

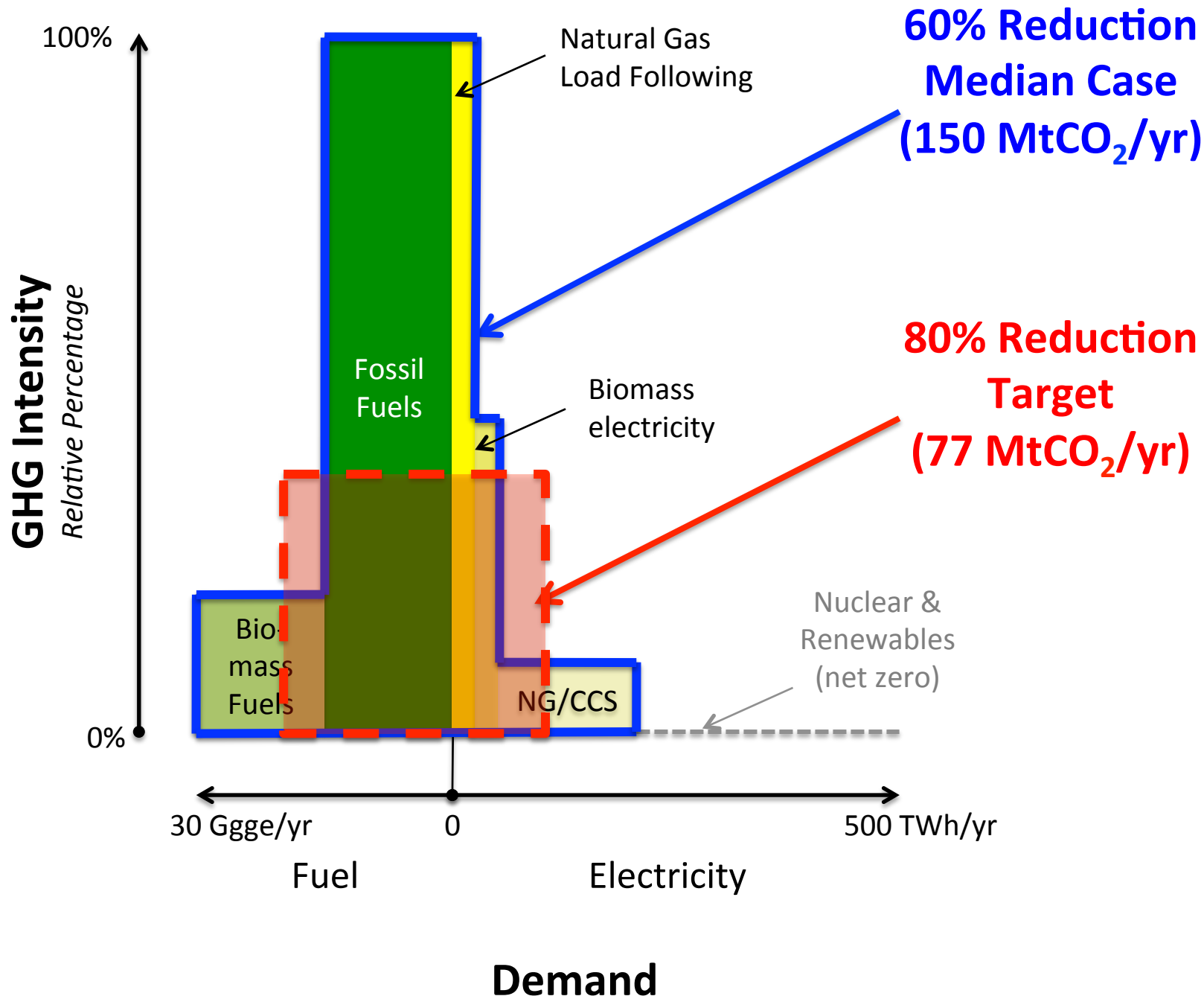


***Mobile Sources in
California's Energy Future:***
Getting to 80% GHG Reductions
Through Electricity and Fuels Strategies

