# BREAKING BARRIERS TO DEEP CARBON REDUCTION BY 2050: CALIFORNIA'S CARBON CHALLENGE

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# OUTLINE

- California 2050 Modeling overview
- Potential Carbon savings from behavior change
- Energy system modeling

# CALIFORNIA'S CARBON CHALLENGE IN BRIEF

- **THE CHALLENGE: HOW TO ACHIEVE 80% CARBON REDUCTIONS** IN CALIFORNIA BY 2050?
  - To meet a 2005 Governor Executive order
- **BARRIERS:**
  - IS THIS TECHNICALLY POSSIBLE AND IF SO, HOW TO ACHIEVE THIS?

- Team members:
  - Itron – Building Energy Efficiency
  - UC-Berkeley – Electricity Modeling
  - UC-Davis - Transportation
  - LBNL – Industry, Integration, Lead
- Sponsors
  - California Energy Commission (CEC)

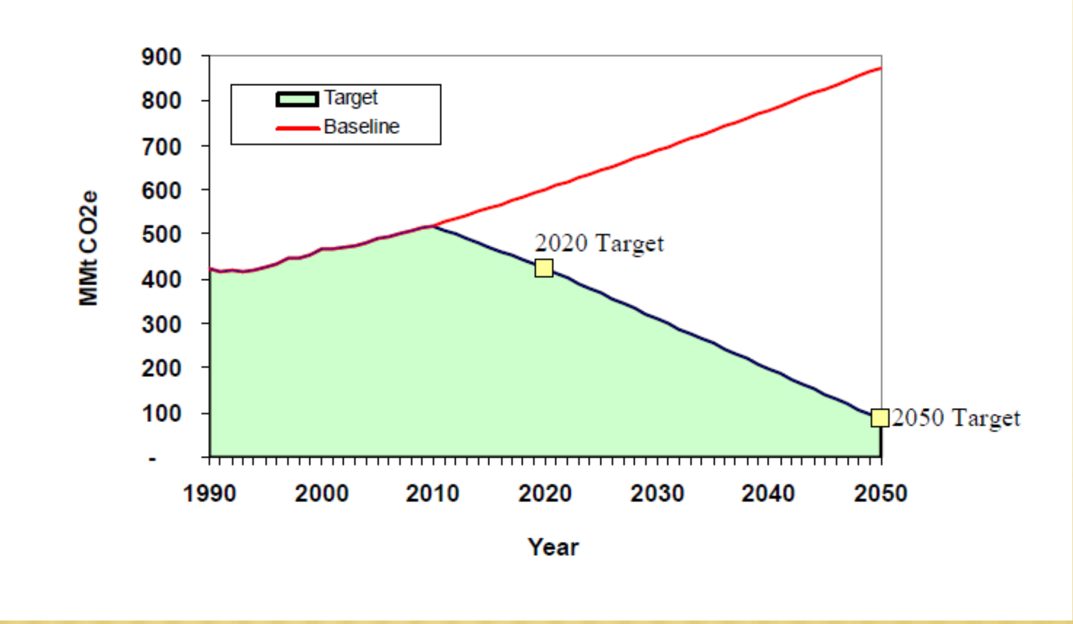
# CALIFORNIA'S CARBON CHALLENGE IN BRIEF

- APPROACH
  - Systems approach
  - Self-consistent energy demand and supply scenarios
  - Bottom up calculations + Detailed electricity optimization model
  - Behavior change model for lower consumption and fuel demand

- IMPACT
  - Provides a comprehensive reference point toward identifying and quantifying key implementation barriers:
    - Technology development
    - Market adoption
    - Policy requirements

# CALIFORNIA'S LONG TERM GHG TARGET

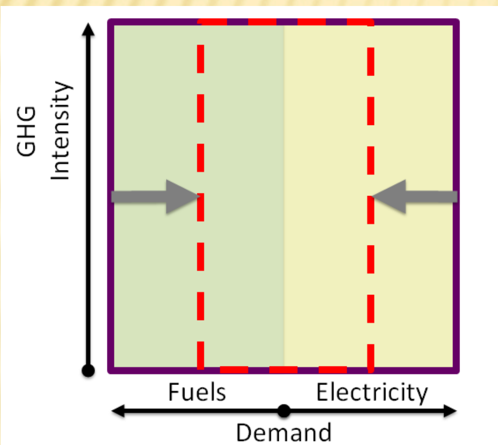
- Reduce emissions to 1990 level by 2020 (AB32)
  - Detailed plans and progress for 2020 target
- Reduce emissions by 80% from 1990 level by 2050
  - How do we meet the 2050 target?



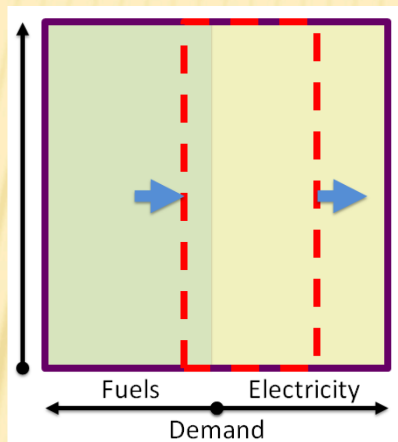
# FIVE KEY PATHWAYS TO DECARBONIZATION

*Emissions = Energy Demand * ( Emissions/ Energy)*

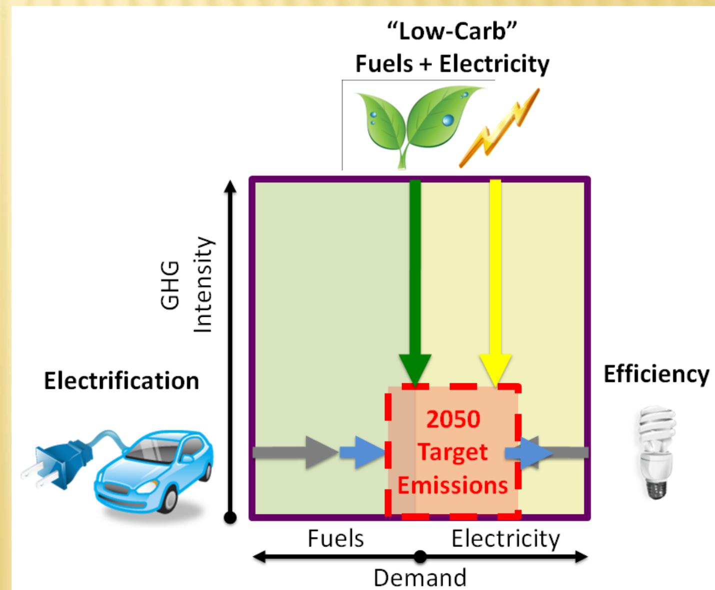
*= Area = Energy * GHG Intensity*




1. Energy Efficiency




2.Electrification
or fuel switching




3. Cleaner fuels and
4. Clean Electricity
5. Reduced driving, consumption

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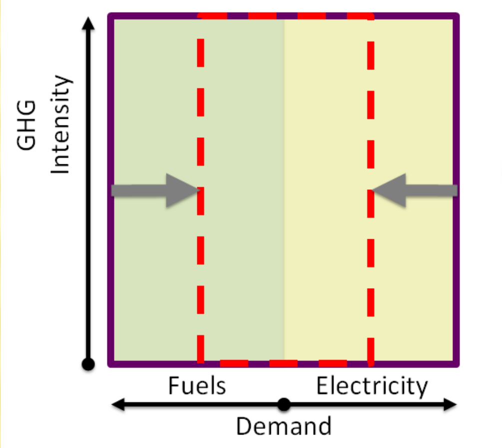
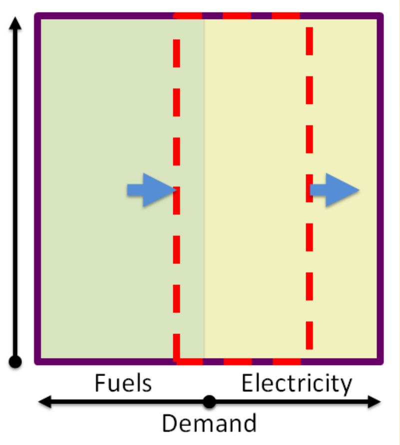
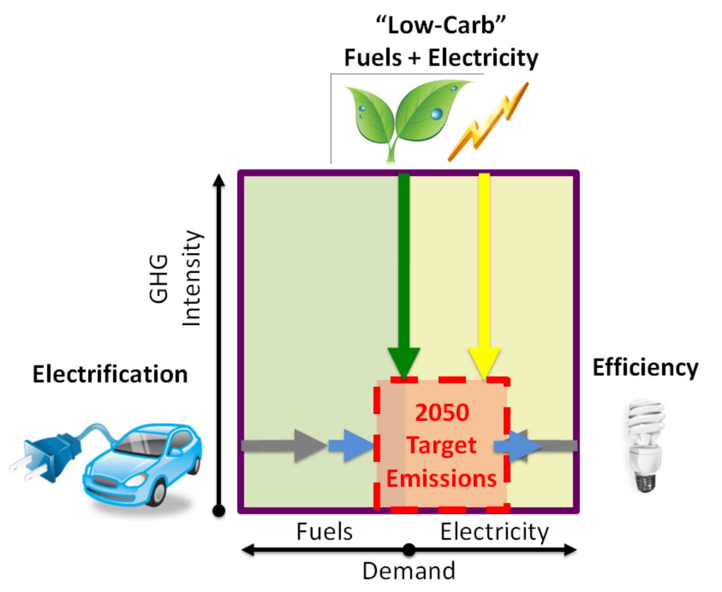


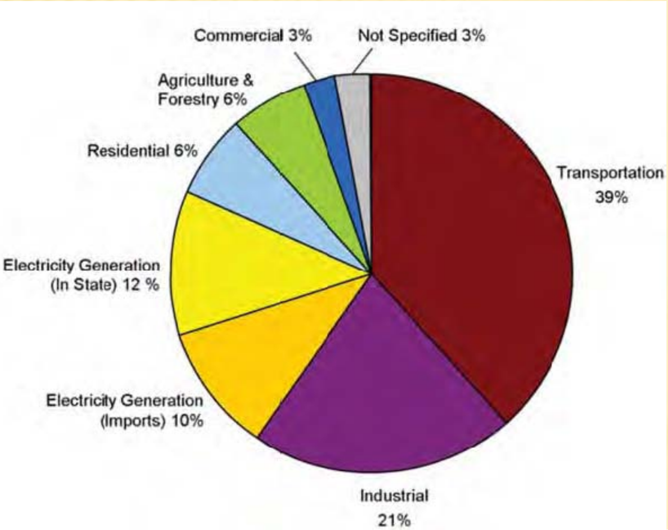




Note that lowering GHG intensity will reduce the impact of demand reductions.

