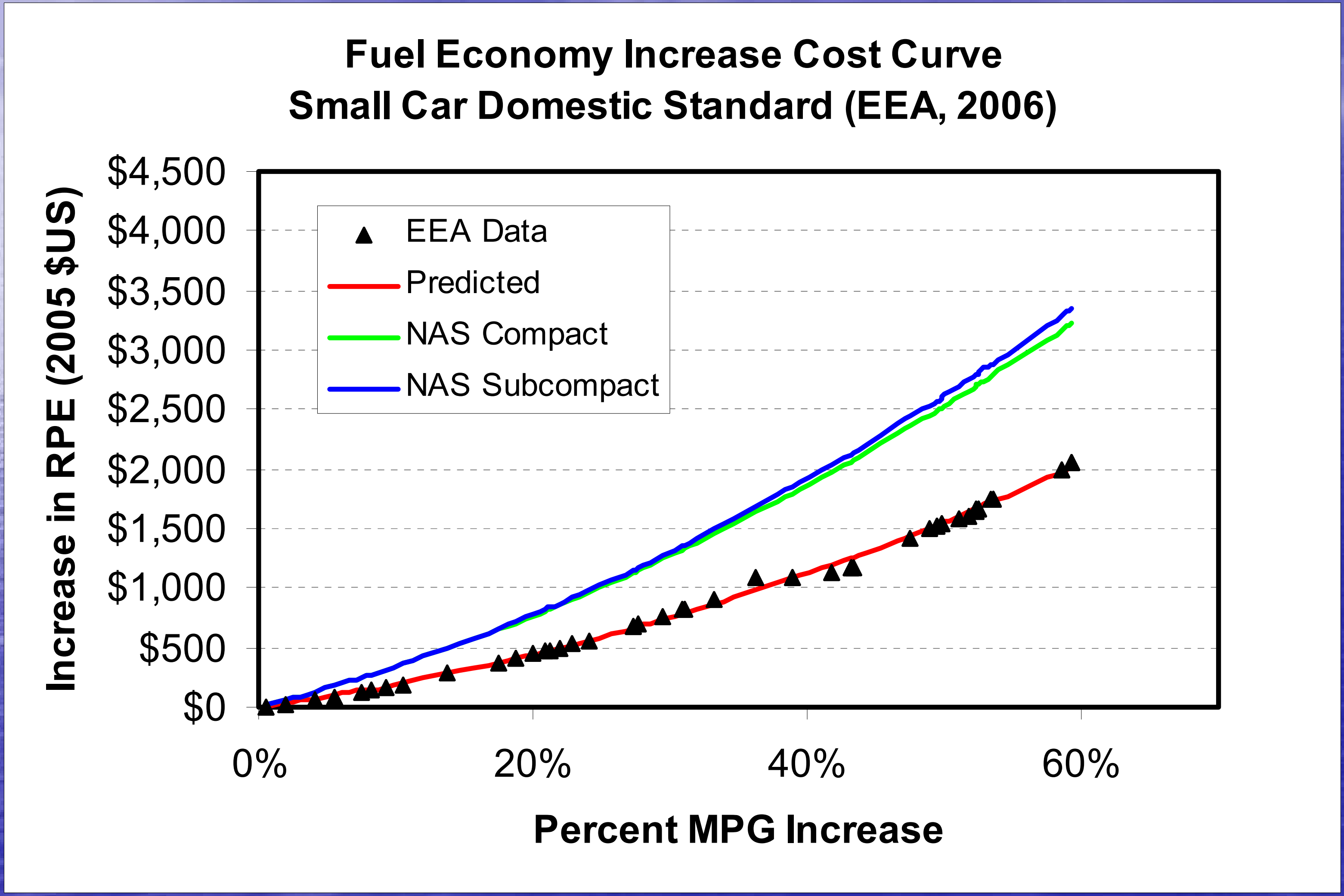
- Confirms CARB's 2004 Pavley Analysis on reducing vehicle GHG emissions
- Different data set
  - K.G. Duleep's 2006 analysis at EEA
  - CARB used NESCCAF, 2004

Fmr. Rep. Fran Pavley

LDV Efficiency, Brief Rundown

- Excluding taxes is a stricter standard
- But gasoline prices have increased and technology price estimates decreased
- Technologies include transmission, valvetrain, fuel injection, cylinders, electrical system, aerodynamics, tires, etc.
- *No change in vehicle performance & interior volume*