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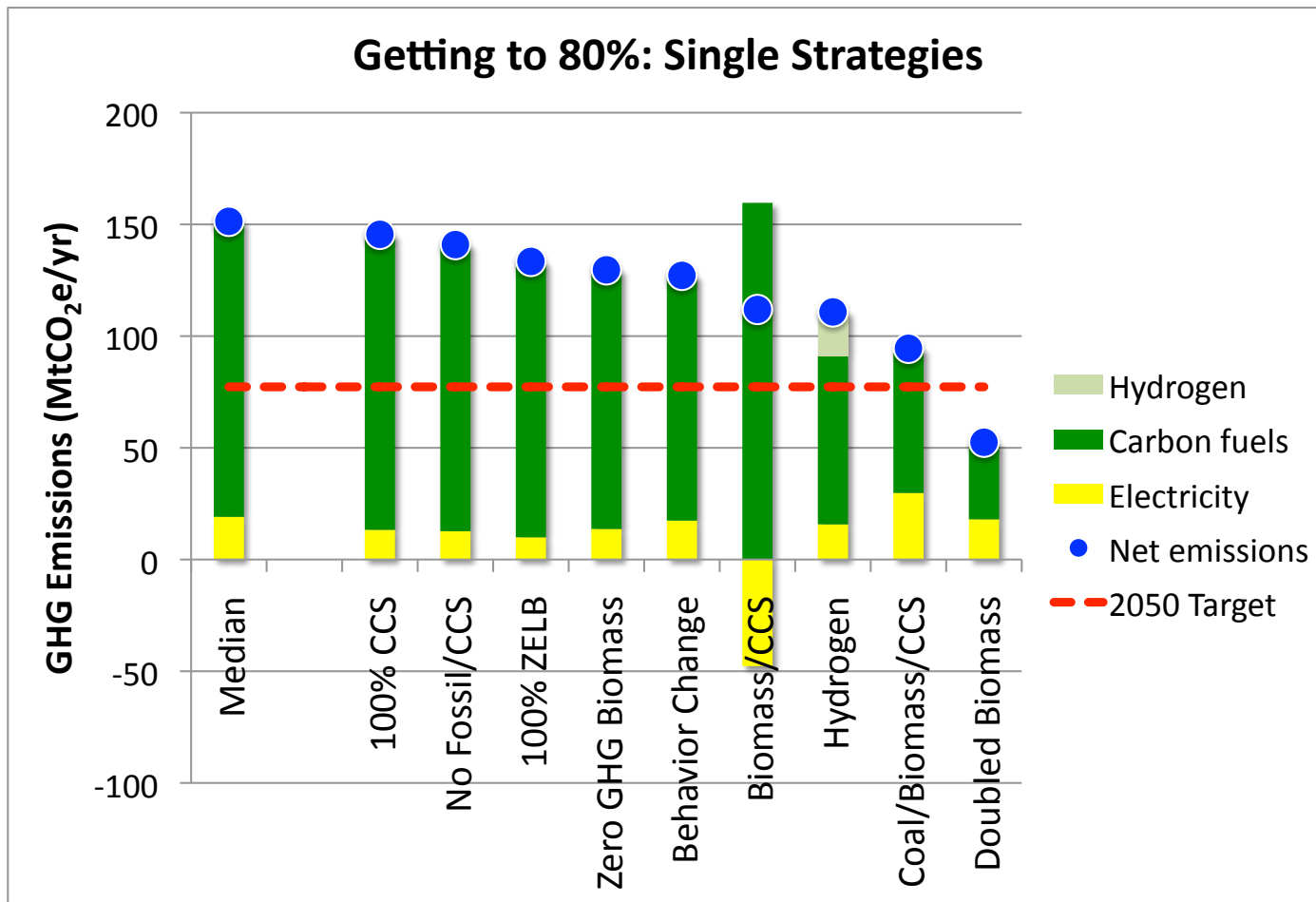
Presentation to CARB, CEC and CPUC staff
CalEPA Building, Sacramento, CA
15 July 2011



Strategies for Getting to 80%

	<u>GHG Impact</u>
1. 100% effective CCS	Small
2. Eliminate fossil/CCS (use nuclear instead)	
3. 100% ZELB for load balancing	Moderate
4. Net-zero GHG biomass	
5. Behavior Change (10% reduction in demand)	
6. Biomass/CCS (20% of electricity, offsets fuels)	
7. Hydrogen (30% replacement of HC fuels)	
8. Biomass/Coal/CCS (make fuels + electricity)	Large
9. Double biomass supply	
10. Fuel from sunlight (need net-zero carbon source)	Trans- formative
11. Fusion electricity	
12. Others?	

Getting to 80%: Single Strategies from the Median Case



100% Effective CCS?

Capture technology	Main constituents	CO ₂ capture limit
Post-combustion	CO ₂ (dilute), N ₂ , O ₂ , H ₂ O	~90%
IGCC pre-combustion	CO ₂ , CO, CH ₄ , H ₂ S	~92%
Oxyfuel combustion	CO ₂ , O ₂ , H ₂ O	96-99%

Conclusions:

- >90% capture is costly, >95% is very costly
- 100% capture is unlikely without breakthroughs
- Would not save much CO₂ in median case (6 MtCO₂/yr)

But:

- **Important incremental savings in CCS-heavy cases**
(**fossil/CCS**, **biomass/CCS**, **biomass/coal/CCS**, **Nat. gas H₂**)

Elimination of CCS



- Slightly greater CO₂ savings than 100% CCS (due to reduced refining emissions), but:
- CCS is probably needed for more than fossil electricity production, so unlikely to eliminate, unless technically- or cost-prohibitive

100% Zero-Emission Load Balancing

Questions:

- How much ZELB is actually required for each scenario?
- How much flexible load capacity is there, and at what cost? What can spur adoption & investment?
- Energy storage is likely to be “backstop” technology, unless costs beat spinning reserves and/or peak generation with natural gas. Are current RD&D investments sufficient?
- Can storage efficiency be increased?
- How do we solve the “GW-day” problem?
- Can gas turbines be cost-effective with CCS?