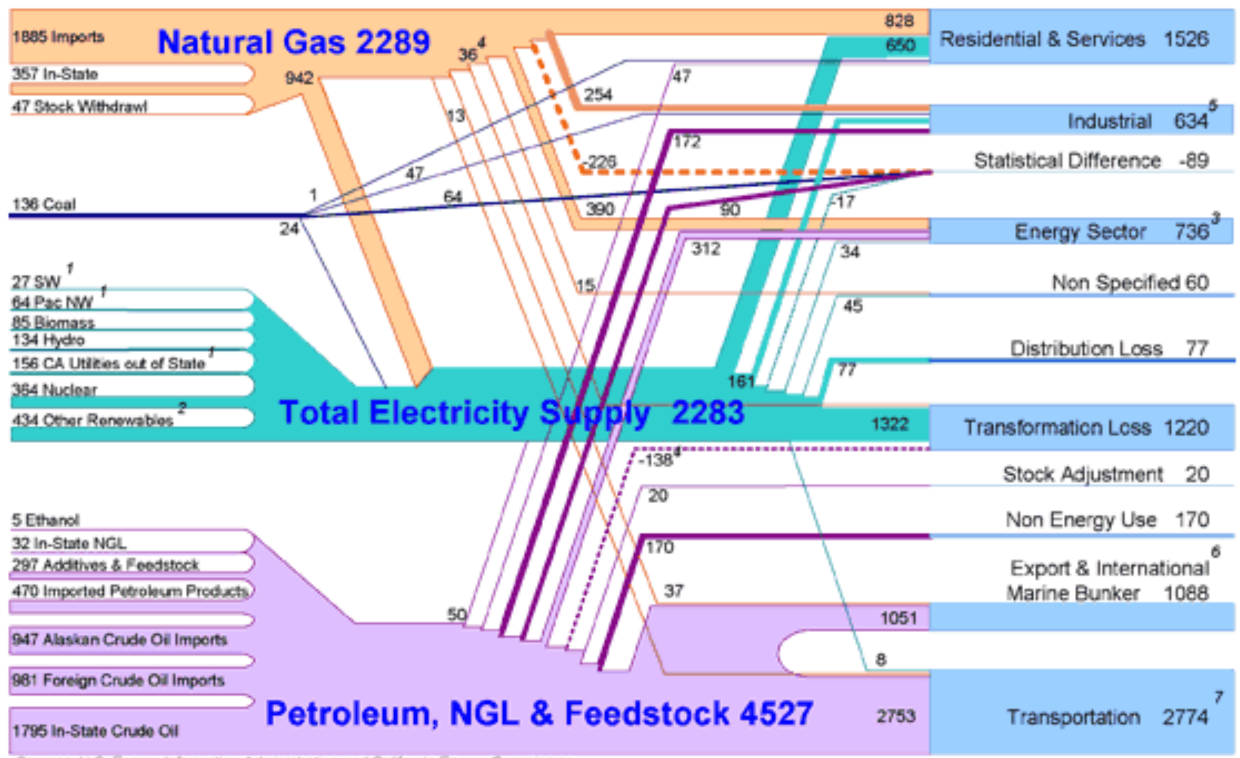
# SOME KEY ASSUMPTIONS

- Technology:
  - Mostly limited to existing or in-market technologies
    - E.g. no algal biofuel
- Growth: Population follow state projections from 2007; GDP "medium" growth
- Overall Cost:
  - Not estimated since large uncertainties in technological progress and development
- Energy Efficiency:
  - Assumes maximal adoption of energy efficient technologies in building, transportation and industry sectors
- Policy:
  - Requires both a continuation and ratcheting up of U.S.-leading climate policies in California

# California GHG Emission Sources and Primary Energy Flows




- GHG Emissions (2006)
  - 40% Transportation, 20% industrial,
  - 22% Electricity, 9% Heating, 9% other
- Primary Energy "Sankey Plot"
  - 29% Nat. Gas; 55% petroluem, 2% coal + 15% other ➔ 85% fossil fuel



# Summary of Pathways, Issues, Barrier Mitigation, and CO2 Savings

| # | Pathway | Key Technical Issues | Implementation Barriers | Key Barrier Mitigation | Outlook | CO2 Savings |
|---|---|---|---|---|---|---|
| 1 | **Energy Efficiency: Buildings** | Building monitoring/operation<br>Building Controls/ grid integration | Retrofitting >> New Buildings<br>Cost/Financing, ROI<br>Transaction Cost vs. Visibility | Innovative financing;<br>Bottom up community-based social marketing | Residential building retrofitting has hit a wall despite $500M+ in ARRA funds | 40-50% |
| 1 | **Energy Efficiency: Industry** | System design/integration<br>Energy Management systems | Risk Aversion<br>R&D budget, Engineering | Industry incentives<br>Industry demos and training | Oil/Chemical industries onboard;<br>Low margin commodity industries lag | |
| 1 | **Energy Efficiency: Transport** | Lightweighting (materials)<br>Battery Development | BEV: cost, infrastructure, range | MPG continues up after 2025;<br>Feebates | New 2016-2025 standards a good start | |
| 2 | **Clean Electricity** | Solar PV, Wind variability;<br>Carbon Capture and Storage viability | Higher cost<br>Siting, Transmission Lines | Renewable Energy Mandates<br>DOE R&D, e.g. Sunshot<br>Storage, Demand Response R&D | California 33% Renewable Energy Mandate in 2020 a good start | 25-30% |
| 3 | **Electrification** | Thermal storage/integration;<br>Industrial high temp electrification | Lack of supporting policies<br>Higher cost of energy | Incentives for electrified heating<br>Supply chain stakeholder training | **Lack of supporting policies; a key gap in integrated system planning and R&D** | 40-50% |
| 4 | **Low C Liquid Fuels** | LCA impacts: indirect land use<br>Conversion yield to biofuel | Fluctuating gasoline price<br>Cost of new biorefinery | Floor on gasoline price or gas tax<br>R&D in advanced biofuels & manuf. | Technology scaling and cost curves seem surmountable; Land use is key | 30-40% |
| 5 | **Behavior/ Consumption Reduction** | Feedback technologies<br>IT enabled info mgmt/networks | Cultural norms/metrics<br>Inconvenience/Time | Price signals as in gas tax<br>Community engagement | Probable enabler for other pathways; but transformative change | 10-15% |

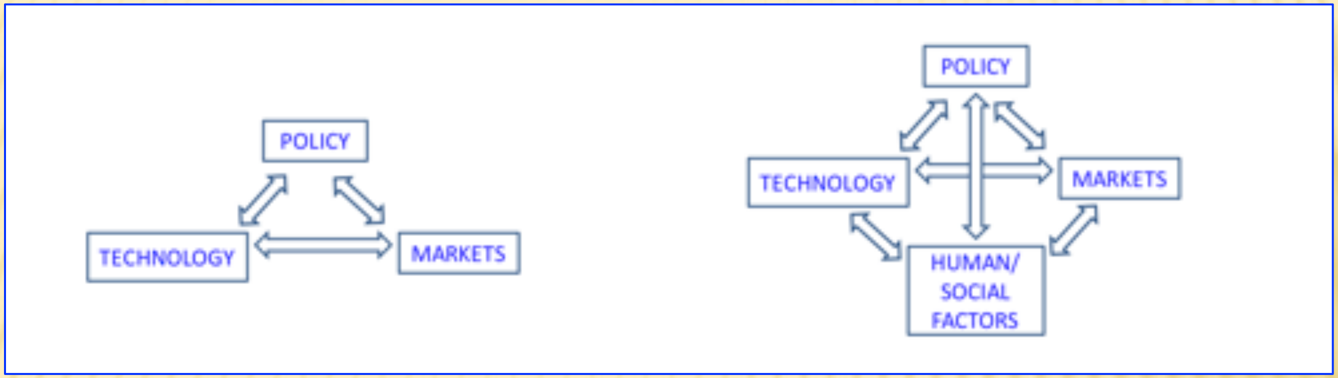
Most of the barrier mitigations are policy-focused, so policy is as much if not a greater issue than technology.

# CONCLUSIONS

- The 2050 GhG target for California appears achievable, but requires significant changes in the way we use energy and in energy production.
  - Portfolio of approaches
  - Sustained technology development needed across sectors (electric vehicles, energy efficiency measures, biomass and biofuel production, renewable electricity, electric storage, …)
- Clean electricity and the development of a high supply of low-carbon biofuels are vital to the scenarios presented here.
- Clean electricity enables large scale electrification as a path to reduce emissions.
- Using a historical database of behaviors suggest that long term behavioral change GHG savings of 10-15% are possible in California.
- From a policy standpoint, California can build upon its policy portfolio to support the long term GHG target
  - e.g. Building codes and appliance standards, EV support, Renewable energy mandates, utility EE programs, Low Carbon Fuel Standard
  - Electrification of heat is a policy gap

# POTENTIAL CARBON SAVINGS FROM BEHAVIOR CHANGE

# AN INTEGRATED FRAMEWORK



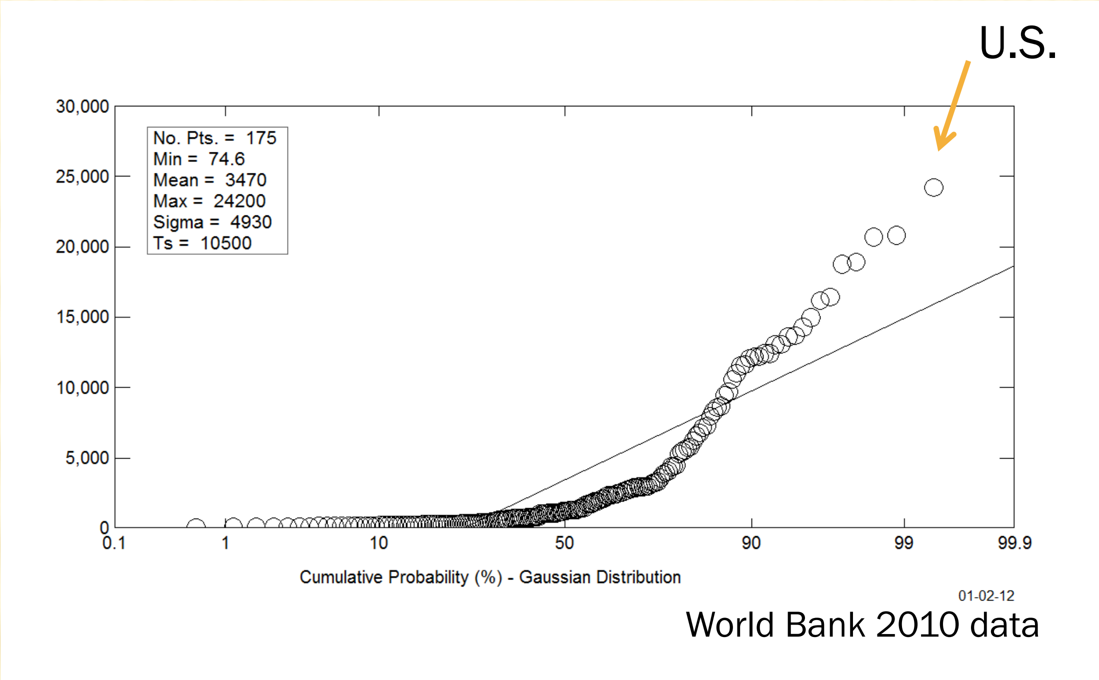

- Interacting system. Example q's:
  - How should latest climate science inform policy?
  - How do successful behavior change programs impact policy?
  - Behavioral interaction with new vehicle technology or direct feedback technology
  - Impact of climate policy on fossil fuel markets
  - How do behavioral factors vary with ethnicity and income?