Example of Duleep's Data



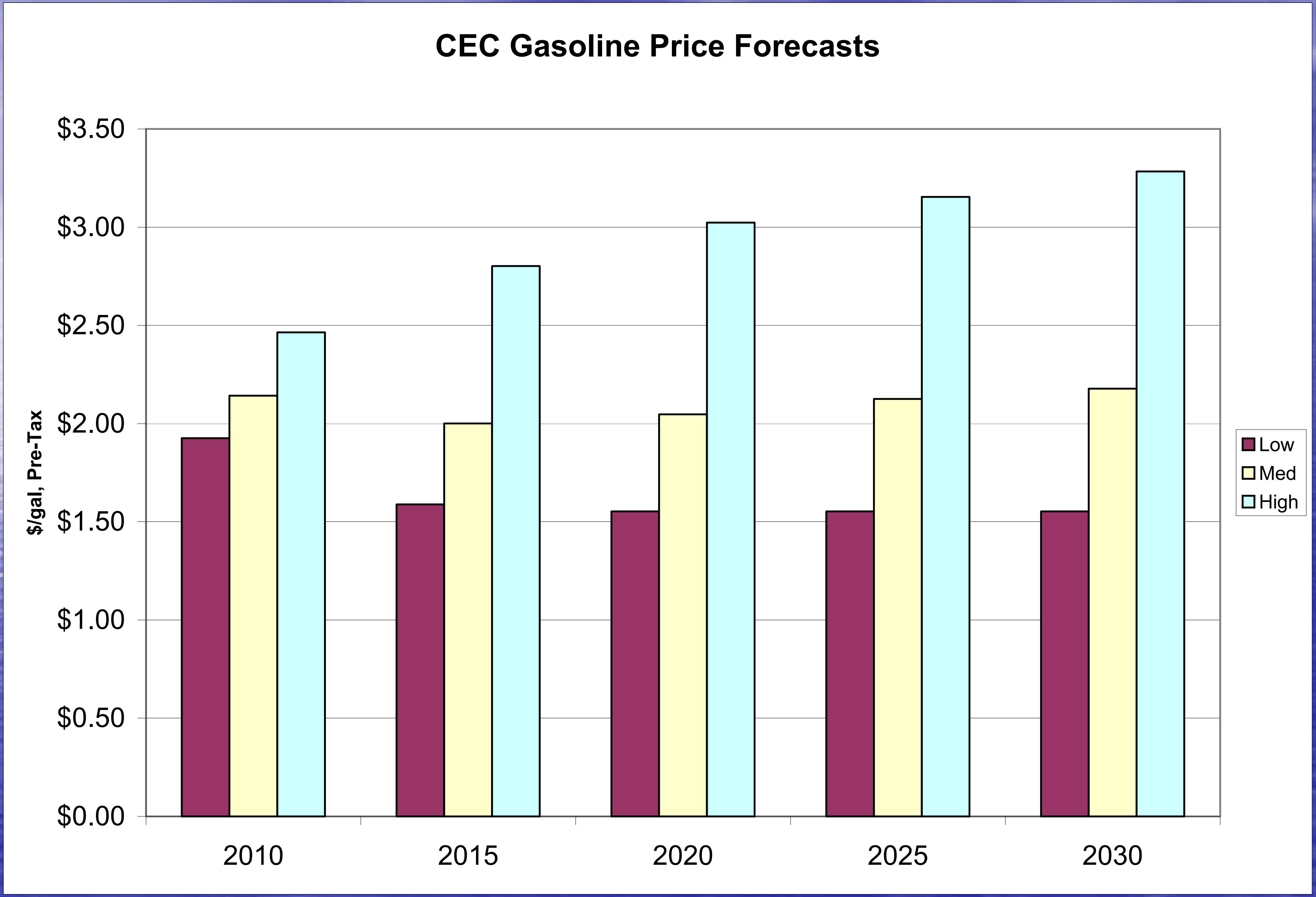
Provided by David Greene, Oak Ridge National Lab

Sources & Assumptions

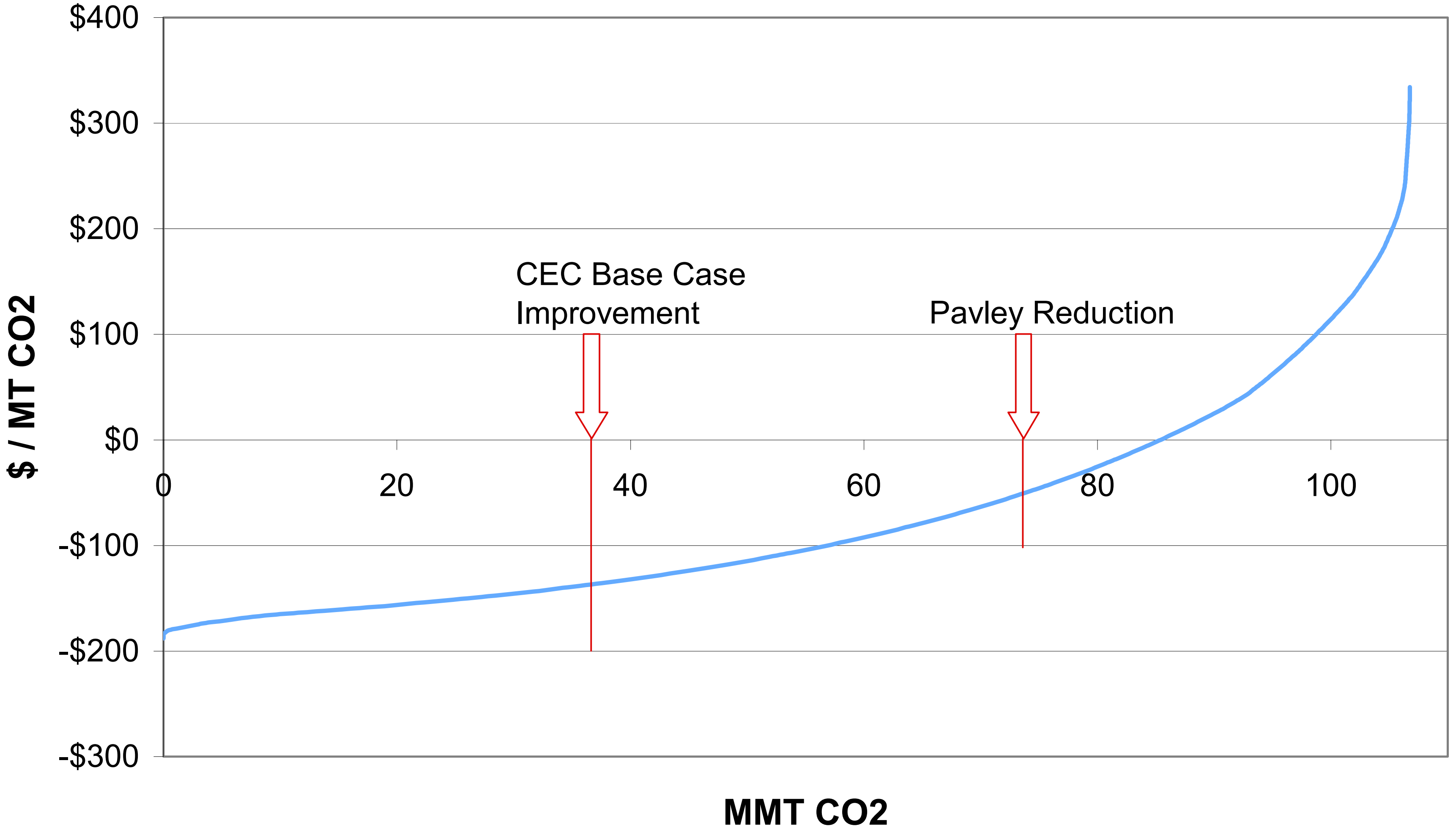
- CEC 2007 IEPR Transportation Energy Forecast provides
  - forecasted gasoline prices
  - fleet sizes (~30M)
  - VMT (~13K mi/yr, per vehicle)
  - baseline fuel efficiencies (~21 mpg)
- LCFS Technical Analysis provides gasoline carbon intensity (including upstream emissions)