VRB Power Systems flow battery

Net Zero GHG Biomass

- Can lifecycle costs be reduced to zero?
- 22 MtCO₂/yr savings over median case
- Important to reduce net emissions from where they are today (>50% of fossil fuels), but not so critical to reduce below ~20%.
- Research questions:
 - Can we produce a cost curve for net GHG biomass emissions?
 - Given other energy component strategies, what is a reasonable net GHG biomass target?

Behavior Change

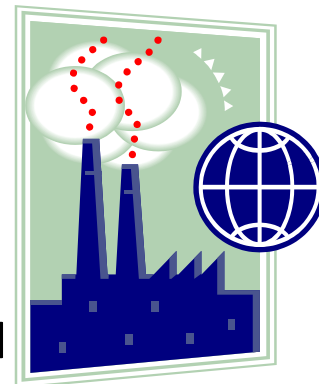


- Many behaviors identified to reduce energy use in the 10-20% range:
 - Greater extremes in variables, including building & water temperatures, light levels, moisture content, etc.
 - Right-sizing of homes, appliance capacities, etc.
 - Trading time for convenience, e.g., “smart” wash cycles
 - More use of manual/“natural” effort, e.g., manual egg beaters, air-drying clothing, playing the guitar instead of watching TV, biking vs. driving
 - Lifestyle decisions regarding location, degree of privacy (detached vs. shared home), car ownership/use (big impact on transportation energy)
- Technology-enablers important, such as room dependent space conditioning and occupancy sensors
- 24 MtCO₂/yr savings from median case with ~10% demand reduction

Behavior Change



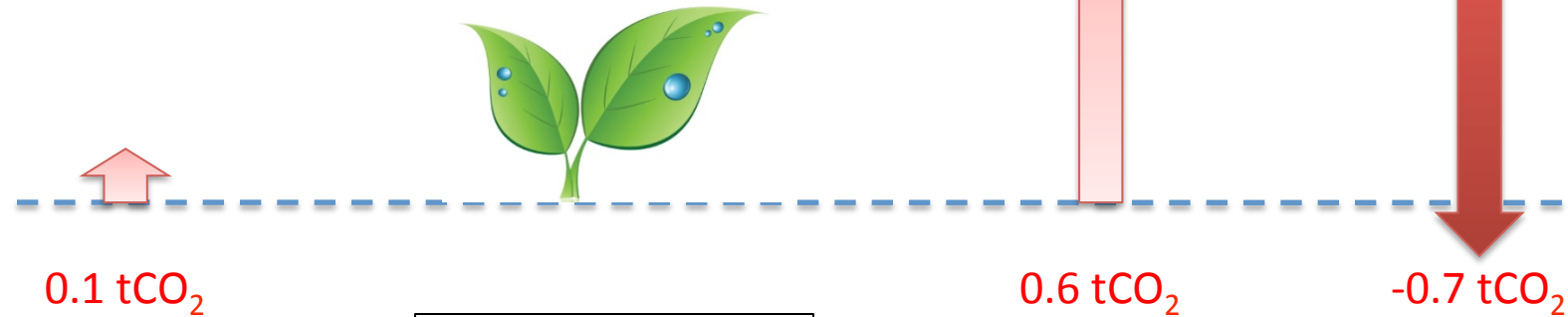
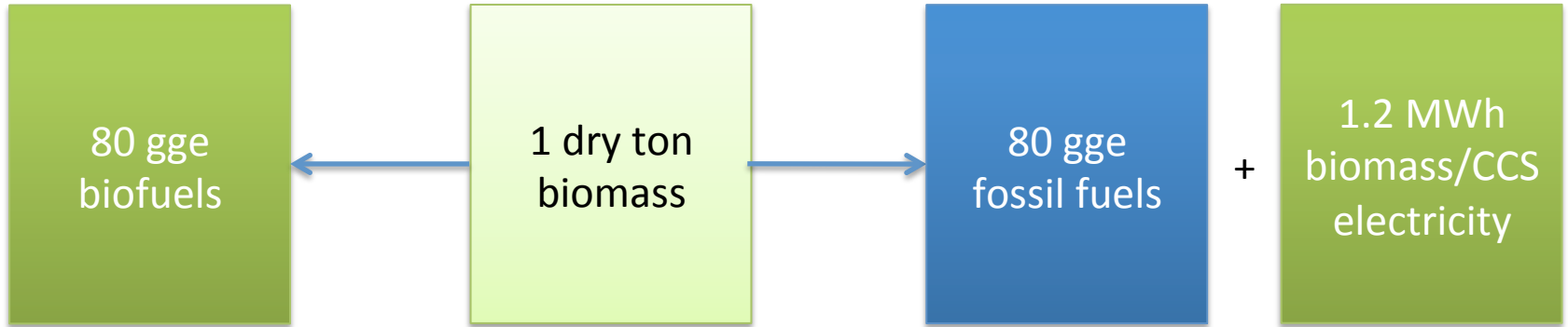
- New research (CEC grant to LBNL) finds that:
 - Behaviors targeting fuel use (e.g., transportation) have larger GHG savings, so policy may choose to focus on these
- Industrial “behavior”:
 - Less raw materials to produce the same products
 - More integrated products to reduce total number produced
 - Longer-lasting products; longer product design cycles
 - Design for ease of recycling or re-use
 - Use of less energy-intensive materials (e.g., composite replacements for steel); minimize packaging
 - Change from consumer ownership to rental/service model