# IMPORTANCE OF HUMAN/SOCIAL FACTORS

- Human/Social factors as the focus for transformative change.
- Key hinge for multiple pathways: consumption and vehicle mile reduction. Also energy efficiency and electrification equipment/vehicle purchases, clean electricity purchases.
- Behavior change and uptake as driver/enabler for policy changes
- If GHG intensity is not reduced, behavioral impact is magnified; Expand portfolio, reduce risk

# HOUSEHOLD FINAL CONSUMPTION IN 2000: WE ARE THE 1%

Household final consumption expenditure in 2000 (constant 2000 US$)

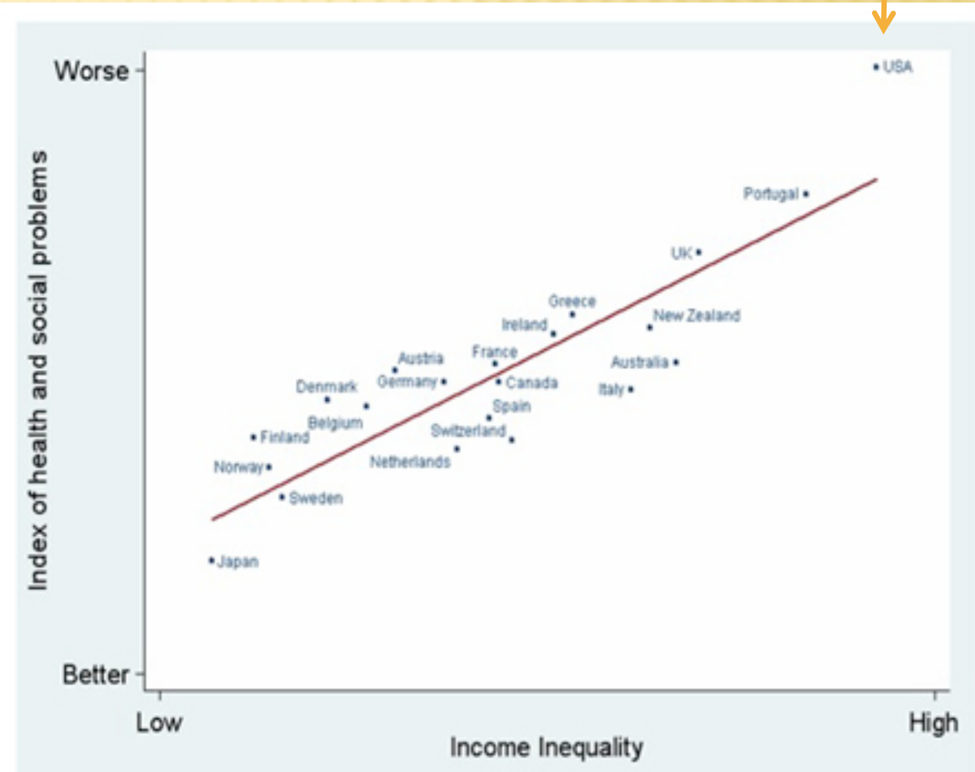



- U.S. the #1 consumer nation by a wide margin
- 175 nations (each nation is one data point)
- India $290 per capita; China $439; U.S. $24,207

# AN UNSUSTAINABLE SOCIETY?

Among developed countries, the U.S. is worst in income inequality and social outcomes (education, physical health/mental health, crime/violence, teenage births, community life)

U.S.




K. Pickett, R. Wilkinson, The Spirit Level

**FACTOIDS**
4 in 10 Americans believe in Evolution

68% American adults overweight or obese
34% American adults obese

7X incarceration rate vs other OECD

Craft message that offers better health, better neighborhood and society, and better planet

# BEHAVIOR CHANGE EXAMPLES



*Energy Demand [Miles driven]* $\sim HH * \frac{VMT}{HH} * \frac{Energy\ [gall\text{-}gas\text{-}eq]}{VMT}$

**Usage or Behavior Term**

*Energy Demand [Lighting Hours of Use]*

$$\sim HH * \frac{Lumens\text{-}hrs}{HH} * \frac{Energy[kWh]}{Lumens\text{-}hr}$$

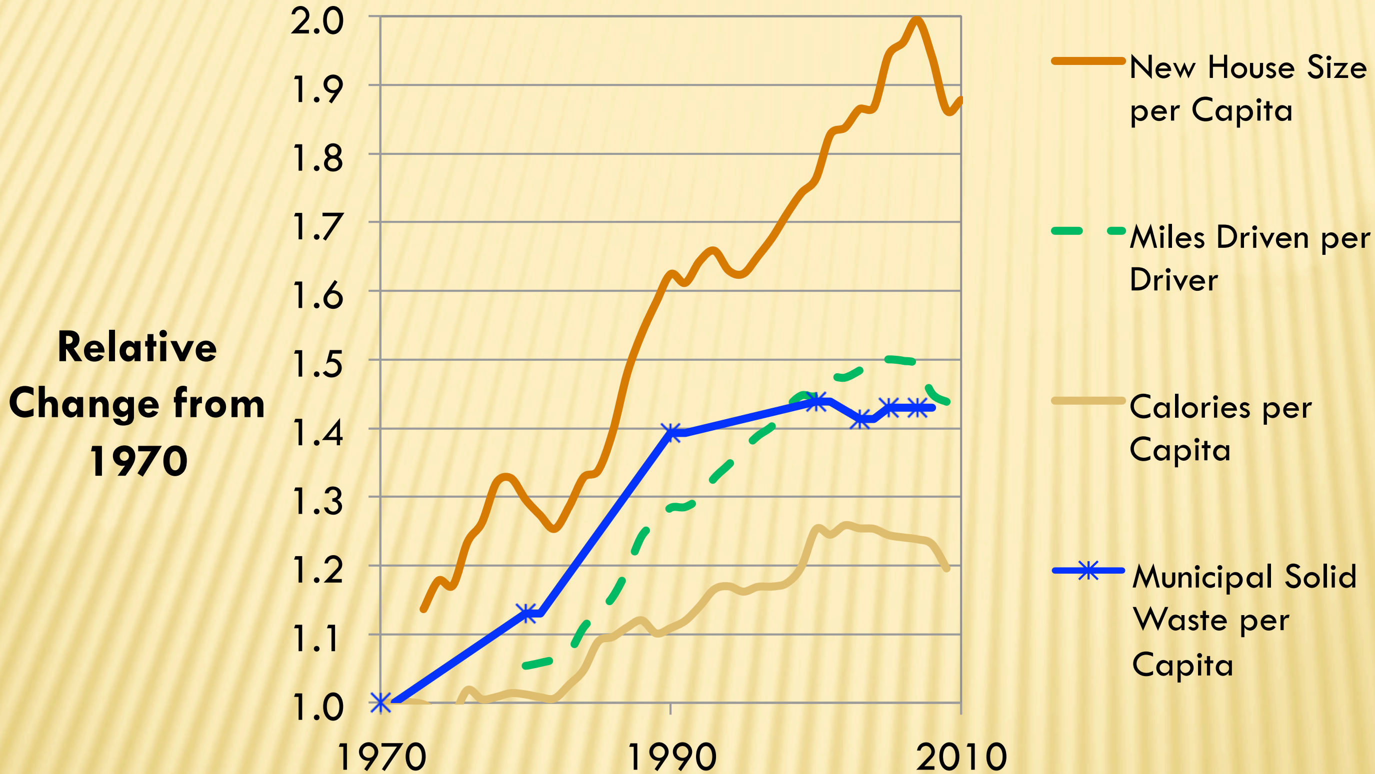
$$\sim HH * \frac{Lumen\text{-}hrs}{HH} * \frac{Watts}{Lumen}$$

**Usage or Behavior Term**

Where
HH: Households
VMT: Vehicle Miles

# A LOOK BACK 40 YEARS

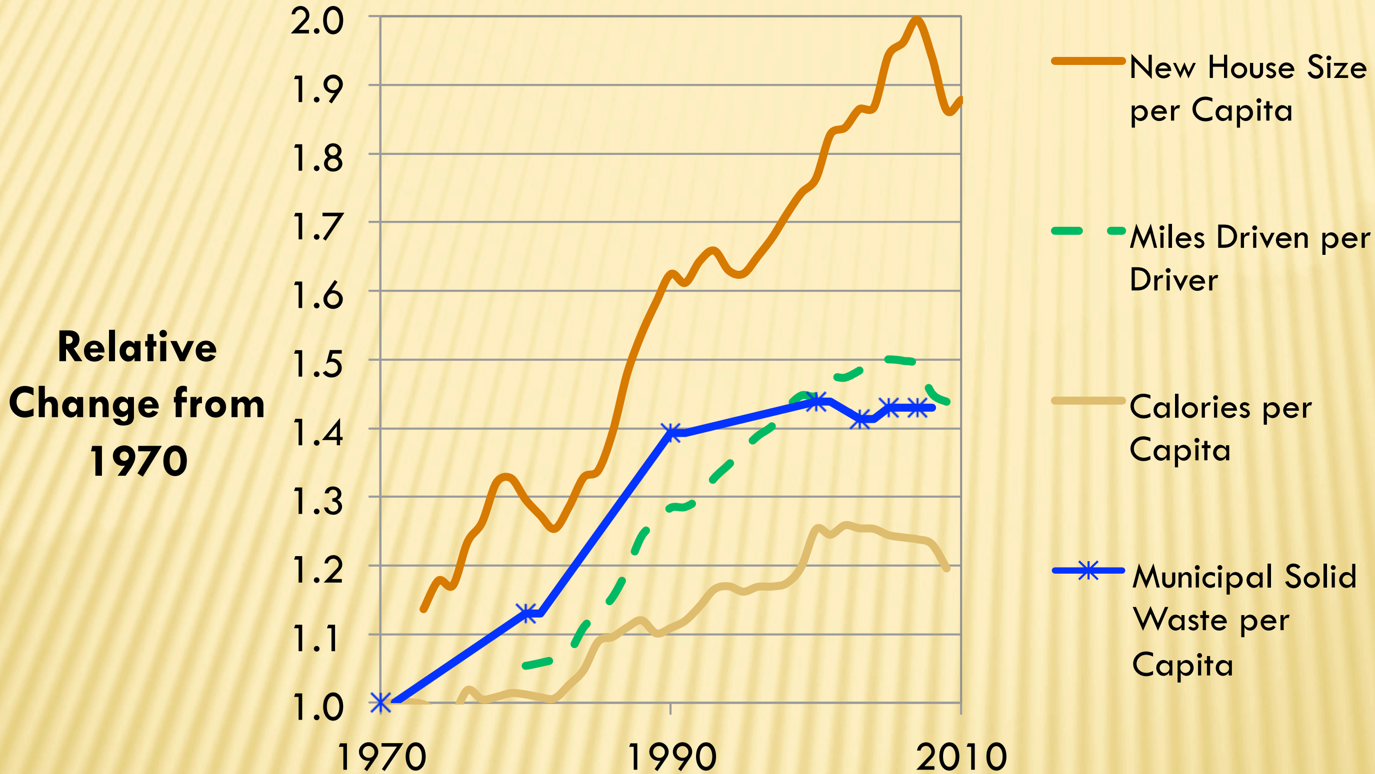





- **Up 88%**
- **Up 44%**
- **Up 20%**
- **Up 43%**

- *How do we reverse these trends?*

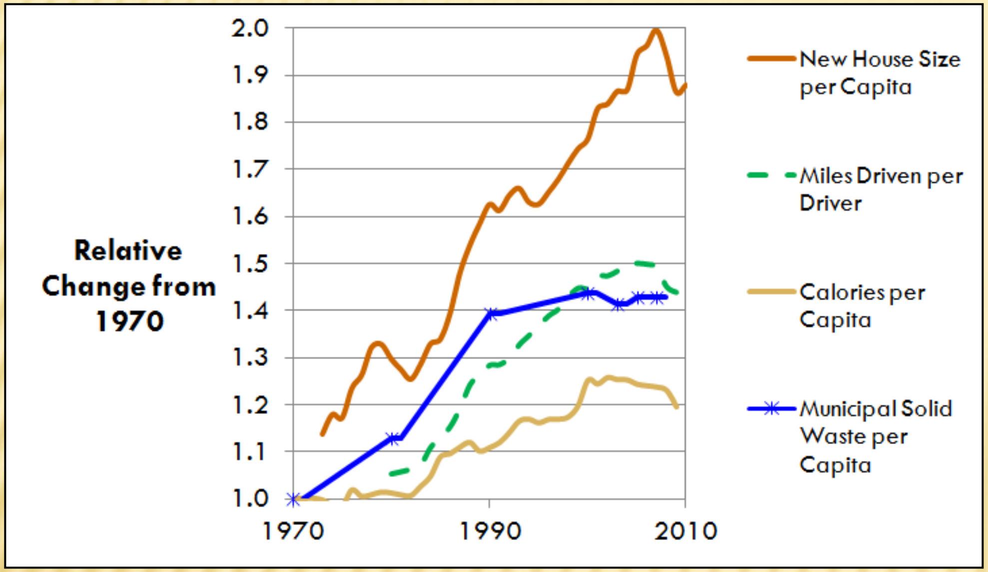
# INEVITABLE ESCALATION?



