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

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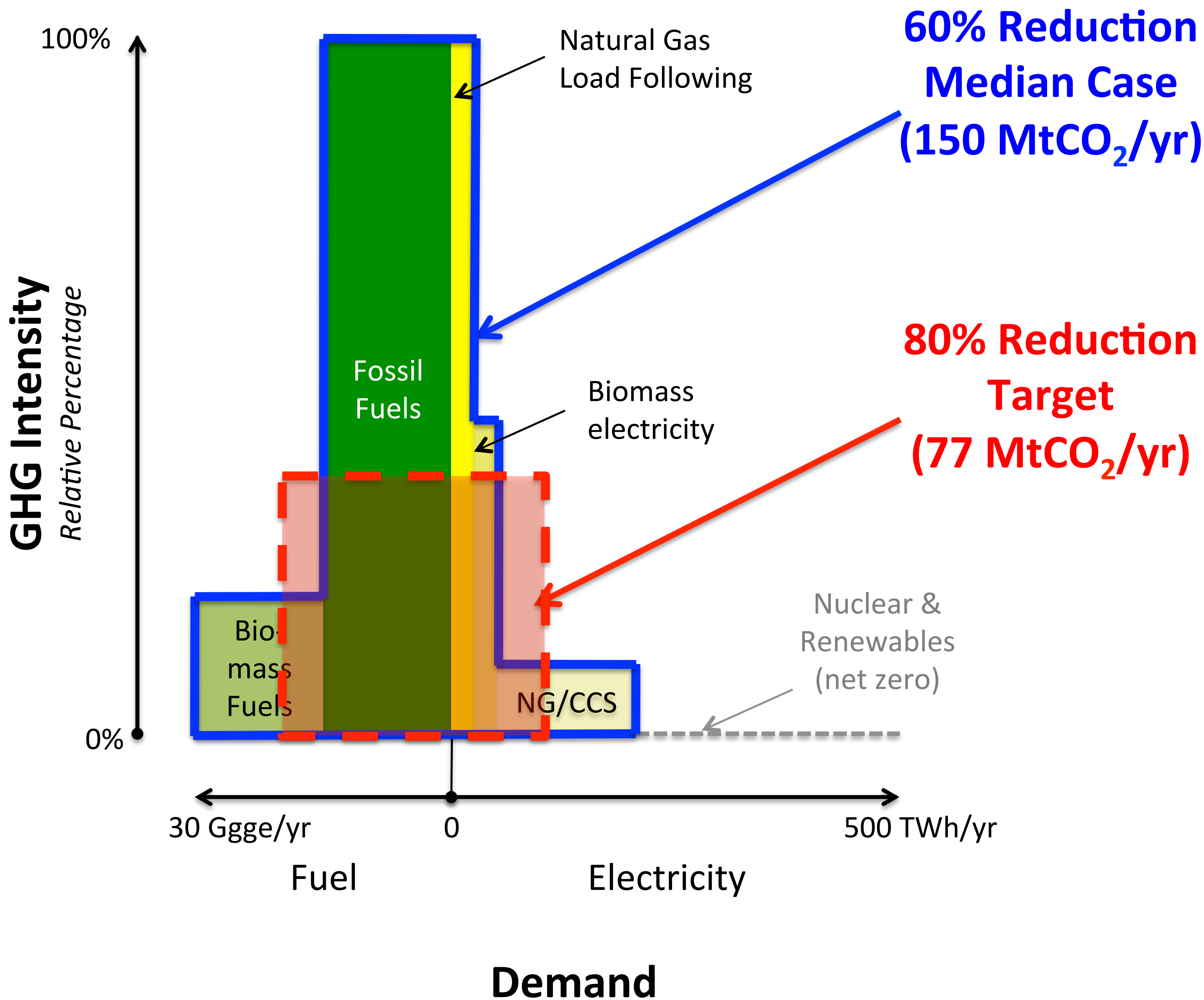
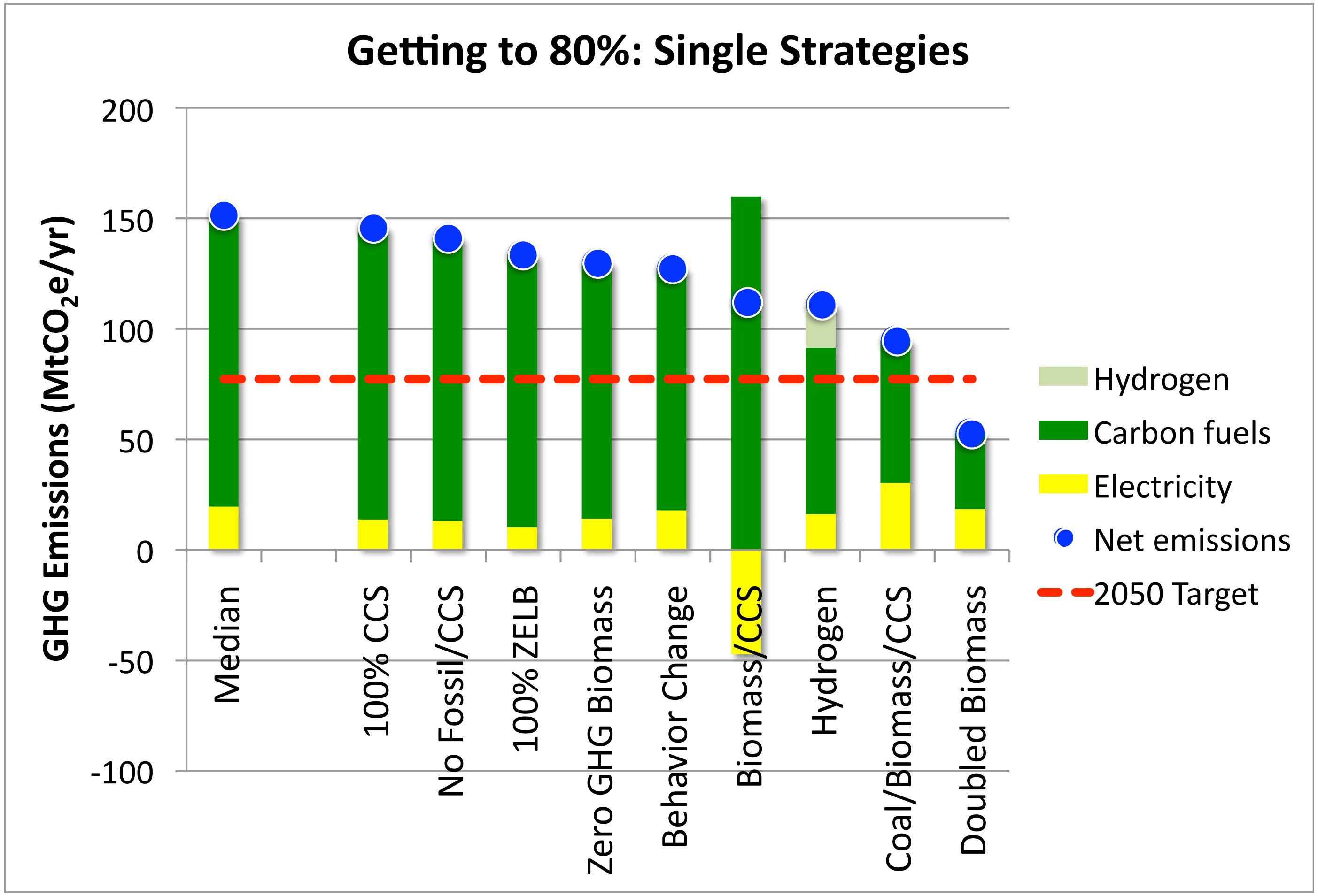