Biofuels

vs.

Biomass/CCS

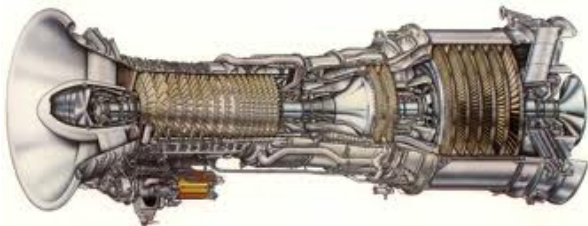


Net GHG:
0.1 tCO₂

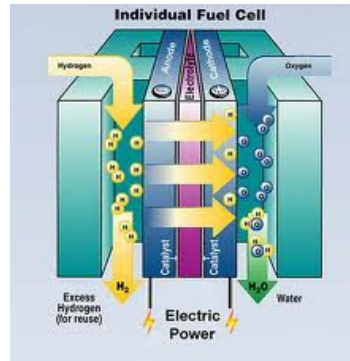
39 MtCO₂/yr
savings over
median case

Net GHG :
-0.1 tCO₂

Hydrogen



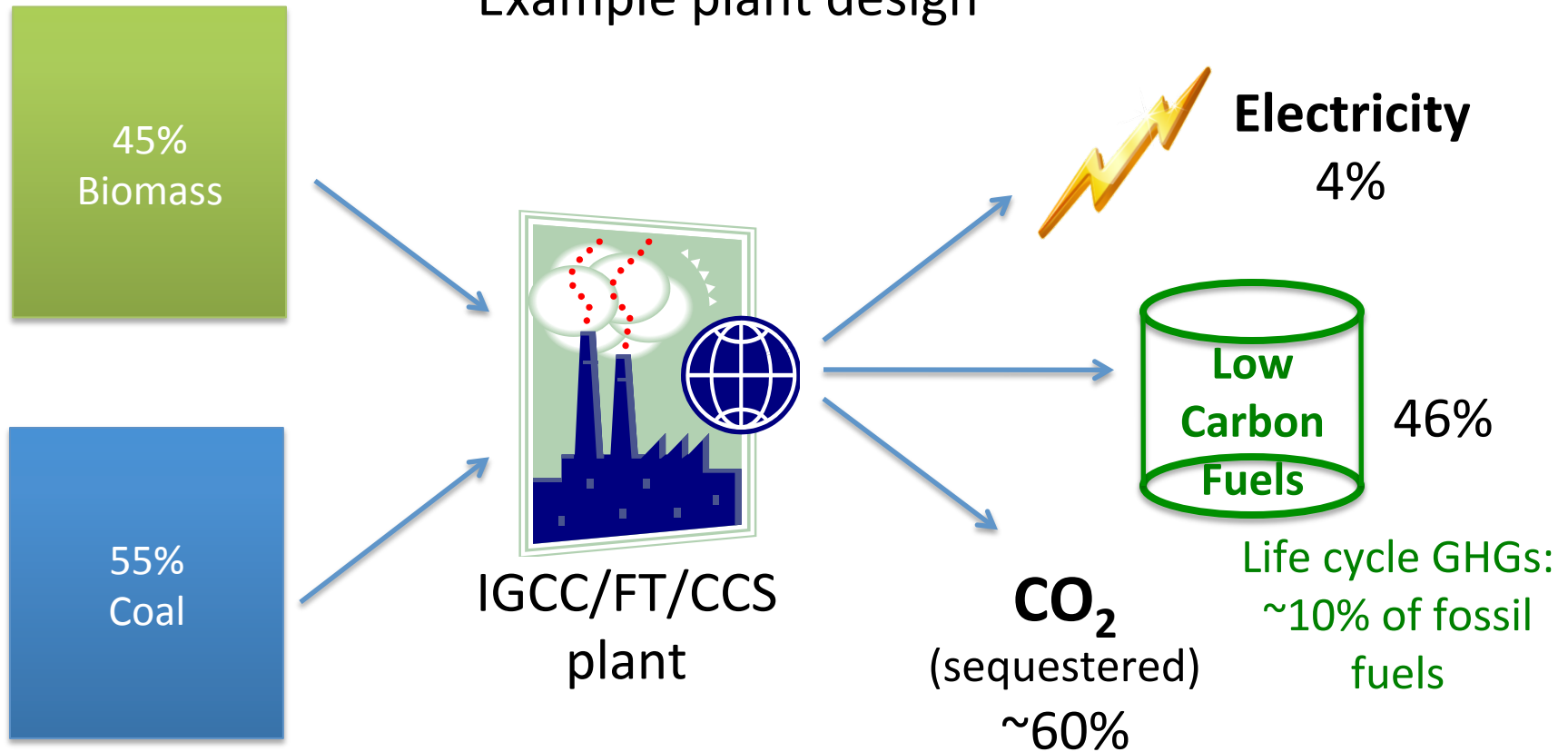
General Electric LM2500 Gas Turbine



- CEF assessment of primary roles for H₂:
 - Light-duty vehicles (22%)
 - Some heavy-duty transport (9% trucks, 100% buses)
 - Industrial heat (21%)
- Production options:
 - Electrolysis: very expensive, unless done at high-temperature