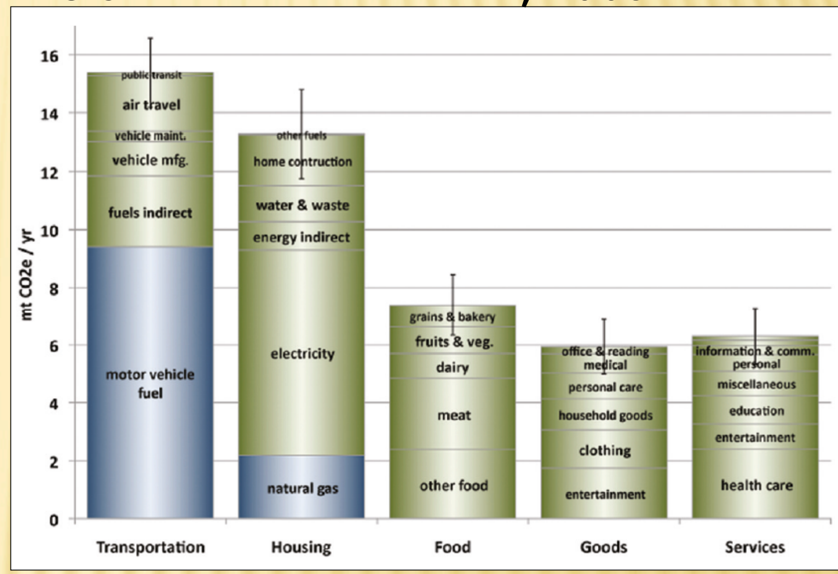

- Up 88%
- Up 44%
- Up 20%
- Up 43%

- Financial policy: New global financial regime in 1971 ended convertibility of dollar to gold with huge increases in fiat money and credit
- Public Health policy: Increase in calories linked to USDA guidelines (fat bad, guidelines since 1980)
- Health outcomes (heart disease, diabetes) are quantifiably worse as a function of density.

# A HEURISTIC FOR BEHAVIOR SAVINGS POTENTIAL (U.S.)




U.S. Household emissions, 2005




C Jones and D Kammen EST 2011

- Transportation and Housing are biggest contributors.
- What if demand were reduced to 1970 levels or halfway to 1970 levels?

# A HEURISTIC FOR BEHAVIOR SAVINGS POTENTIAL (U.S.)

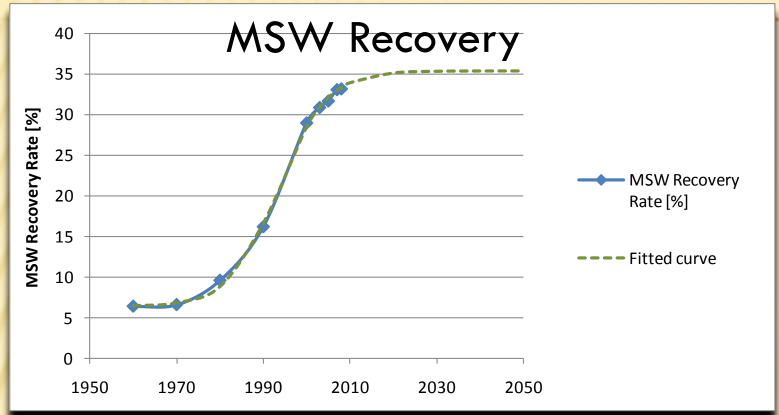


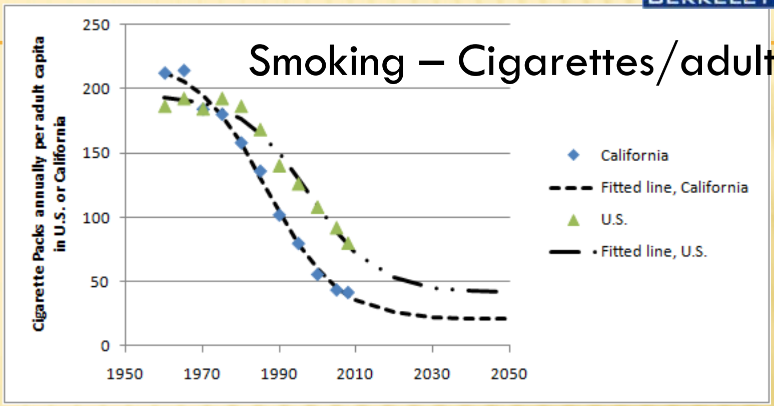
- $CO_2$ savings potential from behavior: 16-33%

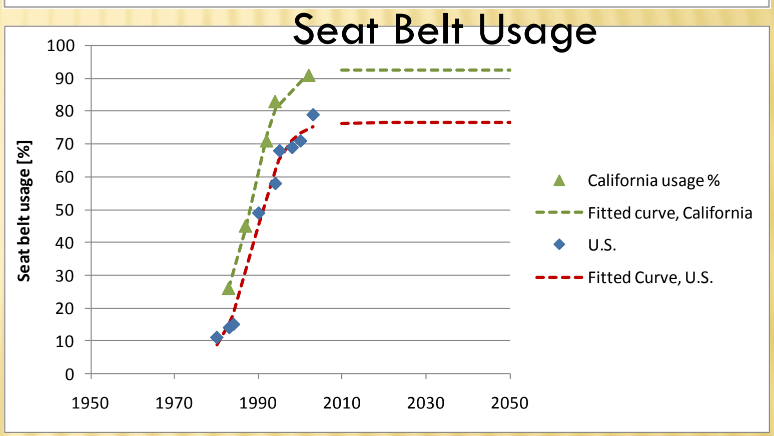
| Sector | Demand Proxy | Fraction of HH Emissions | $CO_2$/HH [tonnes] | Emissions after reduction to halfway of 1970 level | Emissions after reduction to 1970 level |
|---|---|---|---|---|---|
| Transport | VMT/cap | 32% | 15.3 | 12.9 | 10.6 |
| Housing | New house size/cap | 28% | 13.3 | 10.1 | 7.0 |
| Food | Calories/cap | 15% | 7.3 | 6.6 | 6.0 |
| Goods | MSW/Cap | 13% | 6.0 | 5.1 | 4.2 |
| Services | MSW/Cap | 13% | 6.3 | 5.3 | 4.4 |
| Sum | | 100% | 48 | 40.1 | 32.2 |
| Savings | | | | 16% | 33% |

# SOME HISTORICAL ADOPTION CURVES

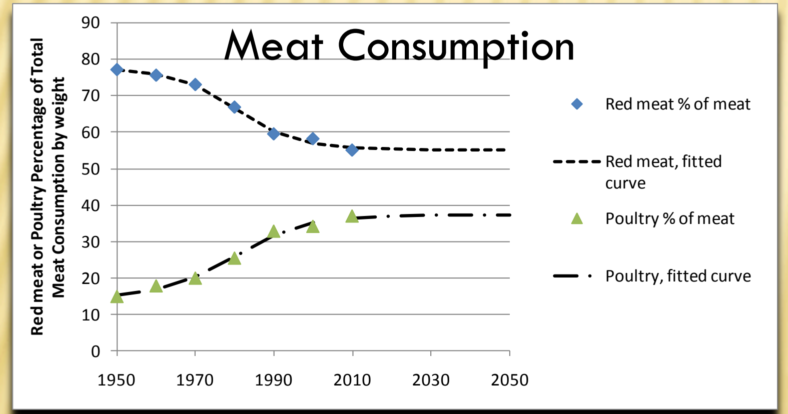


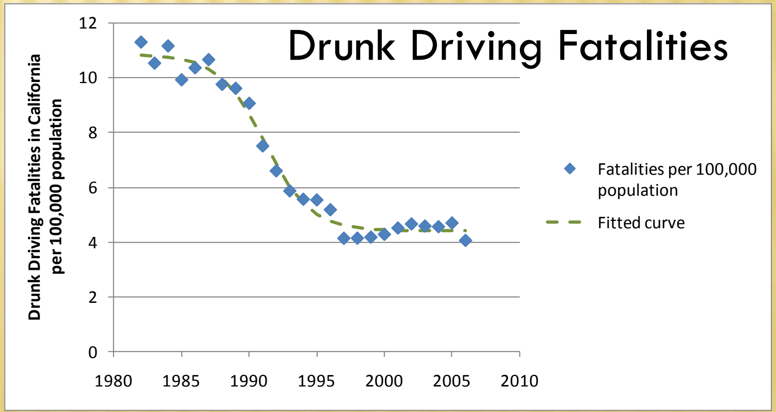


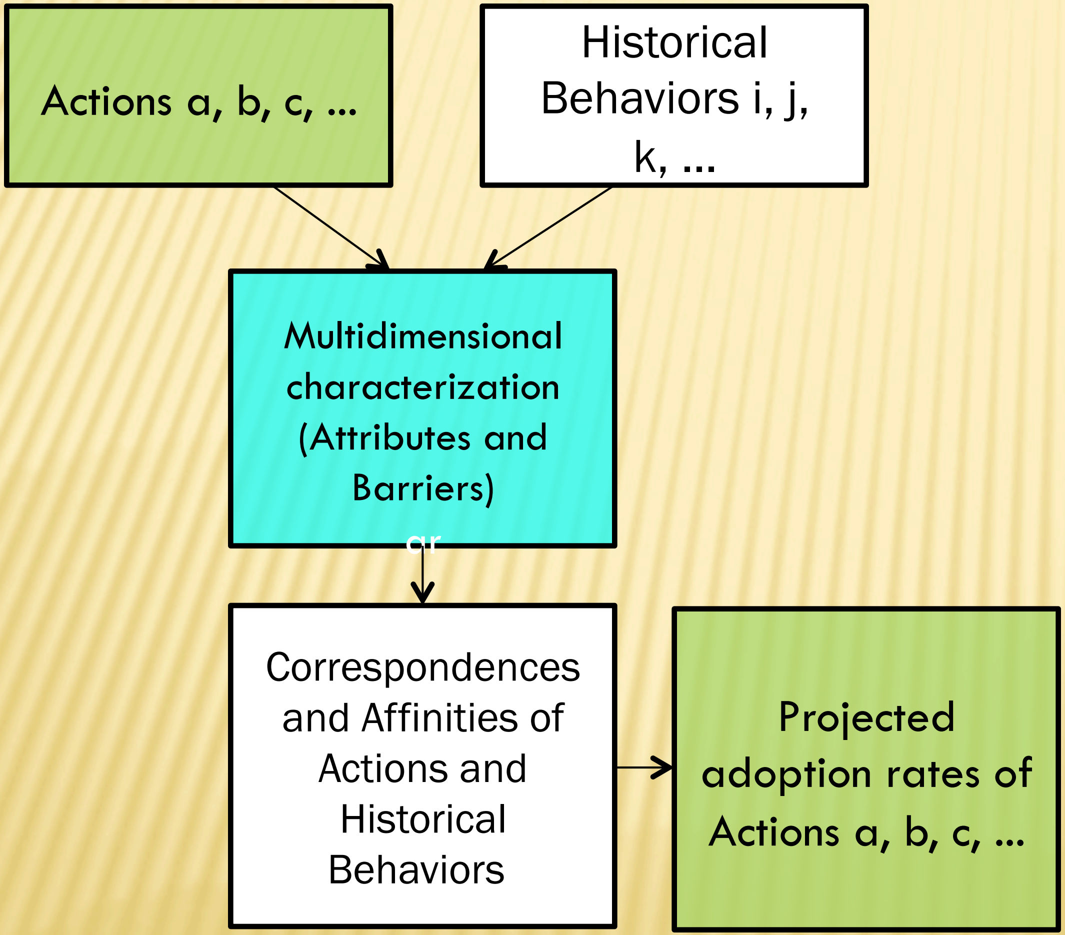

But per capita plastic generation up 50X from 1960 to 2008 (4.3lbs/cap to 197 lbs/cap)