Sources & Assumptions, Cont'd

- CARB's Pavley Analysis provides operating lifetime (16 yr) and discount rate (5% real)
- Supply curve based on lifetime emissions reductions associated with a particular year's new sales
  - Simplifies fleet analysis
  - Since we don't know how to change VMT (without a big gasoline tax), vehicle purchase is the key time for policy intervention


CEC Gasoline Price Forecasts
$3.50
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$0.00
$/gal, Pre-Tax
2010
2015
2020
2025
2030
Low
Med
High

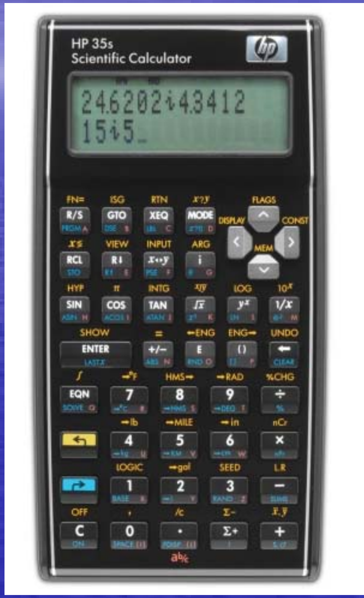
Long Term (~2025) Supply of Emission Reductions from LDVs, without Hybrids or Alternative Fuels



About $10B Savings

You may be wondering…

- If these emission reductions pay for themselves, why won't the free market take care of it?
- High up-front capital
  - Both for consumers & manufacturers
- Consumers fail to discount future fuel savings at market rates.

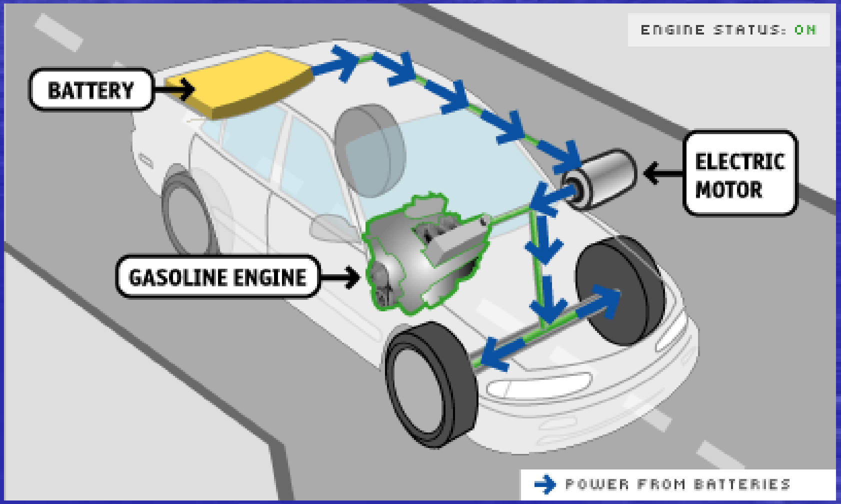


Hybrid-Electric Vehicles

Hybrid-Electric Vehicles (HEVs)

- Literature suggests $4000 incremental capital cost for a 40% fuel consumption reduction
- Possible penetration in 2020: 75% (for supply curves)

2007 Ford Escape Hybrid



Example of Analysis: 2020 HEVs, BAU Baseline

Inputs

Item	Value
Light Duty Vehicle Fleet Size (millions)	32.0
Baseline Fleet Average Fuel Economy (mpg)	21.8
Baseline Fleet Annual VMT / vehicle	13,050
Gasoline Carbon Intensity (g CO2 / MJ)	92.8
Gasoline Energy Intensity (MJ / gal)	121.0
Percentage of Fleet with Upgraded Fuel Eff.	100%
Upgraded Fuel Consumption Reduction	40.0%
Gasoline Price (Excluding Tax, $ / gal)	$2.05
Capital Increment per Efficient Vehicle	$4,000
Discount Rate	5.0%
Operating Lifetime of Vehicle (yr)	16

2020 HEVs, BAU Baseline

Outputs	
Baselines	
Baseline Fleet Specific Fuel Consumption (gal/mi)	0.0460
Baseline Fleet VMT (billion miles)	417.6
Baseline Fleet Fuel Consumption (billion gallons)	19.2
Baseline Fleet CO2 Emissions (MMT)	215.6
Baseline Vehicle Emission Intensity (g CO2 / mi)	516
New Fleet	
CO2 Reduction for Eff. Vehicle (%)	40.0%
New Fleet CO2 Reduction (%)	40.0%
New Fleet CO2 Reduction (MMT)	86.2
New Fleet Gasoline Consumption (billion gallons)	11.5
Avoided Gasoline Consumption (billion gal)	7.7
Costs	
Fuel Savings ($M)	$15,744.0
Annualized Vehicle Capital Costs per Vehicle	$351.50
Annualized Fleet Vehicle Capital Costs ($M)	$11,248.1
Net Total Costs ($M)	-$4,495.9
Abatement Costs in $/tonne CO2	**-$52**

Plug-In Hybrid Electric Vehicles

Plug-in Hybrids (PHEVs)

- Batteries: primary driver
- CARB's 2007 ZEV Study: extensive battery technology analysis
  - With confidential company questionnaires, verified by their engineers, etc.
- $300-$700 / kWh
  - Need about 7-8 kWh for PHEV 20

Batteries

- Li-ion batteries have many chemistries
- Each chemistry has its own advantages
- A123 (Watertown, MA) makes Li $FePO_4$ batteries
  - Safe, durable & powerful

Battery Comparison Chart

Chemistry	Energy	Power	Cost	Life	Stab. / Safety	Development
$LiCoO_2$	+		x		x	+
$Li(Ni\text{-}Co\text{-}Al)O_2$ (NCA)	+					
$Li(Ni\text{-}Co\text{-}Mn)O_2$ (NCM)	+					
$LiMnO_2$ (LMS)		+	+	x*		
$LiFePO_4$		+	x*	+	+	
Li-Polymer	+	+	+	+	+	x
NiMH	x	x	x	+	+	+
*Potential for improvement						

Batteries

GM Volt

- Biggest remaining challenges:
  - Cost
  - Calendar life
    - (But PHEV 20 → PHEV 16 isn’t so bad)

PHEVs, Conclusion

LADWP NGCC Plant

- Advantages of PHEVs
  - Clean electricity in CA
    - Cheap off-peak night-time charging opportunity
  - Large electric drivetrain efficiency advantage
  - When in gasoline mode, still runs like a regular hybrid
  - PHEV 20 saves about 50% of CO_2 (NGCC electricity)
- $0.07 / kWh electricity is like $0.54 / gallon gasoline.
- PHEVs are likely to be economic well before 2020.