100%
0%
GHG Intensity
Relative Percentage
Natural Gas
Load Following
Fossil
Fuels
Biomass
electricity
Bio-
mass
Fuels
NG/CCS
Nuclear &
Renewables
(net zero)
60% Reduction
Median Case
(150 $MtCO_2$/yr)
80% Reduction
Target
(77 $MtCO_2$/yr)
30 Ggge/yr
0
500 TWh/yr
Fuel
Electricity
Demand

Strategies for Getting to 80%

Strategy	GHG Impact
1. 100% effective CCS 2. Eliminate fossil/CCS (use nuclear instead)	Small
3. 100% ZELB for load balancing 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)	Moderate
8. Biomass/Coal/CCS (make fuels + electricity) 9. Double biomass supply	Large
10. Fuel from sunlight (need net-zero carbon source) 11. Fusion electricity 12. Others?	Trans-formative

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_2O	~90%
IGCC pre-combustion	CO_2, CO, CH_4, H_2S	~92%
Oxyfuel combustion	CO_2, O_2, H_2O	96-99%

Conclusions:

- >90% capture is costly, >95% is very costly
- 100% capture is unlikely without breakthroughs
- Would not save much CO_2 in median case (6 $MtCO_2$/yr)

But:

- **Important incremental savings in CCS-heavy cases**

(fossil/CCS, biomass/CCS, biomass/coal/CCS, Nat. gas H_2)

Elimination of CCS

- Slightly greater CO_2 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

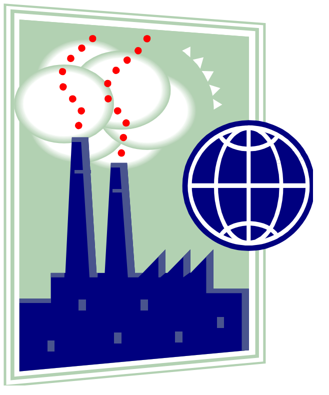
- Can lifecycle costs be reduced to zero?
- 22 $MtCO_2$/yr savings over median case
- Important to reduce net emissions from where they are today (>50% of fossil fuels), but not so critical to reduce below ~20%.
- Research questions:
  - Can we produce a cost curve for net GHG biomass emissions?
  - Given other energy component strategies, what is a reasonable net GHG biomass target?

Behavior Change

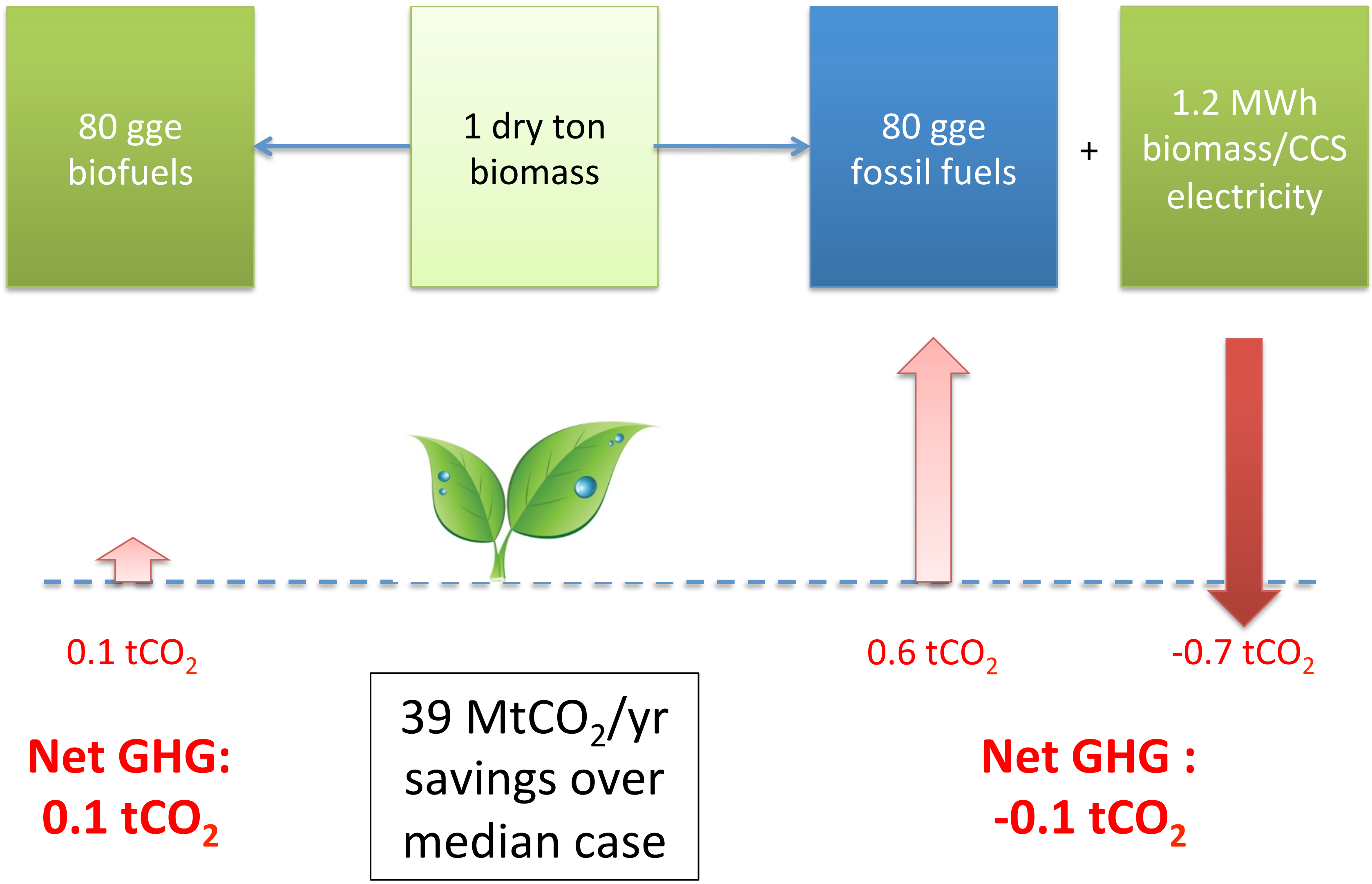
- Many behaviors identified to reduce energy use in the 10-20% range:
  - Greater extremes in variables, including building & water temperatures, light levels, moisture content, etc.
  - Right-sizing of homes, appliance capacities, etc.
  - Trading time for convenience, e.g., “smart” wash cycles
  - 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 $MtCO_2$/yr savings from median case with ~10% demand reduction