Like Market adoption curves, so treat like market penetration problem

# ESTIMATION APPROACH FOR BEHAVIOR ACTIONS




Characterization attributes and barriers

| Characterization Feature | Description |
|---|---|
| Attributes | Visibility to Others |
| | Visibility of Benefits to consumer |
| | Ease of Substitution |
| | Ease of Behavior |
| | Feedback Visible? |
| | Enabling long term technologies? |
| | Enabling Policies, campaigns? |
| Barriers | Habit |
| | Indifference |
| | Info/Education |
| | Institutional/Cultural |
| | Risk Aversion/Safety |
| | Economic Cost |
| | Physical (Infrastructure) |
| | Labor/Inconvenience |
| | Lack of Incentive/Pleasure |
| | Climate/Weather |
| | Persistence/Stickiness |

# BEHAVIOR ACTIONS AND ADOPTION RATES, CALIFORNIA



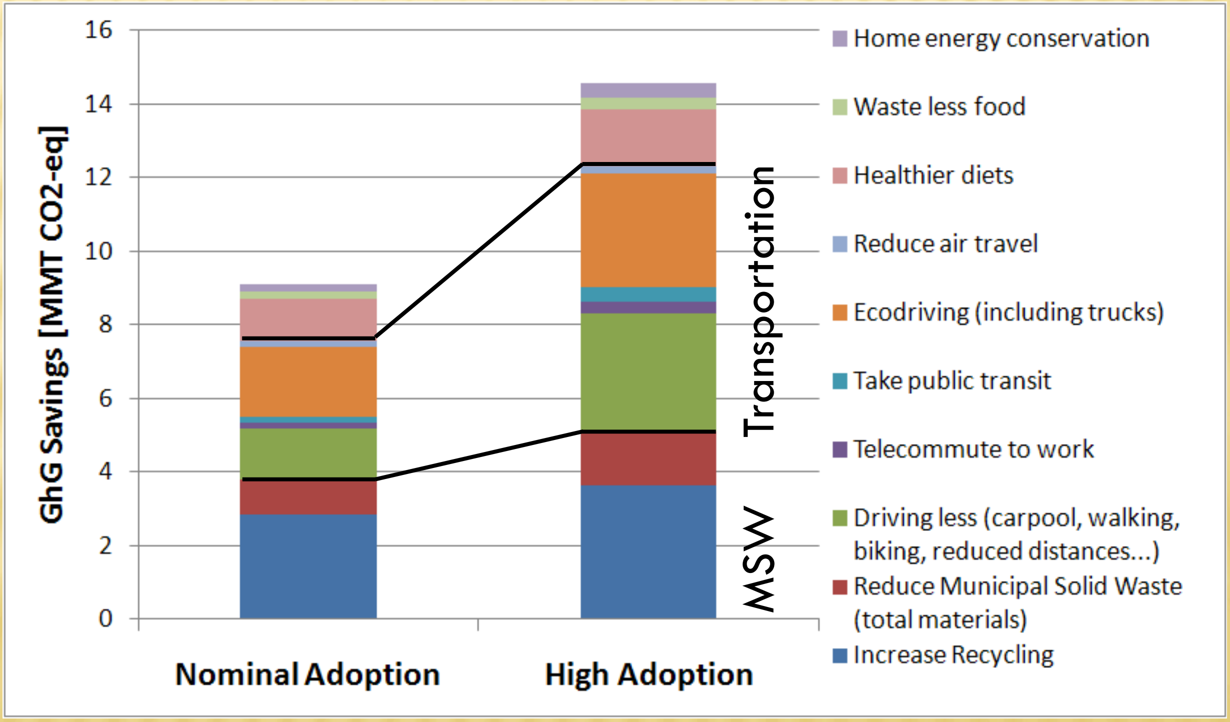
| Action | Starting Adoption Rate | 2050 Nominal Adoption Rate | 2050 High Adoption Rate | Change in Behavior |
|---|---|---|---|---|
| Increase Recycling | 54% | 80% | 90% | Full recycling |
| Reduce Municipal Solid Waste | 10% | 22% | 35% | 33% less waste |
| Drive less (carpool, biking, reduced distances...) | 15% | 16% | 37% | 30% lower VMT |
| Ecodriving (including trucks) | 16% | 50% | 80% | Lower top speed, reduce hard stops and starts |
| Take public transit | 6% | 22% | 35% | Overall public transit miles increase by 200% |
| Reduce air travel | 10% | 29% | 49% | Reduce air travel mile by 30% |
| Telecommute to work | 4% | 20% | 35% | Telecommute 4 days per month |
| Healthier diet | 10% | 28% | 37% | Less red meat and dairy, more plant based food |
| Waste less food | 10% | 12% | 20% | Waste 25% less food |
| Turning off electronics | 20% | 57% | 80% | Turn off electronics when not in use |
| Line dry clothes | 8% | 13% | 20% | Line dry clothes instead of dryer |
| Lower thermostat in winter | 53% | 69% | 80% | Turn down thermostat at night |
| Raise thermostat in summer | 68% | 83% | 87% | Higher daytime thermostat setting |
| Cold water clothes washing | 10% | 36% | 80% | Use cold water instead of hot water |

- Generally in-line with Dietz PNAS 2009 “daily, adjustment, maintenance” actions
- Cal climate differs from rest of U.S. in heating/cooling, so thermostat control less impact than rest of country

# 2050 BEHAVIOR SAVINGS POTENTIAL: CAL



- Transportation (Vehicle Mile) reduction and Recycling/reduced MSW are largest levers, then diet/food.
- 10-15% GHG savings potential



# BARRIERS TO BEHAVIOR CHANGE

- Existing metrics and policies
- Cultural / psychological
- Lack of ability (e.g. infrastructure)
- Convenience / Lack of time
- …

# OVERCOMING OVERCONSUMPTION

- Education: Ethics, Well-being (psychology/health/finances), Basic science and Technology, Humans in ecology, then Global Warming
- Price Signals and Policies: Pro-consumption to Pro- Community and Pro-climate
  - E.g. Integrated land and transportation planning (SB375)
  - Gasoline tax, junk food tax, environmental footprint charges (e.g. beef)
  - Transportation policies: congestion charges, dynamic parking meters
  - Repeal of mortgage income tax deduction
- New Metrics – Beyond GDP → GPI, social outcomes
  - How to define these for cities? Thrivability Indices
- Models of Change and Scalability
  - Units of change: Cities, institutions/organizations, families, individuals
  - Community engagement with peer support groups; Target early adopters
  - Offer an attractive message: get to know neighbors, community building, improved safety, disaster preparedness – not saving money or just global warming
  - Target holistic set of actions / seek to quantify and make benefits visible

# REASONS FOR OPTIMISM / PESSIMISM

- "**Never underestimate the power of a few committed individuals** to change the world. Indeed, it's the only thing that ever has."
  - – Margaret Mead
- Innovation is an inexhaustible resource
- To change the system, change the rules

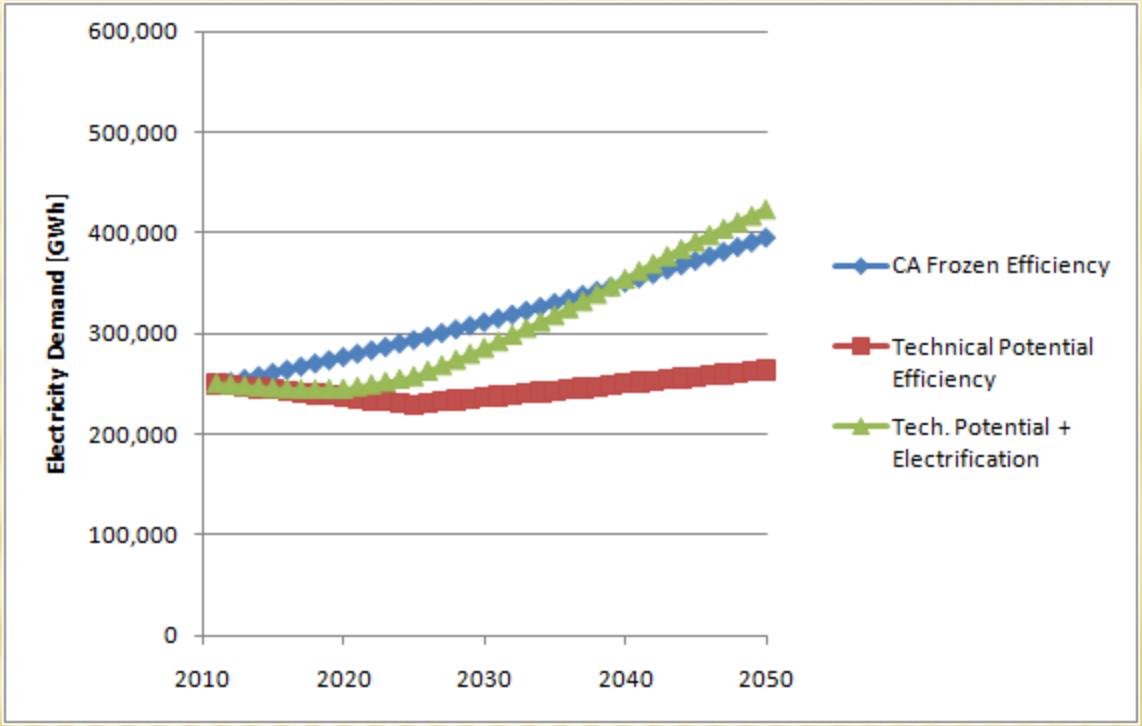
- Citizens of developing world emulating the American lifestyle
- U.S. Science and Technology: #48
- Political dysfunction and regulatory capture

# ENERGY SYSTEM MODELING

# Electricity System: SWITCH model
## (Solar, Wind, Hydro, and Conventional generators and Transmission)

- Optimization model calculates the lowest total system cost, given a carbon cost or energy policy
  - WECC region
  - Carbon CAP set at 80% lower than 1990 emissions
- Constraints to meet projected hourly electricity loads with reserve margin and other operational constraints.
  - Projected loads / load profiles based on base case and variants.
  - Maintains 15% reserve margin for reliability
  - Generator and transmission investments every 4 years
  - Generator and transmission dispatch hourly
    - Peak and median day of historical months from 2004 and 2005 and winter peaking days in base case.