Compressed Natural Gas Vehicles

Compressed Natural Gas (CNG)

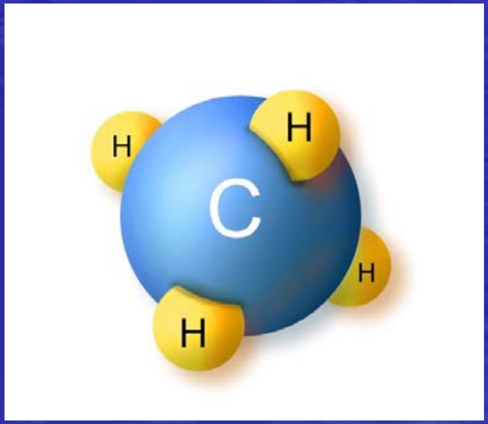
- NG: less carbon per unit energy than gasoline
  - About 20-30% reduction in practice (LCFS, 2007)
  - Depends upon fugitive methane emissions & relative drivetrain efficiency
  - Sources disagree somewhat
- Already used extensively in New Delhi
  - Lower criteria pollutant emissions

CNG LDVs, Cont'd

- Need storage tank, moderate engine modification, and fueling infrastructure
  - Distribution infrastructure already exists
  - Stations or home refueling < $2000 / vehicle
- Main source: CEC Pet. Red. Opt. Study (2005)
- Suggestion for incremental capital cost:
  - $4800 to $6400 initially
  - $2600 to $5300 after moderate mass production
  - Zero ultimately.
- Assume moderate production by 2020

CNG LDVs, Conclusion

- Like electricity, NG is a cheap vehicle fuel
- 1.15 therm (0.115 MMBTU) = 1 gallon gasoline equivalent
- $8/MMBTU NG = $0.92 gasoline (plus markup)
- Solid economics, moderate CO_2 reduction



E85

85% Ethanol

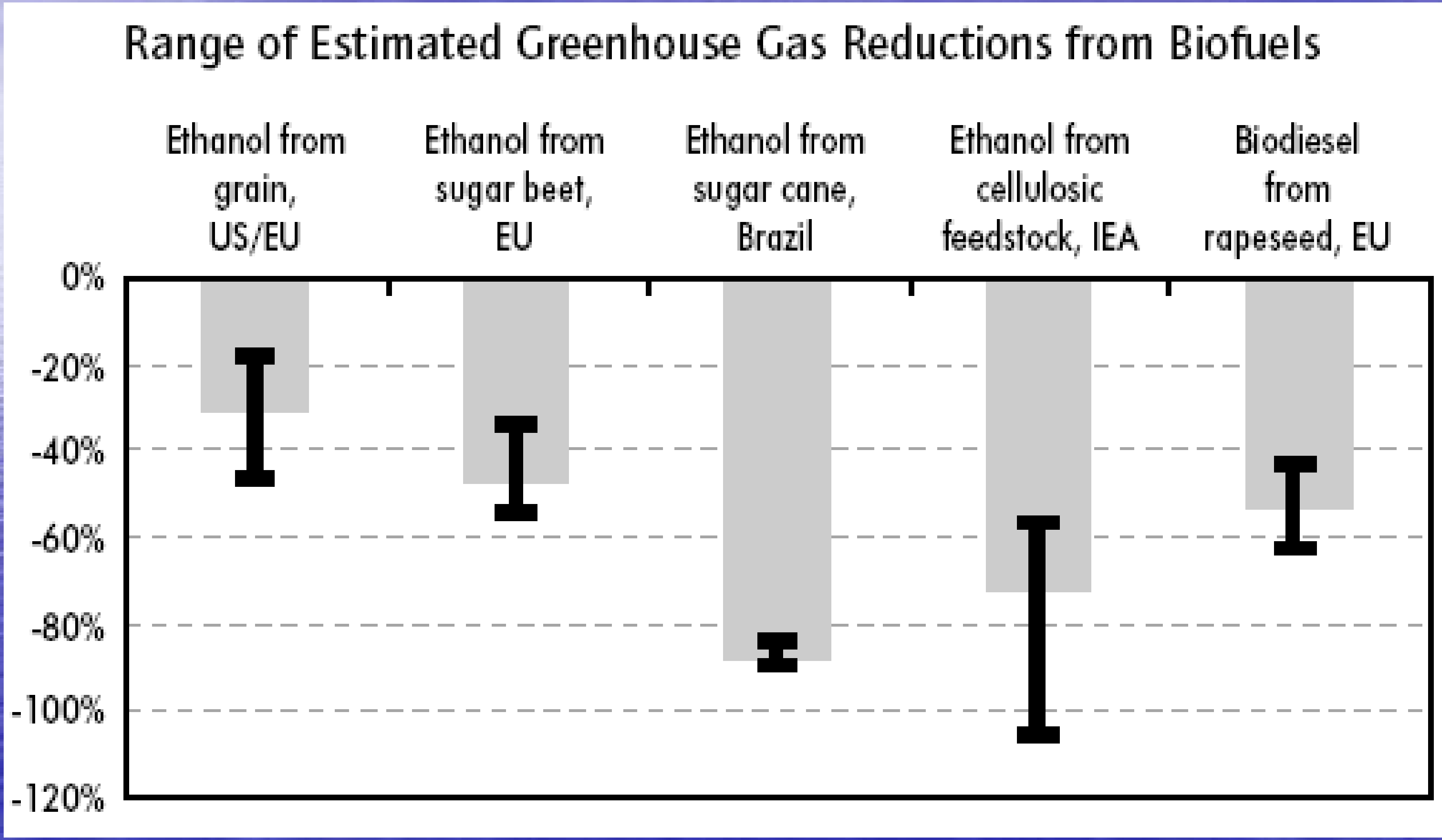
Ethanol

Ethanol

- Grain ethanol (e.g. US corn): marginal *at best*
- Sugarcane ethanol is superior economically and environmentally
- Cellulosic ethanol
  - Close to commercialization?
  - Energy crops on dedicated land
  - *Or* wastes & ag residues