Behavior Change

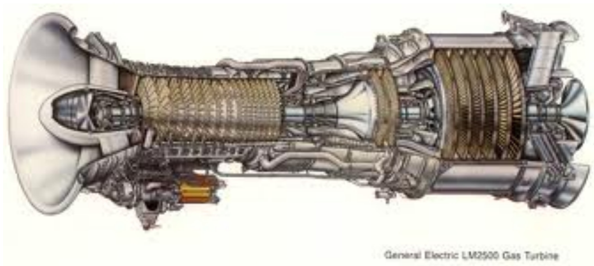
- New research (CEC grant to LBNL) finds that:
  - Behaviors targeting fuel use (e.g., transportation) have larger GHG savings, so policy may choose to focus on these
- Industrial "behavior":
  - Less raw materials to produce the same products
  - More integrated products to reduce total number produced
  - 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

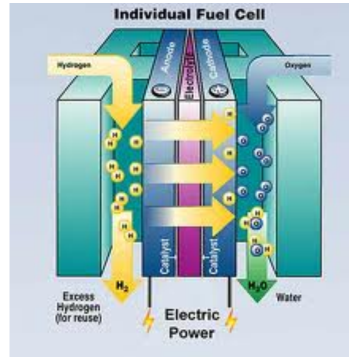


Biofuels vs. Biomass/CCS



Hydrogen

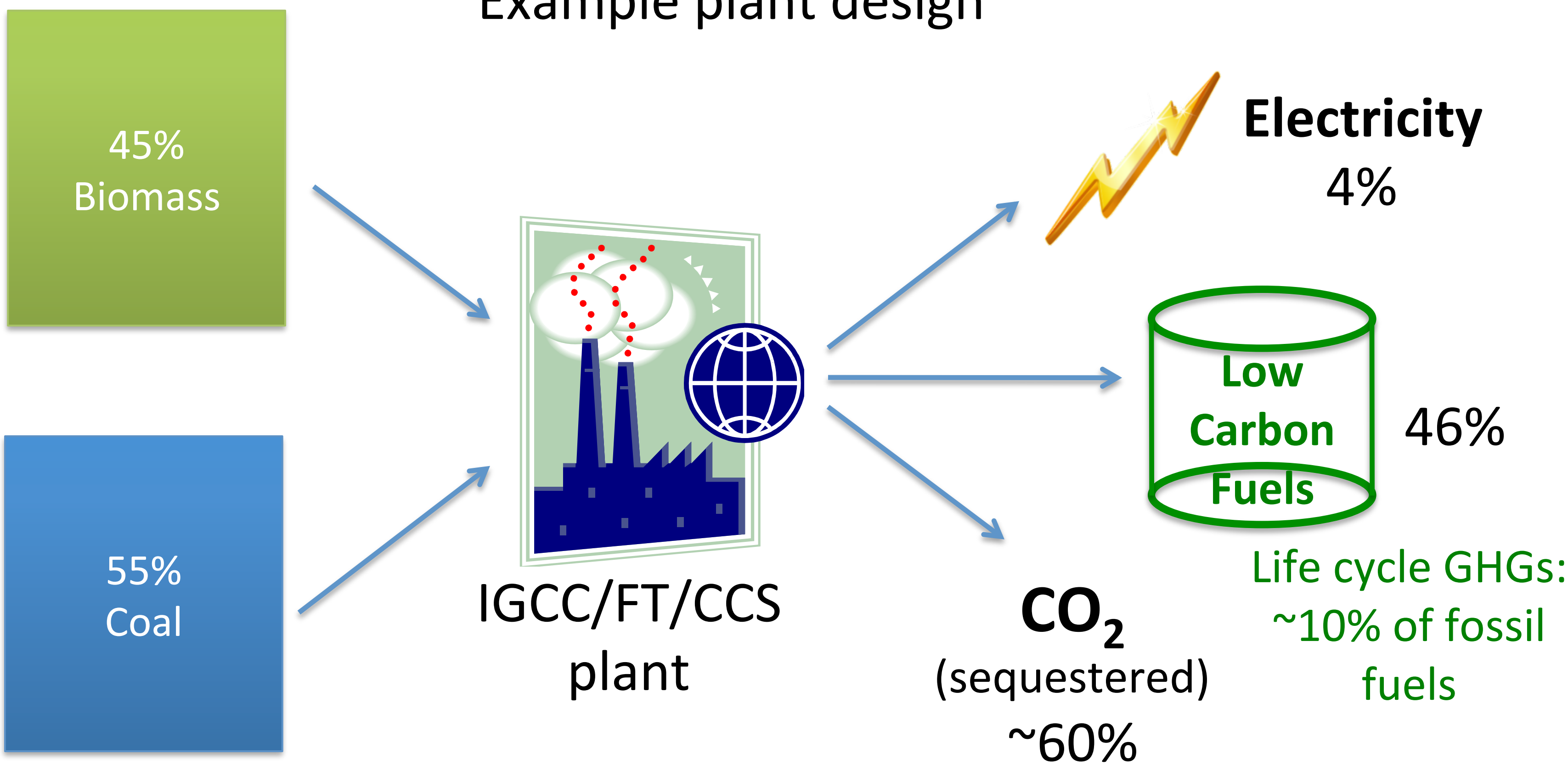




- CEF assessment of primary roles for H_2:
  - Light-duty vehicles (22%)
  - Some heavy-duty transport (9% trucks, 100% buses)
  - Industrial heat (21%)
- Production options:
  - Electrolysis: very expensive, unless done at high-temperature
  - Thermochemical from coal or natural gas with CCS
- 40 $MtCO_2$/yr savings over median case
- Research questions:
  - When is hydrogen "better" than electrification or biofuels?
  - Can hydrogen be used in heavy-duty transporation, e.g., airplanes (Jacobson & Delucchi, *EnPol,* 2011)?

Biomass and Coal with CCS

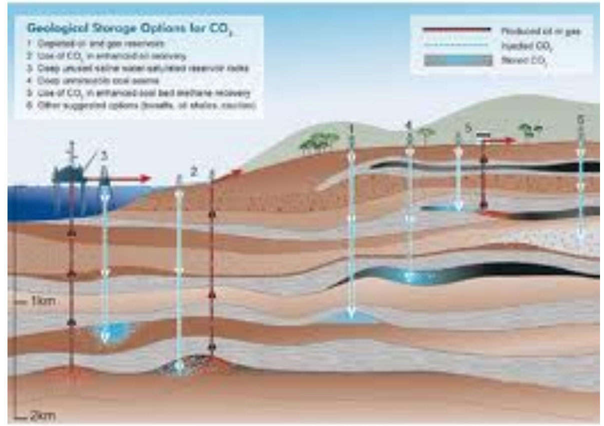
Example plant design



94 mdt/yr biomass → 12-15 bgge/yr fuels
56 $MtCO_2$/yr savings

Source: Guangjian Liu, Eric D. Larson, Robert H. Williams, Thomas G. Kreutz and Xiangbo Guo (2010) Making Fischer- Tropsch Fuels and Electricity from Coal and Biomass: Performance and Cost Analysis. Energy Fuels, Article ASAP doi: 10.1021/ef101184e