 - Thermochemical from coal or natural gas with CCS
- 40 MtCO₂/yr savings over median case
- Research questions:
 - When is hydrogen “better” than electrification or biofuels?
 - Can hydrogen be used in heavy-duty transportation, e.g., airplanes (Jacobson & Delucchi, *EnPol*, 2011)?

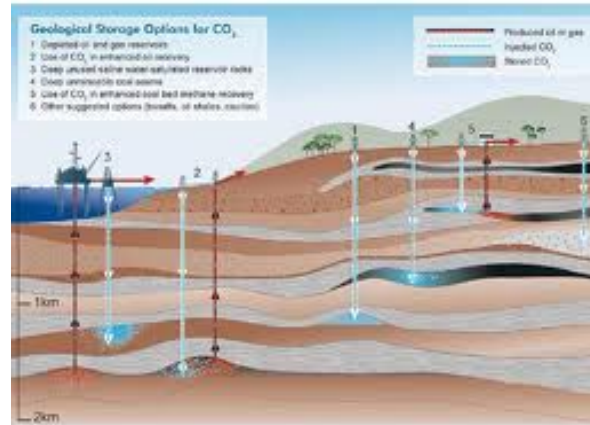
Biomass and Coal with CCS

Example plant design



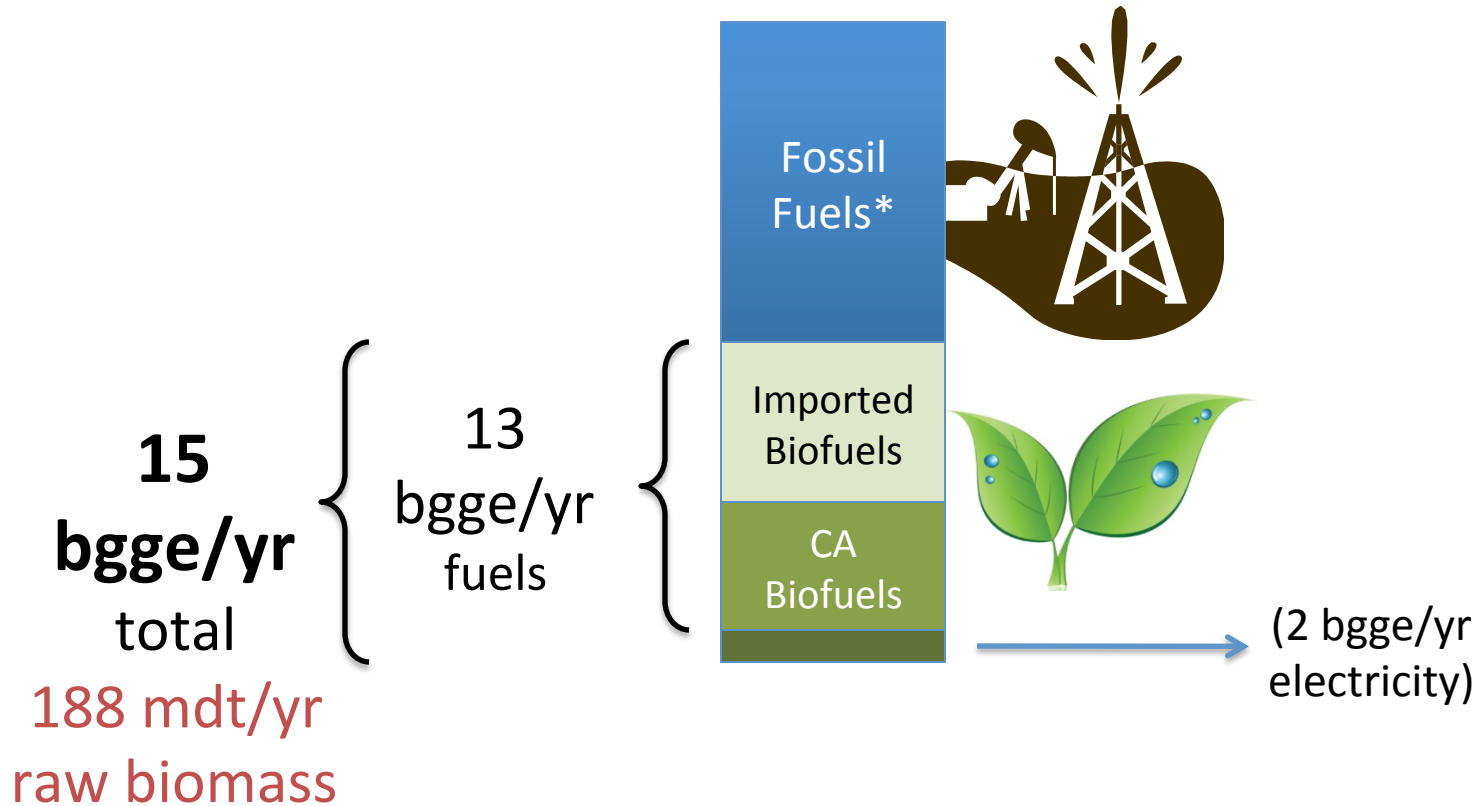
94 mdt/yr biomass → 12-15 bgge/yr fuels
56 MtCO₂/yr savings