# ELECTRICITY PROJECTIONS

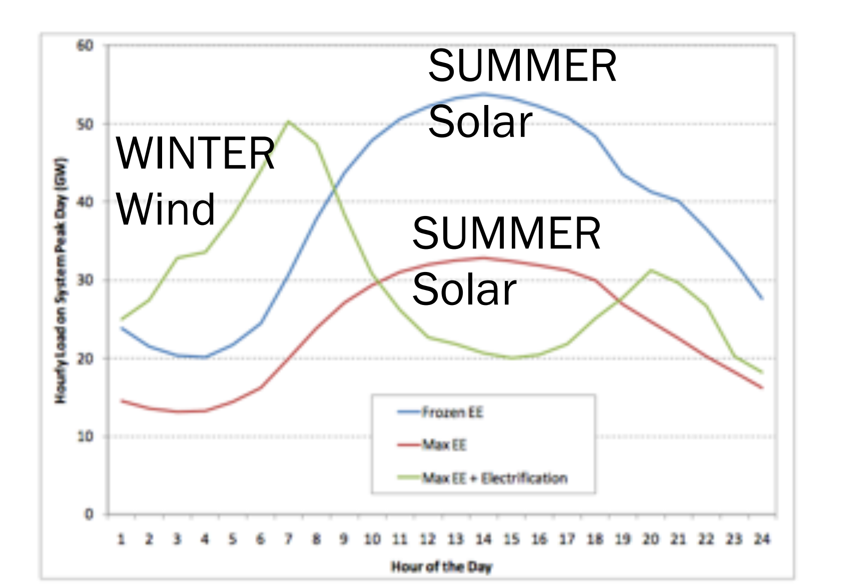



- California demand with maximal efficiency and electrification of vehicles and heat (green curve) about 1.7X higher than current electricity demand

# ELECTRICITY SYSTEM RESULTS

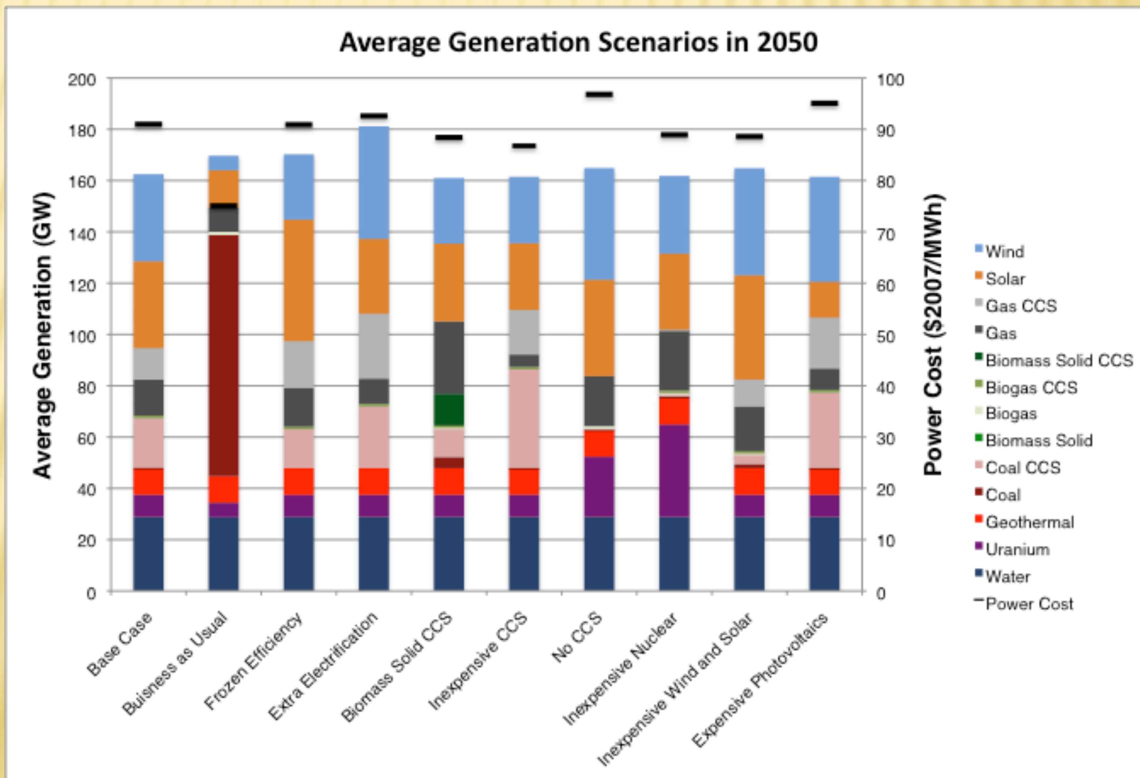
- Intermittent sources can contribute as little as one third or as much as one half of generated power economically by 2050 within WECC
- Optimal wind and solar deployment are a function of the temporal characteristics of the load profile, with increasing levels of vehicle and heating electrification favoring wind power over solar power.
- Increasing coordination in electricity planning and dispatch and over large areas allows the cost of electricity to stay relatively low, even with deep de-carbonization

Peak electricity demand shifts from Summer afternoon to Winter morning



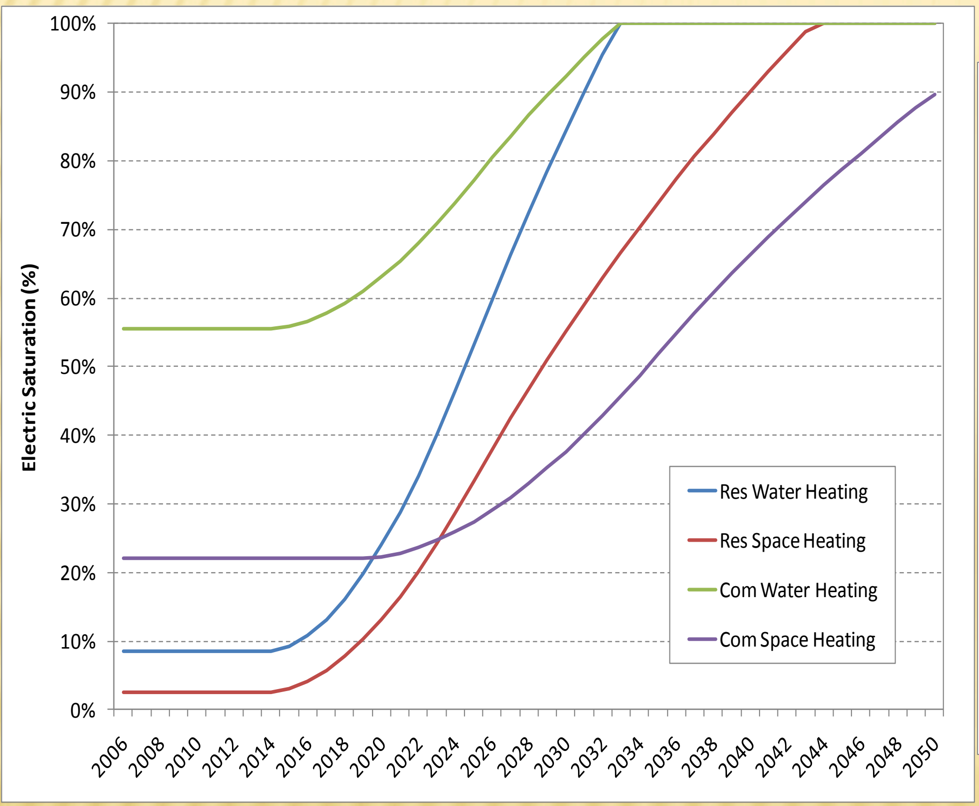
# ELECTRICITY MODELING OUTPUT

- Fairly tight band of power cost projected for various electricity supply mix scenarios