Central Role of CCS



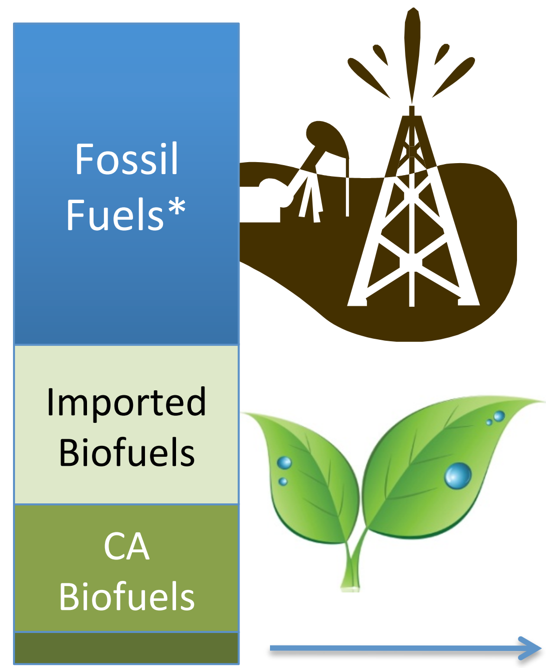
- Huge enabler of:
  - Fossil electricity, including possibly natural gas turbines
  - Biomass electricity to offset fossil fuel in transport
  - Fuel production from biomass + fossil
  - Hydrogen production
- Research needs:
  - Legal resolution of CO_2 responsibility (federal issue?)
  - Resource assessment 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

15 bgge/yr total

188 mdt/yr raw biomass

13 bgge/yr fuels

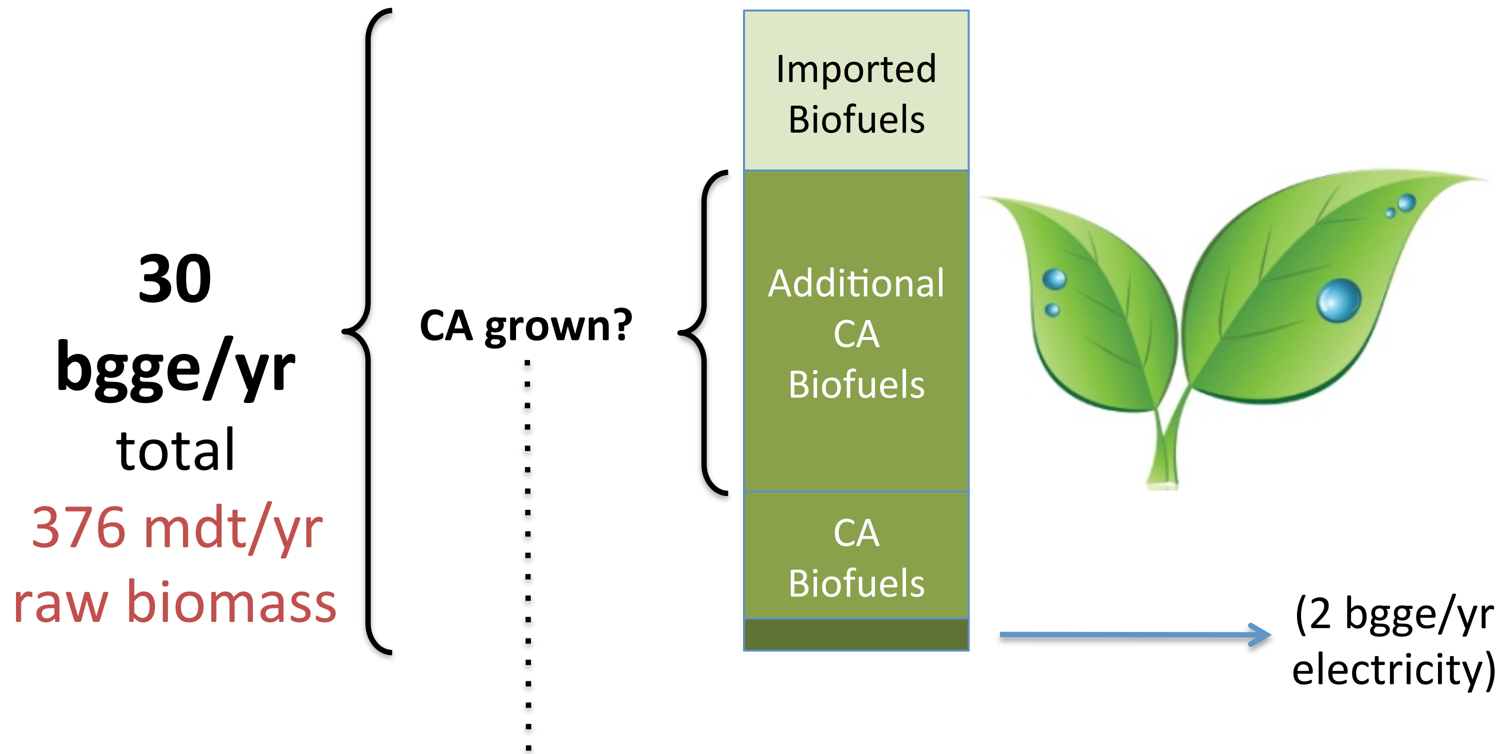


(2 bgge/yr electricity)