- Might be eclipsed by butanol, FT diesel, "renewable" gasoline / diesel, algal biodiesel, etc.
  - Ethanol's tendency to mix with water makes it incompatible with existing fuel distribution infrastructure.
  - Requires lots of energy for distillation

IEA 2004 Biofuels Study



Land Use Debate

- But more recently, analysts have focused on the land use problem.
- Corn, soy, & wheat prices have nearly doubled in the last year!
  - US ethanol policy
  - Chinese meat consumption
- Bad for urban poor
- Increases pressure to cut down rainforest
- 15 g CO_2 / MJ penalty for sugarcane

Clearing in Amazon

Brazilian Sugarcane Ethanol

- Proxy in the supply curve
  - Land use concerns
  - Politics: $0.50 / gallon import tariff
  - But commercially viable now
- Ethanol production cost in Brazil as low as $1.08 / gallon gasoline equivalent.
  - Price in 1990 (in 2007$) was $1.89.
  - Not counting import costs
  - Consumer not likely to see production cost savings

Ethanol Economics $

- >10,000 gallons of fuel over vehicle life
  - Fuel price relative to gasoline: main driver
- $0.10 shift in fuel price = $694 in capital
  - Enough to pay for flex fuel vehicle capital & substantial fueling infrastructure.
  - CEC: FFV is only $200-$400 more
- Some advanced biofuels: no need for *any* infrastructure change

PHEVs, CNG, & Ethanol Market Penetration in Supply Curves

- Based on LCFS (2007) scenarios for 2020:
  - 5% CNG
  - 9% EtOH (currently 4% by mandate)
- 20% PHEV
- Higher?
  - I'd bet on PHEV