Central Role of CCS



- Huge enabler of:
 - Fossil electricity, including possibly natural gas turbines
 - Biomass electricity to offset fossil fuel in transport
 - Fuel production from biomass + fossil
 - Hydrogen production
- Research needs:
 - Legal resolution of CO₂ responsibility (federal issue?)
 - Resource assessment in oil/gas reservoirs & saline aquifers, both inside and outside CA
 - Economic assessment of best role & locations for CCS
 - Membrane capture, IGCC, oxyfuel technologies
 - Pilot plants needed (2 PIER-funded projects underway)
 - Value of >90% capture?

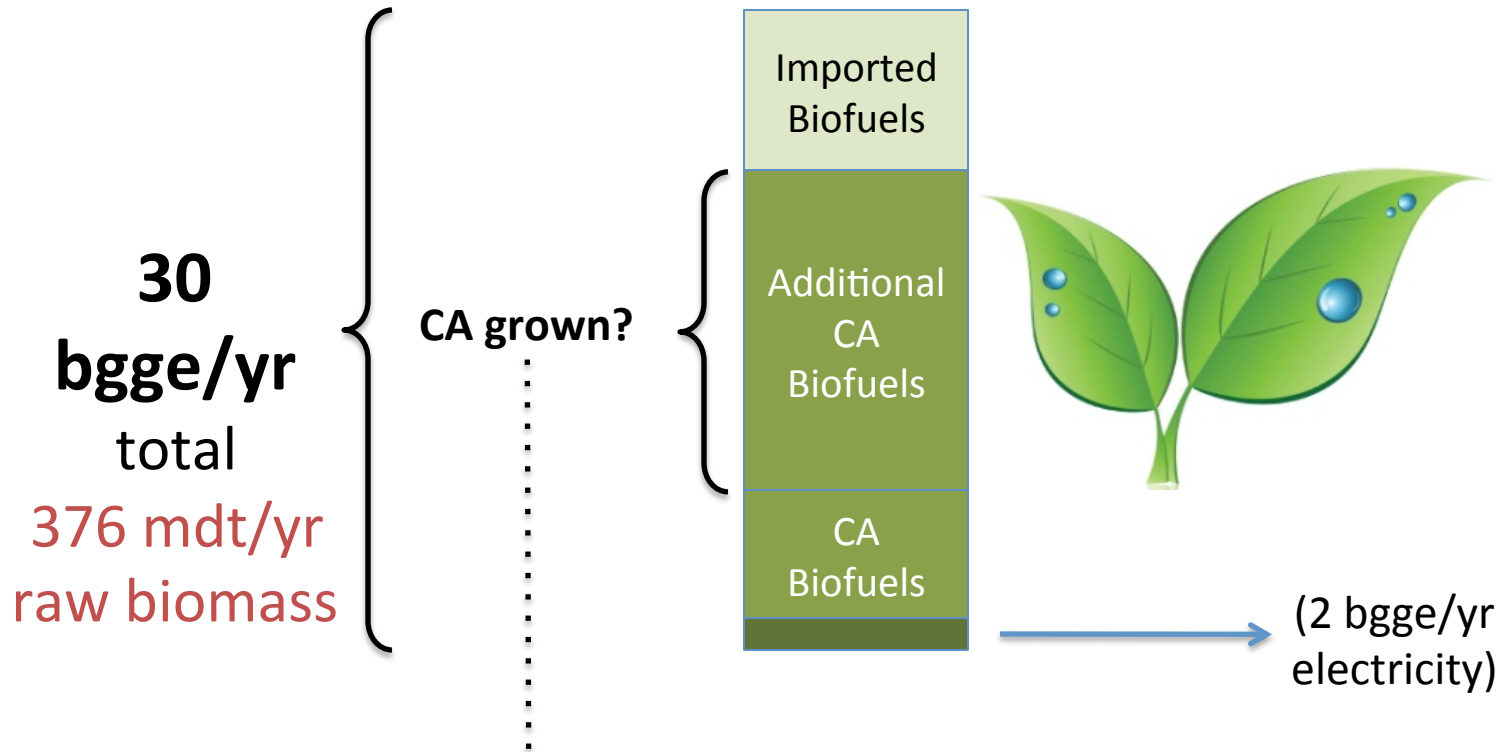
Doubling Biomass Supply



Median case

*Not including natural gas for CCS

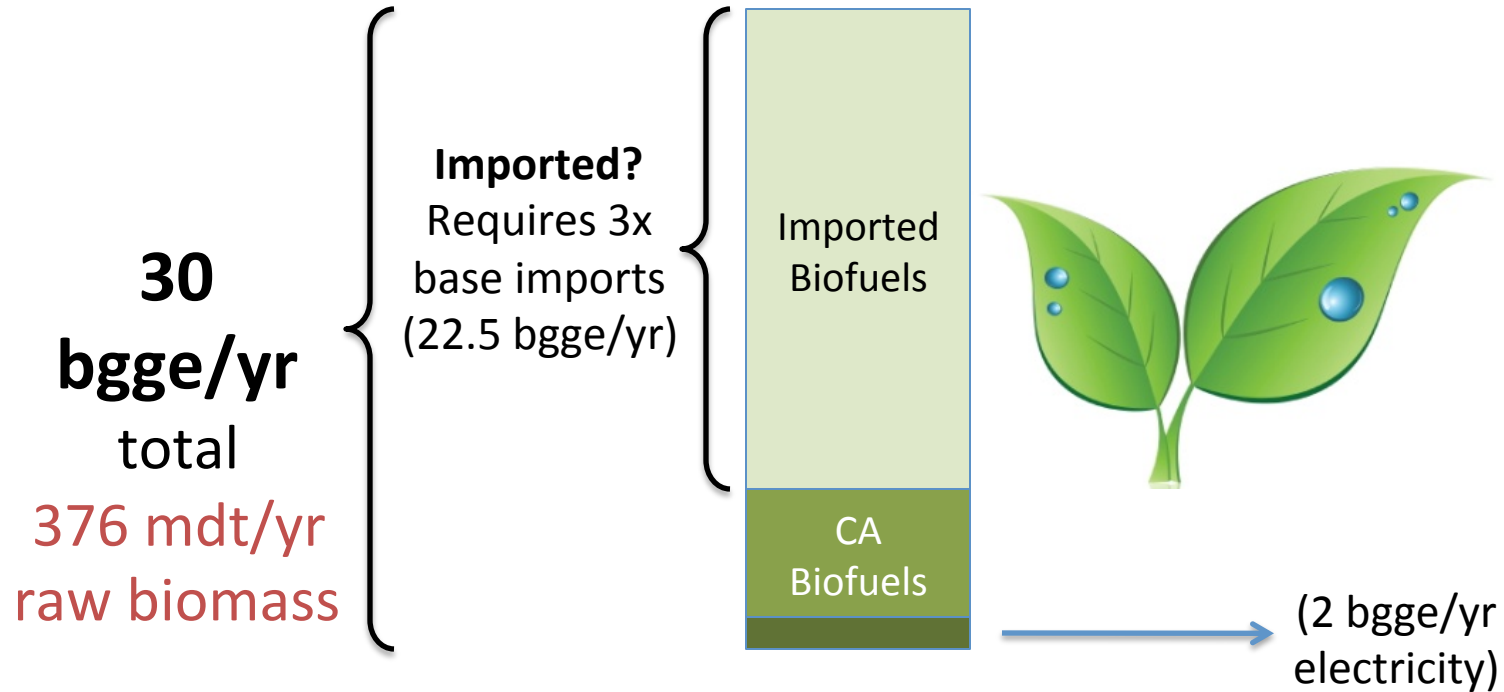
Doubling Biomass Supply



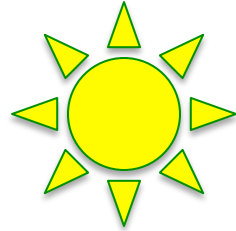
Where could this land come from?