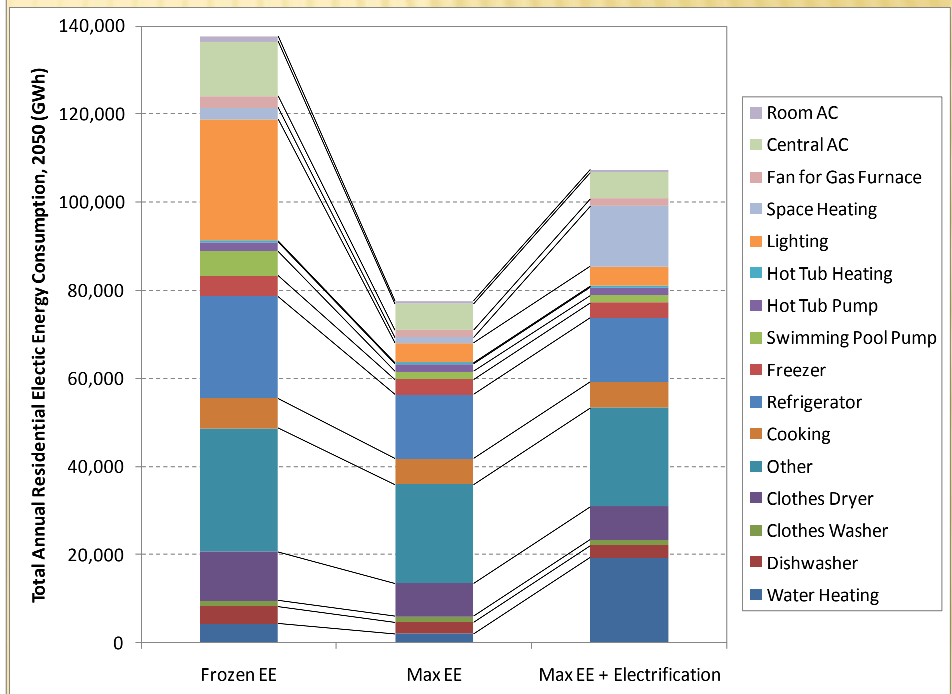


# BUILDING EFFICIENCY AND FUEL SWITCHING TO 2050

Fuel Switching rates assumed

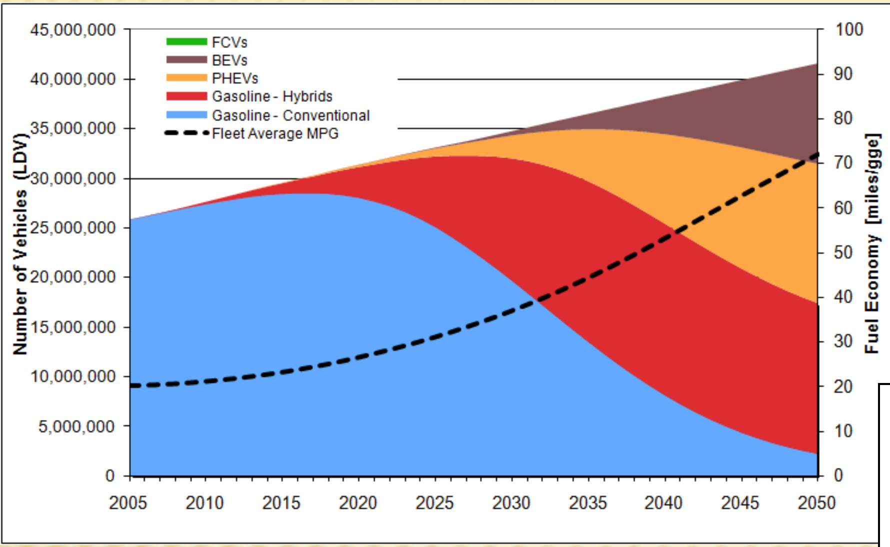



Residential End use in 2050 California



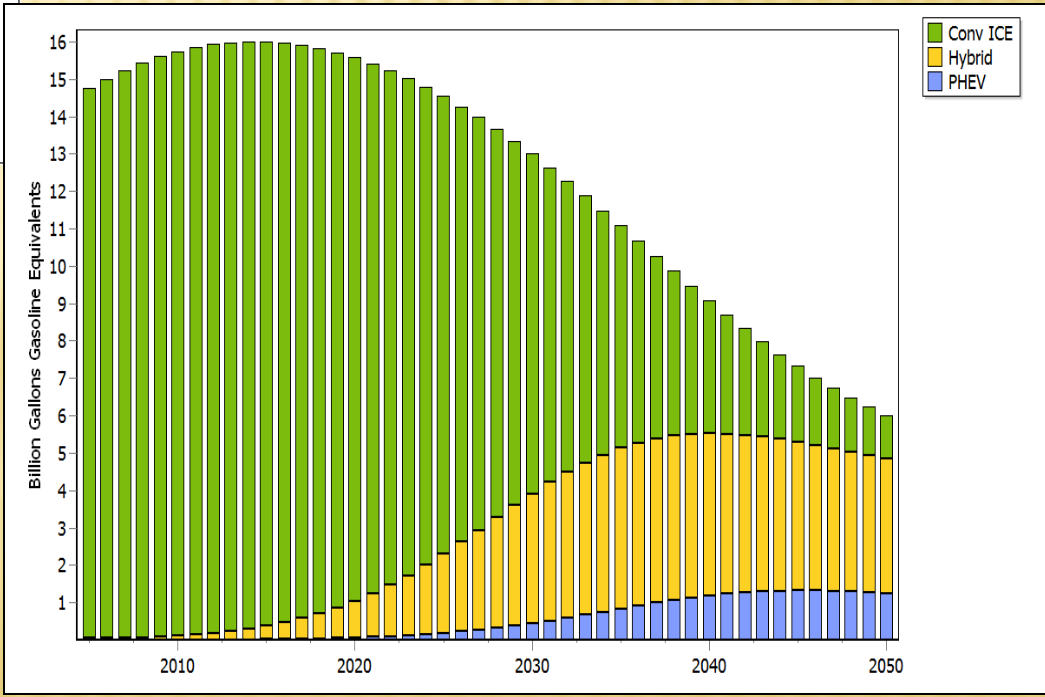

Space and water heating are electrified *(shift from natural gas)*

# TRANSPORTATION FUEL EFFICIENCY AND ELECTRIFICATION TO 2050




**Passenger vehicle adoption curves and fleet MPG (dotted)**

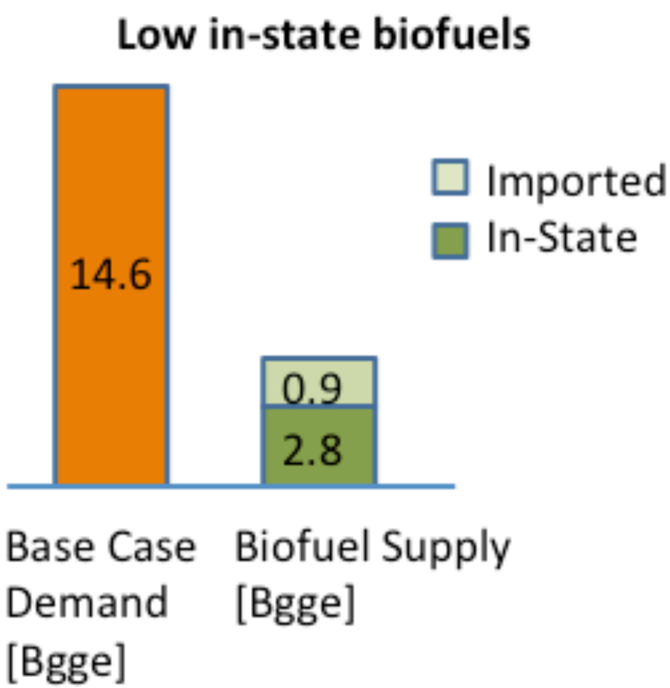
**Remaining Liquid Fuel**

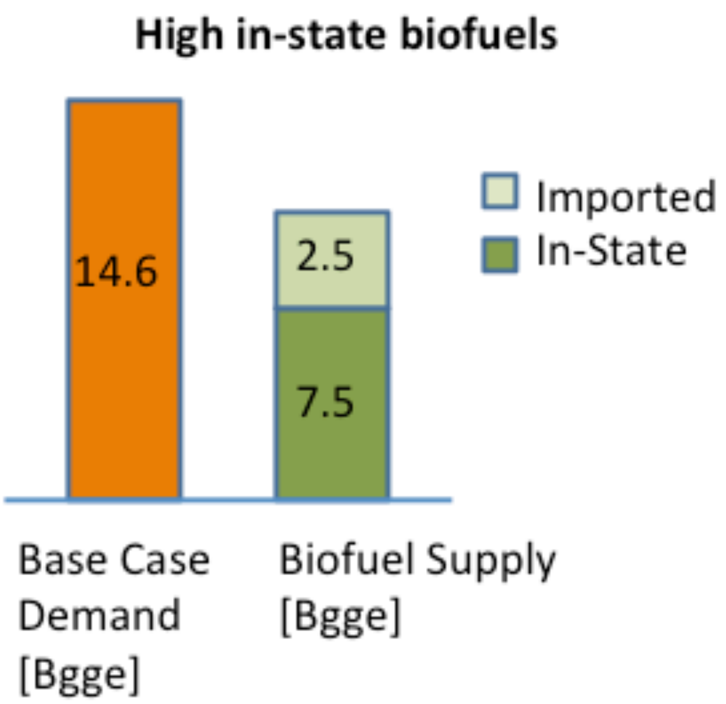



*45% of passenger vehicle miles are electrified.*

# Biofuels in 2050

- Biomass supply directed to biofuel since many technologies for clean electricity
  - 35 M dry tons in state near term estimate (2.8 billion gallons gasoline equivalent)
  - 95M dry tons "technical potential" (7.5 Bgge)
- Imports limited to 25% of California total per Executive order S-06-06 (2006)



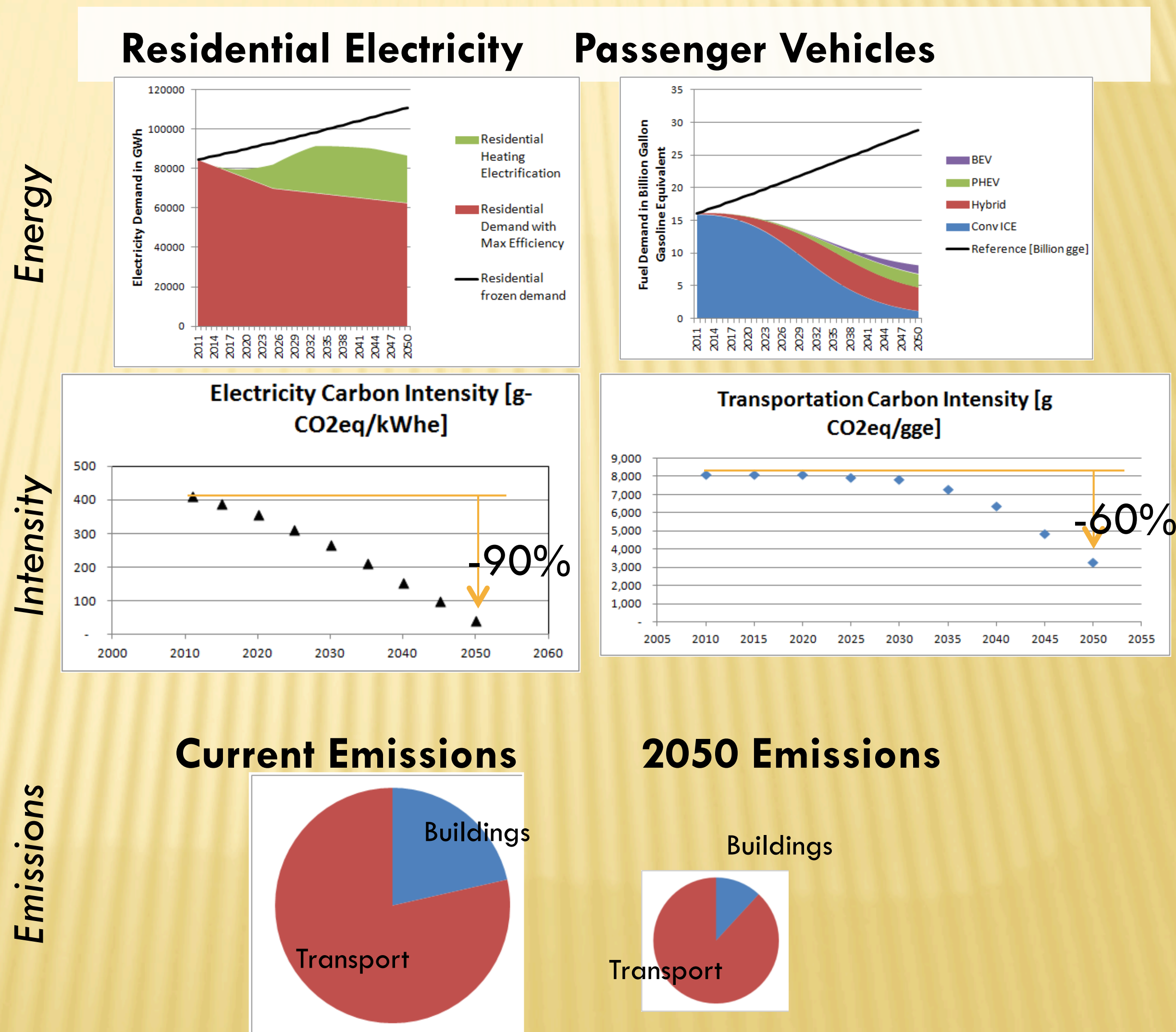




***Insufficient biofuel supply to replace Base case liquid fuel demand (15 Bgge)***

# CALIFORNIA BASE CASE: HOUSEHOLD ELECTRICITY AND TRANSPORTATION ENERGY, INTENSITY, AND EMISSIONS



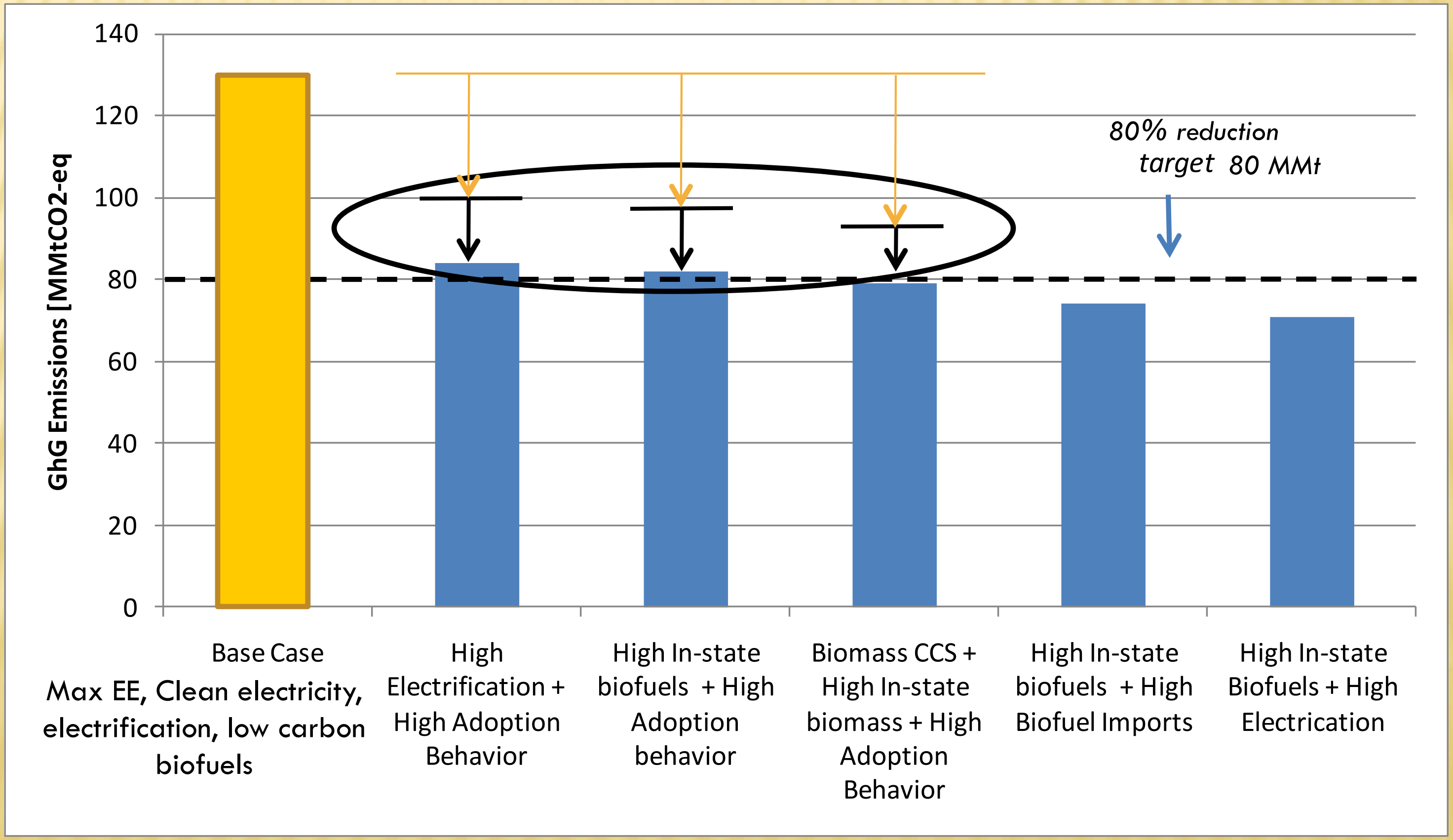
Key takeaways:
(1)Electricity pathway to 90% decarbonization, but transportation harder to decarbonize.
(2)Resulting emissions in 2050 are dominated by transportation



# SCENARIOS MEETING CALIFORNIA TARGET



- Behavior change can provide a key 10-15% contribution to meet long term 2050 target.