Truck Fuel Efficiency

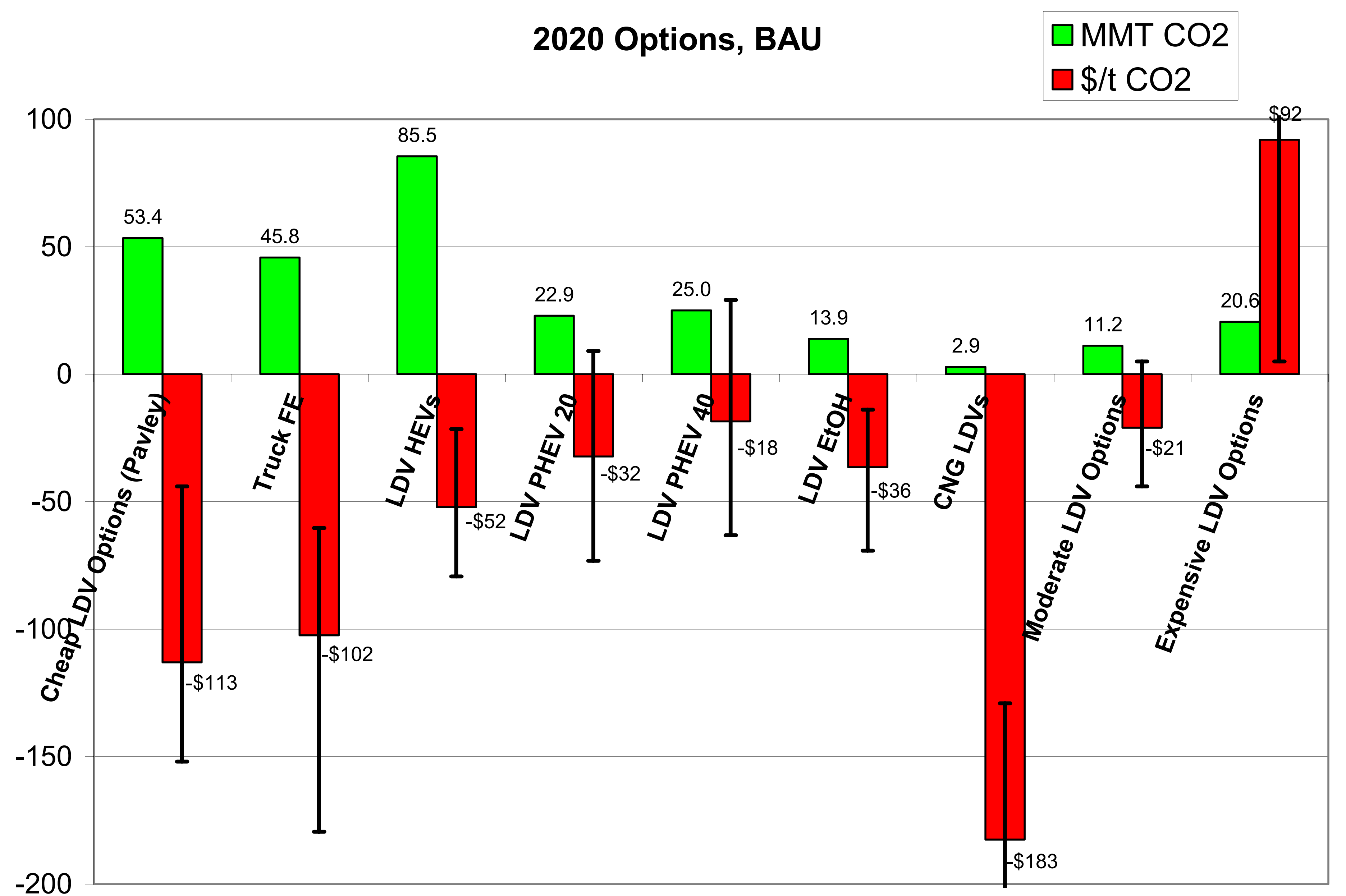
Truck Fuel Efficiency

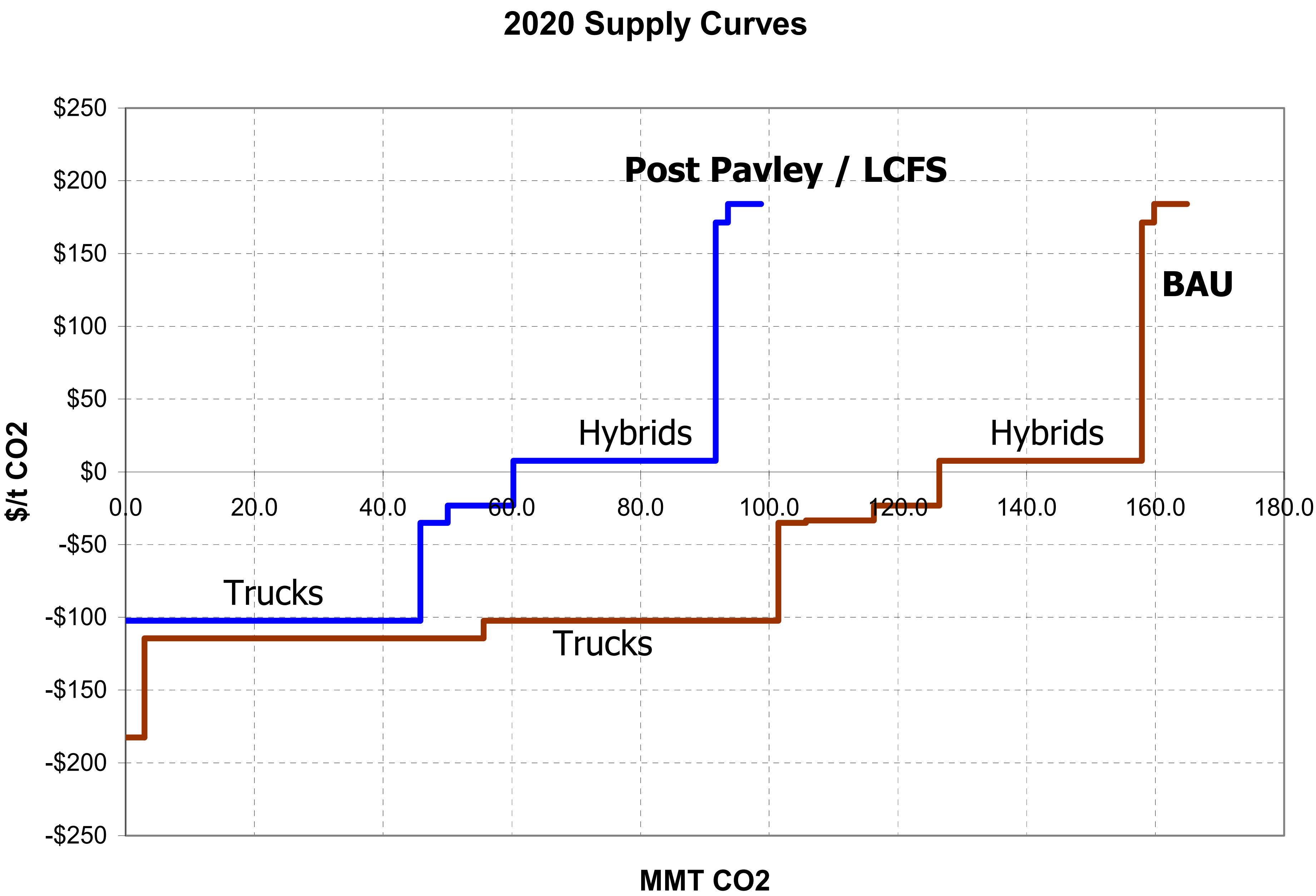
- Chris Saricks et al, ANL, 2003
- Provides incremental capital cost and fuel consumption reduction
  - Dozen technologies
  - 4 classes of truck
  - 3 used here: heavy diesel, medium (7-13 tons) diesel, & medium gasoline
- For heavy diesel, 41.1% reduction at $21K