- Abandoned crop + unproductive timber land
- Increased recovery of existing waste streams

Doubling Biomass Supply

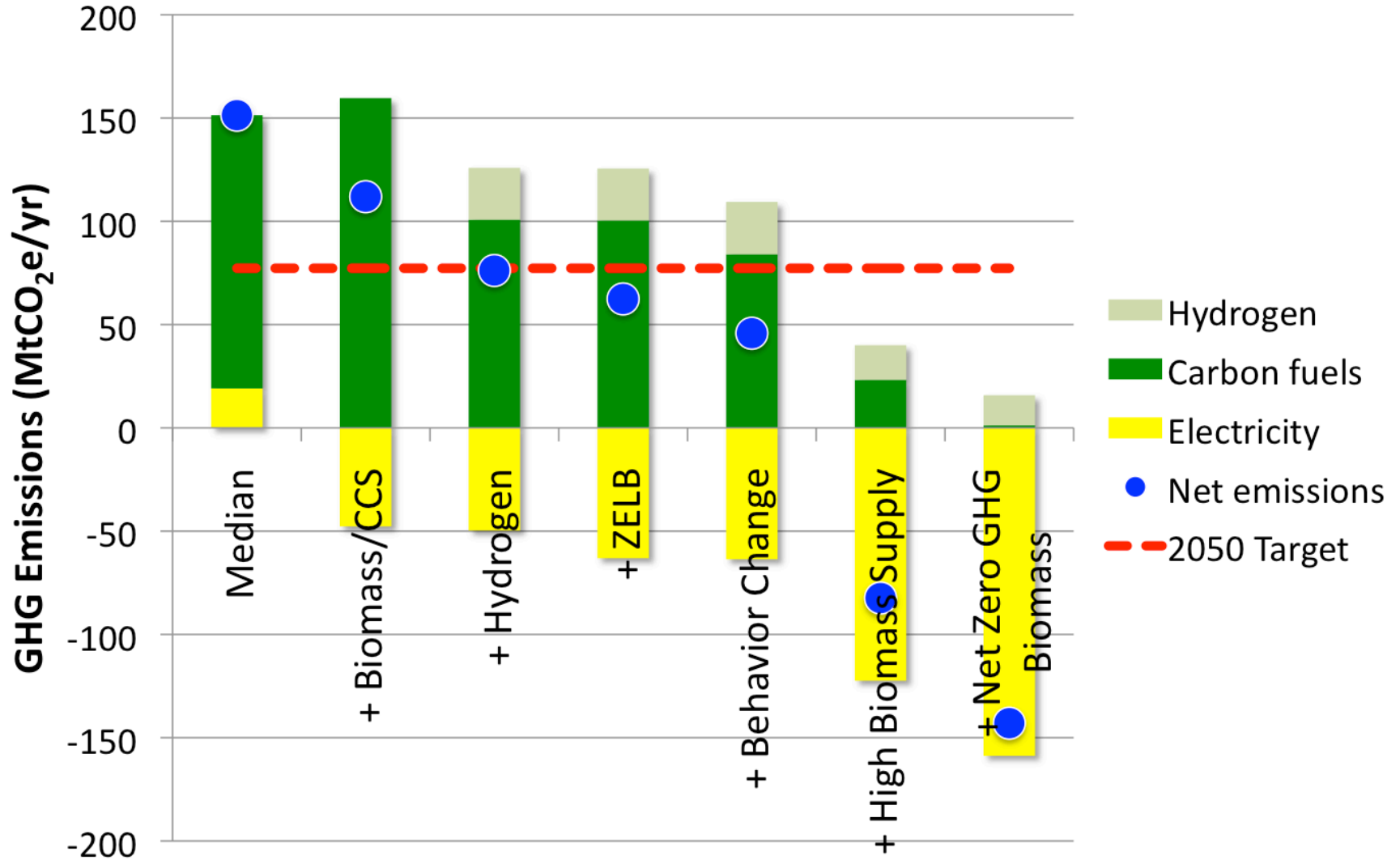


Advanced Technologies



- Fuel from sunlight
 - Would relieve biomass resource constraint
 - Probably necessary if CCS fails or is too expensive
- Fusion
 - Would it really produce cheaper electricity? If so, how would solutions change (e.g., cheap electrolysis)?
 - Might be better baseload solution than nuclear fission, fossil/CCS or geothermal
- What else could help?

Getting to 80%: Example of Multiple Strategies



Conclusions

- 80% solutions are achievable with technical (and for behavior, social) innovation
- Multiple strategies are probably needed
- Key uncertainties/challenges:
 - Biofuels are uncertain, and greatly expanded supplies would change nature of solution
 - CCS is an important enabling technology; will it work at scale?
 - How should hydrogen best be used?
 - Load balancing without emissions needed (storage and flexible loads), particularly for renewables
- Further research needed:
 - Biomass/CCS for electricity
 - Biomass/Coal/CCS for fuels
 - Fuel from sunlight (and possibly fusion)