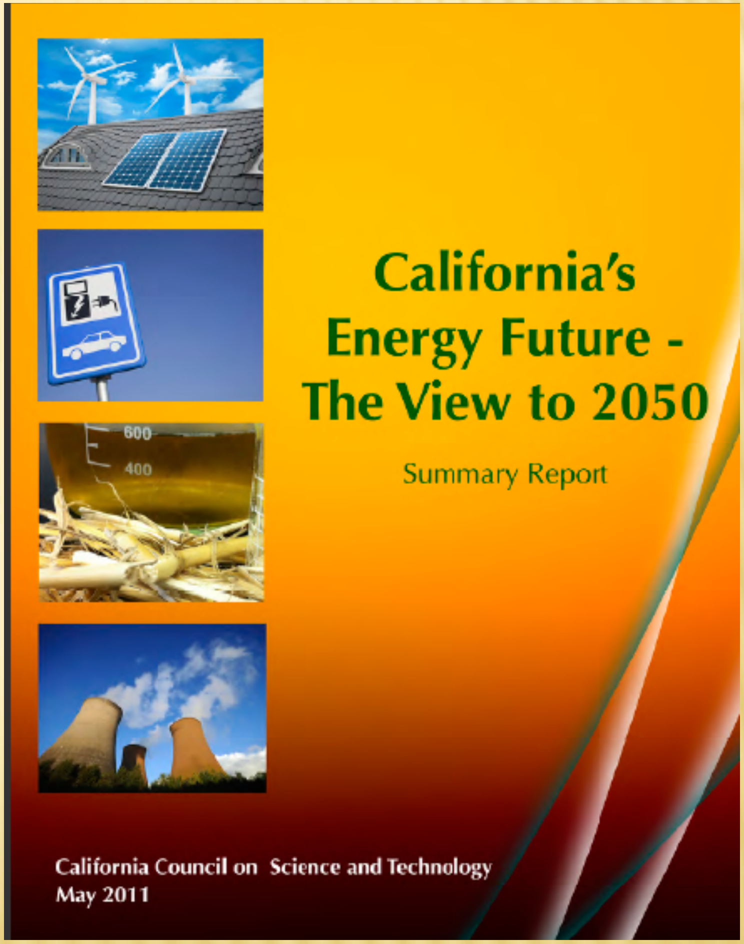


- ACKNOWLEDGEMENTS
  - Guido Franco, California Energy Commission

# BACKUP

# CALIFORNIA ENERGY FUTURE REPORT

- Sponsored by California Council of Science and Technology and California Energy Commission
  - Released May 2011
- Closely related but distinct from this work, which has not been published yet.



# BACKGROUND: SOME TYPES OF POLICIES

- Intensity standards
  - E.g. Renewable Power Mandates, also called Renewable Portfolio Standards
  - Low Carbon Fuel Standard
  - Energy efficiency standards [e.g. lumens/watt]

- Absolute targets
  - E.g. CO2-eq emissions, Cap and trade

Energy efficiency, in and of itself will not necessarily reduce emissions

e.g. own 2nd refrigerator;  build a 3000 sq. ft LEED platinum home

# BACKGROUND: GHG ACCOUNTING

1. Sectoral vs. Consumption
   - Electricity, Industry, etc. vs How much for food?
2. In-state vs Embodied emissions (e.g. goods)
   - Domestic manufacturing vs Imported cars
3. Direct Emissions vs Life Cycle Accounting
   - Car tailpipe exhaust vs Full life cycle of bio fuel
4. In-state vs Interstate (Transportation)
   - Passenger vehicles vs interstate, int'l air, shipping

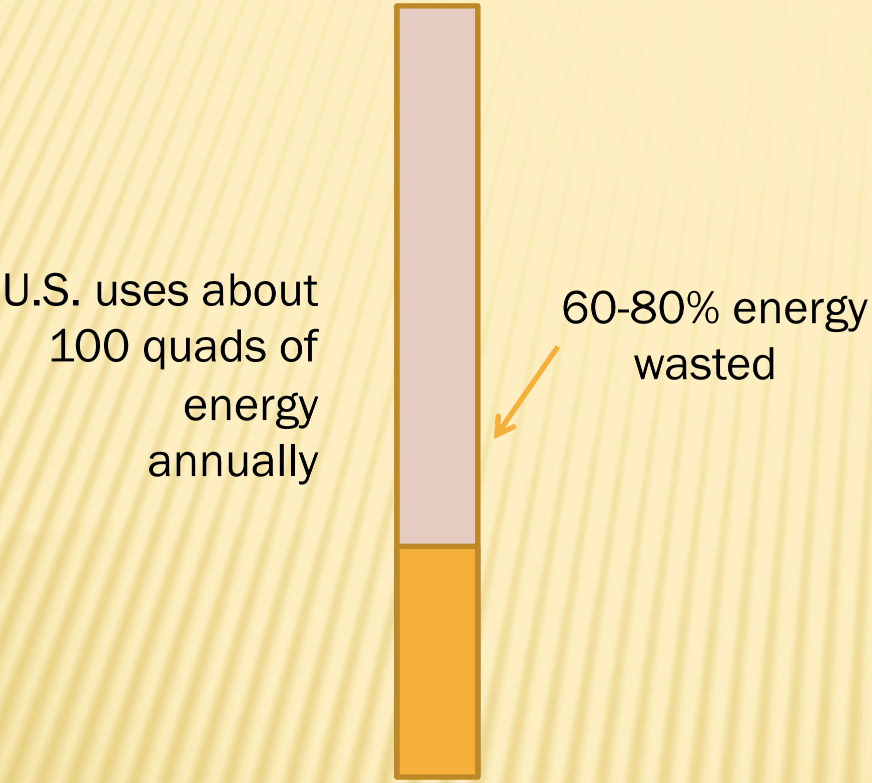
GHG accounting non-trivial – our estimates "incomplete" (2,3,4), estimates evolve as regulatory agencies grapple with these issues

# BACKGROUND: GHG ACCOUNTING

1. Sectoral vs. Consumption
   + Electricity, Industry, etc vs How much from food?
2. In-state vs Embodied emissions (e.g. goods)
   + Domestic manufacturing vs Imported cars
3. Direct Emissions vs Life Cycle Accounting
   + Car tailpipe vs Full life cycle of bio fuel
4. In-state vs Interstate (transportation)
   + Passenger vehicles vs interstate, int'l air, shipping?

Conforming to state conventions, Cal Air Resources Board (ARB)

# BACKGROUND: TOTAL ENERGY CONSUMPTION IN U.S.




- About eight times higher than energy for HDI 0.8 countries (e.g. Eastern Europe)
- 60-80% of energy is wasted (efficiency opportunity)

# BARRIERS TO EFFICIENCY IN BUILDINGS AND INDUSTRY

**Table 10. Barriers to building efficiency improvement**

| Barrier | Examples | Possible mitigation strategies | Level of difficulty |
|---|---|---|---|
| Cost | Retrofit cost prohibitive | Increased adoption will lower costs | Medium |
| Labor | Trained workforce in short supply | Increased vocational and architectural school training, on-the-job training, increased public awareness and support | Medium |
| Lack of confidence, belief in efficiency benefits | Few examples of success, and high variability among existing programs | Adoption of best practices; improved data collection; new financing mechanisms to shift risk from consumer to builder (possibly with public subsidy) | Easy-Medium |
| Financing | Limited financing for efficiency improvements | Greatly expanded, long-term financing options; long-term (permanent?) public commitment to subsidize efficiency | Medium |
| Public policy – new construction | Current new building codes weak | Aggressive new construction building codes | Medium |
| Public policy - retrofits | Current existing building codes weak; retrofit programs overwhelmingly voluntary | Aggressive existing building codes coupled with strong requirements for compliance at time of sale and/or permit | Medium-Hard |

**Table 14. General barriers for industrial efficiency improvements**

| Barrier | Applica-bility | Example | Mitigation | Difficulty to Overcome |
|---|---|---|---|---|
| Risk Aversion | General | Many examples of decision not to change process despite significant projected savings (glass, food) | Establishment of more advanced technology and electro-technology application centers for demos and pilots<br>Increased funding for industry specific guidebooks and training<br>Establish target levels of energy intensity with threat of penalties/tariffs or voluntary agreements | High |
| Elevated hurdle rate and high transaction costs | General | Many examples of decision not to change process despite significant projected savings (glass, food) | Energy management practices/ training<br>Emerging energy management standards ISO 50001<br>Energy assessment/training<br>Incentives and grants<br>Voluntary agreements | High |
| Competition for Capital | General | Limited capital among marketing, sales, manufacturing, R&D, and other functions. | Safety and compliance are number one priorities for capital within each industry business, so tighter climate policies required. | High |
| No organizational structure to manage energy use. | General | Operations budget separate from capital allocation budget; Competition for capital | Energy management best practices, systems<br>Monitoring/Verification/Records of energy savings<br>EMS/Energy Manager system integration | High |
| Lack of understanding or capability on how to implement energy | General | Facilities which lack engineering support for monitoring/redesign | Protocols for System Assessment<br>Protocols for Monitoring & Verification<br>CEC/SEP Certification programs<br>Training for Implementation and Inspection | High |

**Table 15. Electrification barriers.**

| Barrier | Applicability | Example | Mitigation | Difficulty to Overcome |
|---|---|---|---|---|
| Highly integrated existing systems | Industry Electrification | Petroleum refining/ petro-chemicals | Incentives for new plant design with lower energy intensity | High |
| Economic: energy cost | Industry Electrification | Cost of electric heating higher than gas heating | Minimum carbon price for greater certainty<br>Establishment of more advanced electrotechnology application centers for demos and pilots | High |
| Economic: capital cost | Industry Electrification | Microwave heating systems more expensive than fuel systems | Incentive programs, government/industry partnership for higher end use efficiency<br>Rebates to mitigate higher capital costs | High |
| Procurement and Distribution availability | Industry Electrification | Lack of off-the-shelf electric equipment but availability of fossil fuel dryer (food sector) | R&D targeting advanced electric heating technologies | High |