Truck Fuel Efficiency, Cont'd

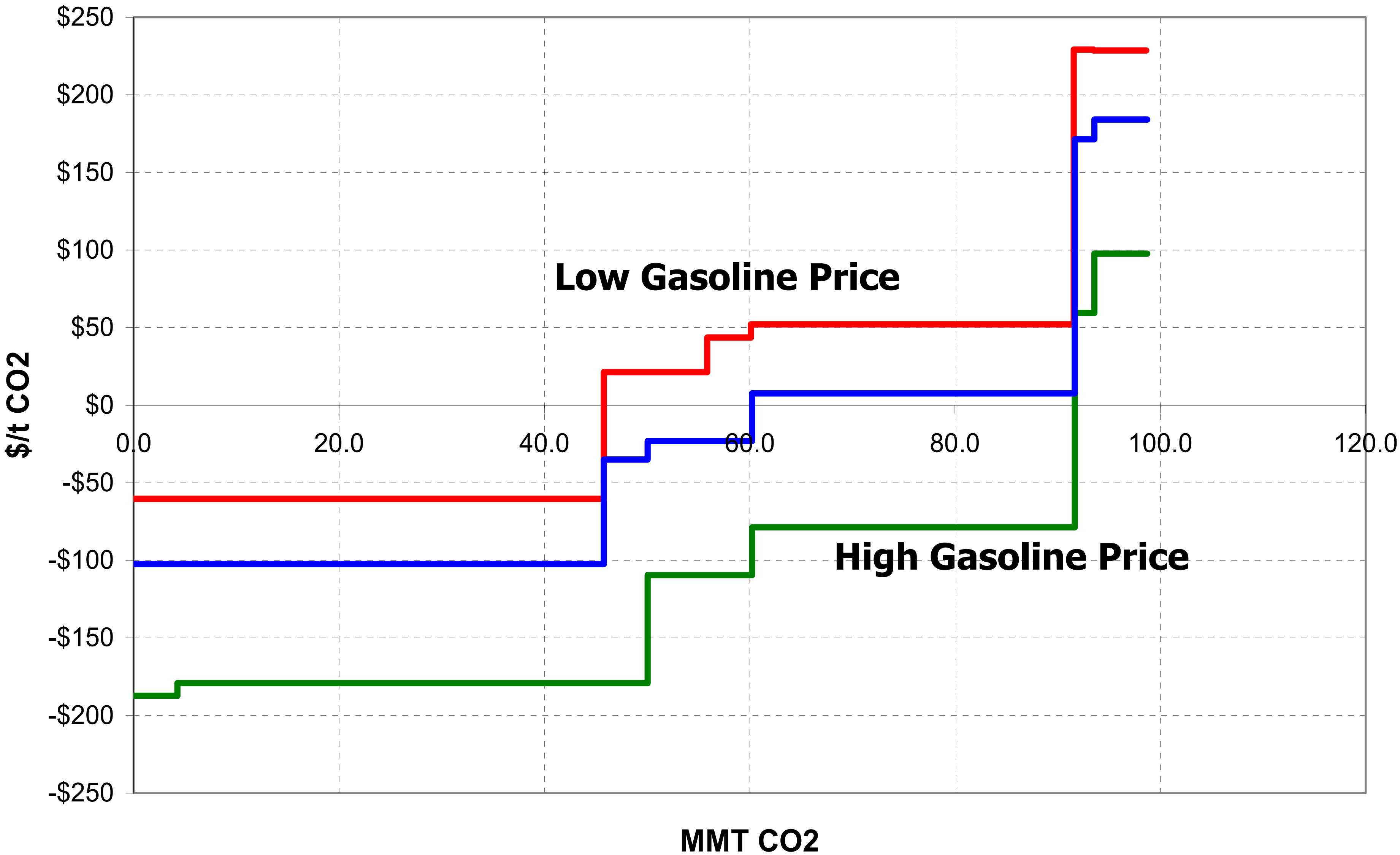
- Additional sources / assumptions:
  - Fleet data from ANL VISION Model (Scaled to California based on population)
  - Diesel C Intensity from LCFS Tech. Rep. (2007)
  - 20 yr Lifetime based on VISION fleet data
  - Diesel Price from CEC Forecast
- Population scaling → overestimate
  - State's geography → refueling outside of CA
  - Best if done as regional policy

Supply Curves

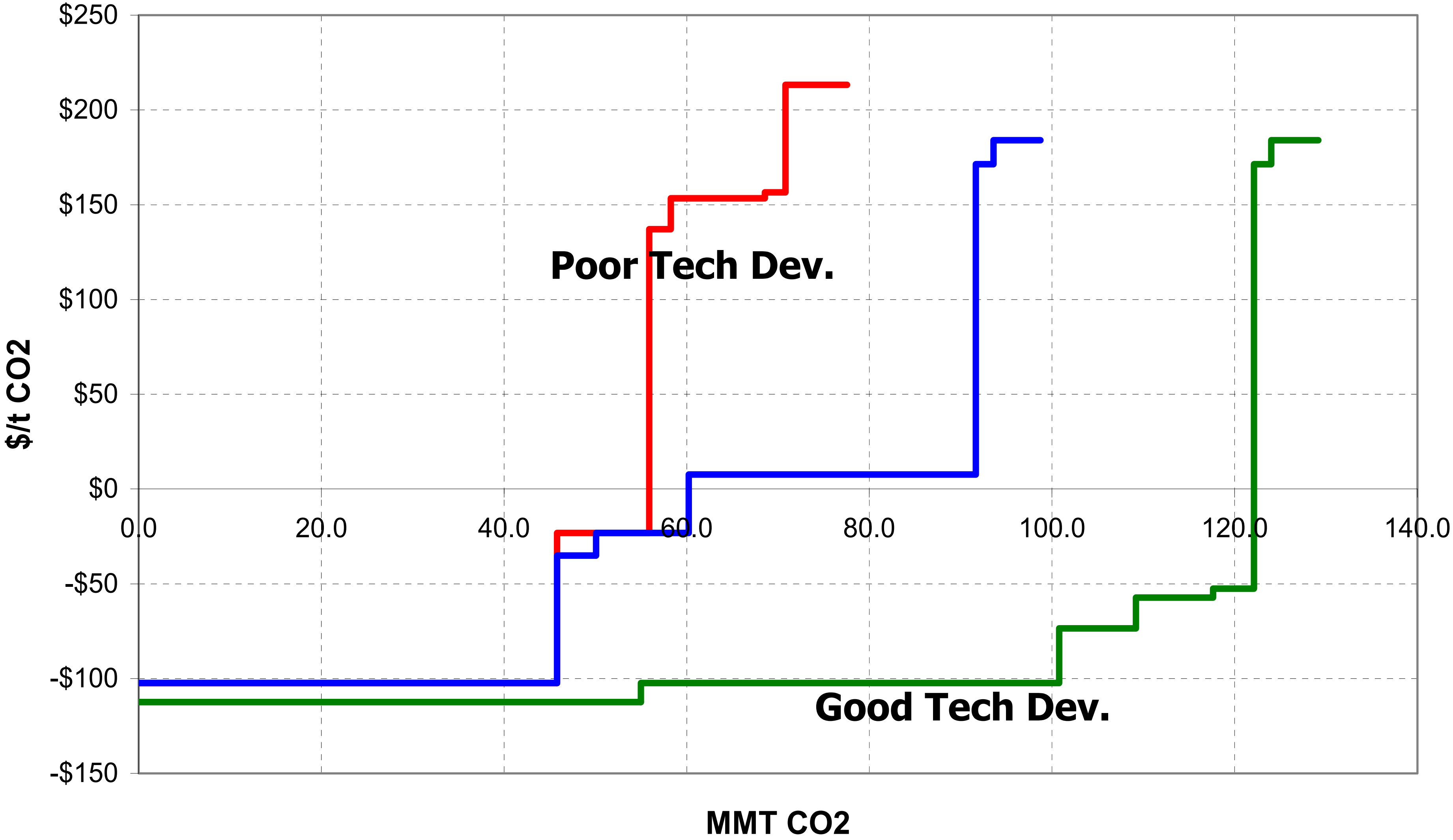

2020 Options, BAU
MMT CO2
$/t CO2
100
50
0
-50
-100
-150
-200
53.4
45.8
85.5
22.9
25.0
13.9
2.9
11.2
20.6
-$113
-$102
-$52
-$32
-$18
-$36
-$183
-$21
$92
Cheap LDV Options (Pavley)
Truck FE
LDV HEVs
LDV PHEV 20
LDV PHEV 40
LDV EtOH
CNG LDVs
Moderate LDV Options
Expensive LDV Options

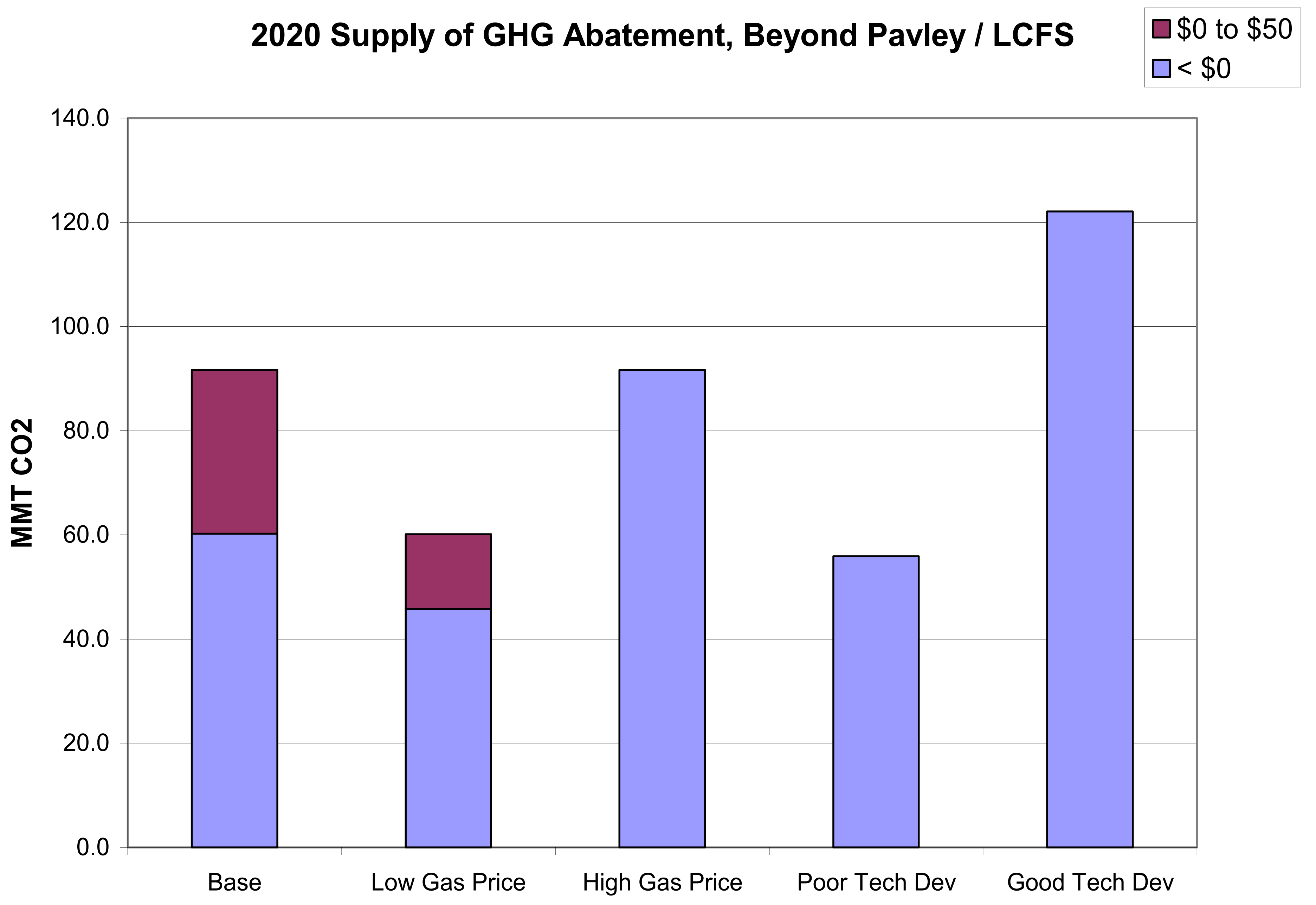

2020 Supply Curves
$250
$200
$150
$100
$50
$0
-$50
-$100
-$150
-$200
-$250
$/t CO2
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
MMT CO2
Post Pavley / LCFS
BAU
Hybrids
Hybrids
Trucks
Trucks

2020 Supply Curve (Beyond Pavley / LCFS) Gas Price Sensitivity



2020 Supply Curve (Beyond Pavley / LCFS), Sensitivity to Tech Development / Market Penetration / Price




2020 Supply of GHG Abatement, Beyond Pavley / LCFS
$0 to $50
< $0
MMT CO2
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Base
Low Gas Price
High Gas Price
Poor Tech Dev
Good Tech Dev

What does this mean?

- Additional transportation policies / regulations could contribute significantly to AB 32 goals.
- Even if Pavley and the LCFS are fully implemented, significant low cost or negative cost opportunities remain.
- At the very least, further research should be done by the state as part of the AB 32 process.

Possible Policy Options?

- Pavley 2
- Hybrid mandate / subsidy
- Resurrect the ZEV requirement (& include PHEVs)
- Include transport fuels in a cap & trade
  - Lee Friedman is working on this.
- Feebates (now under discussion)
- Low interest loans (to cover extra purchase cost: $1-5K) for efficient / alternative fuel vehicles, to be paid back with fuel savings

Acknowledgements

- CPUC & CARB funding for E3 electricity sector modeling
- Jim Williams, Ren Orans, & other E3 Staff
- Prof. Alex Farrell for comments
- CARB tuition grant for last fall
- Dr. Robert Sawyer

Further Info

- Working Paper available on web
- *Energy Policy* draft in progress
- Contact subin@berkeley.edu