Median case

*Not including natural gas for CCS

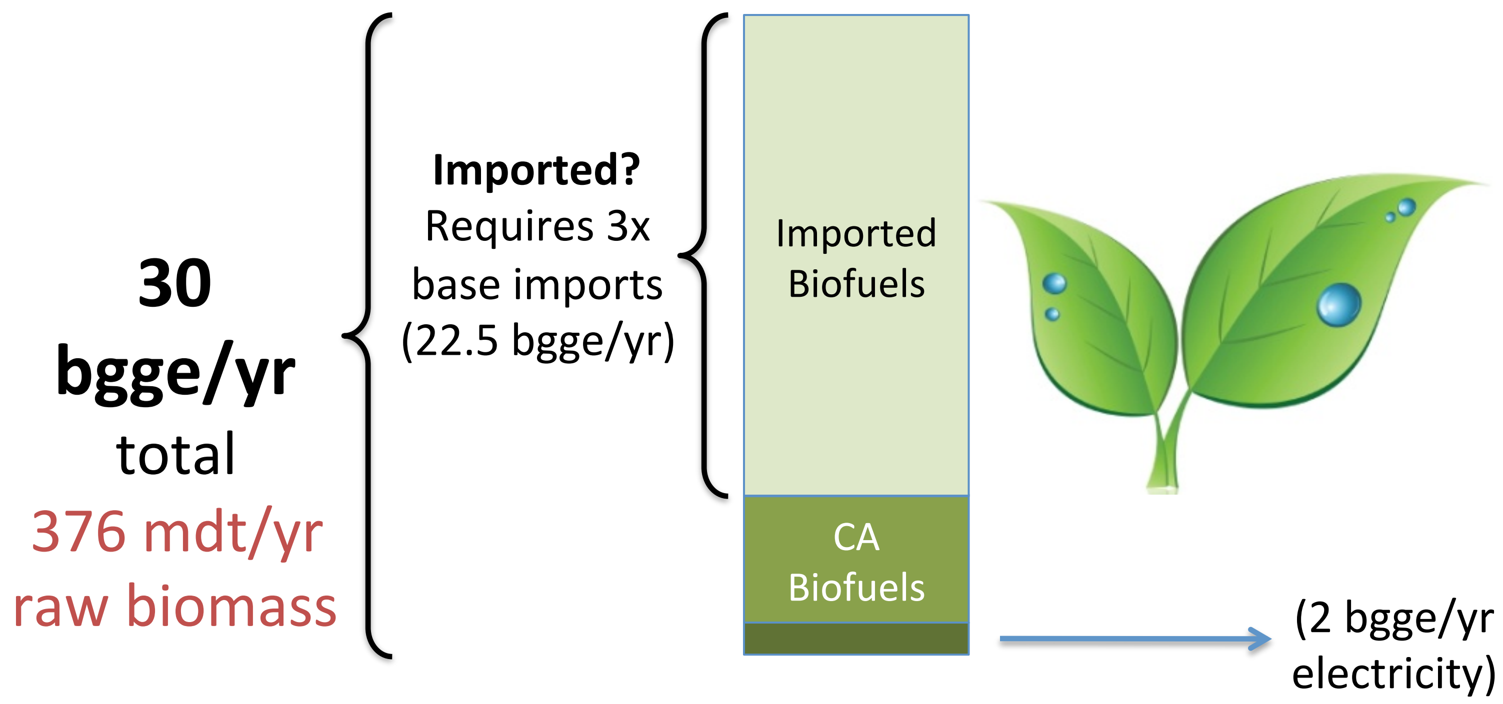
Doubling Biomass Supply



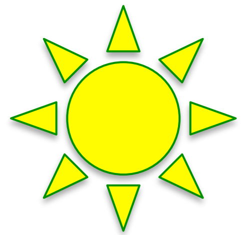
Where could this land come from?

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

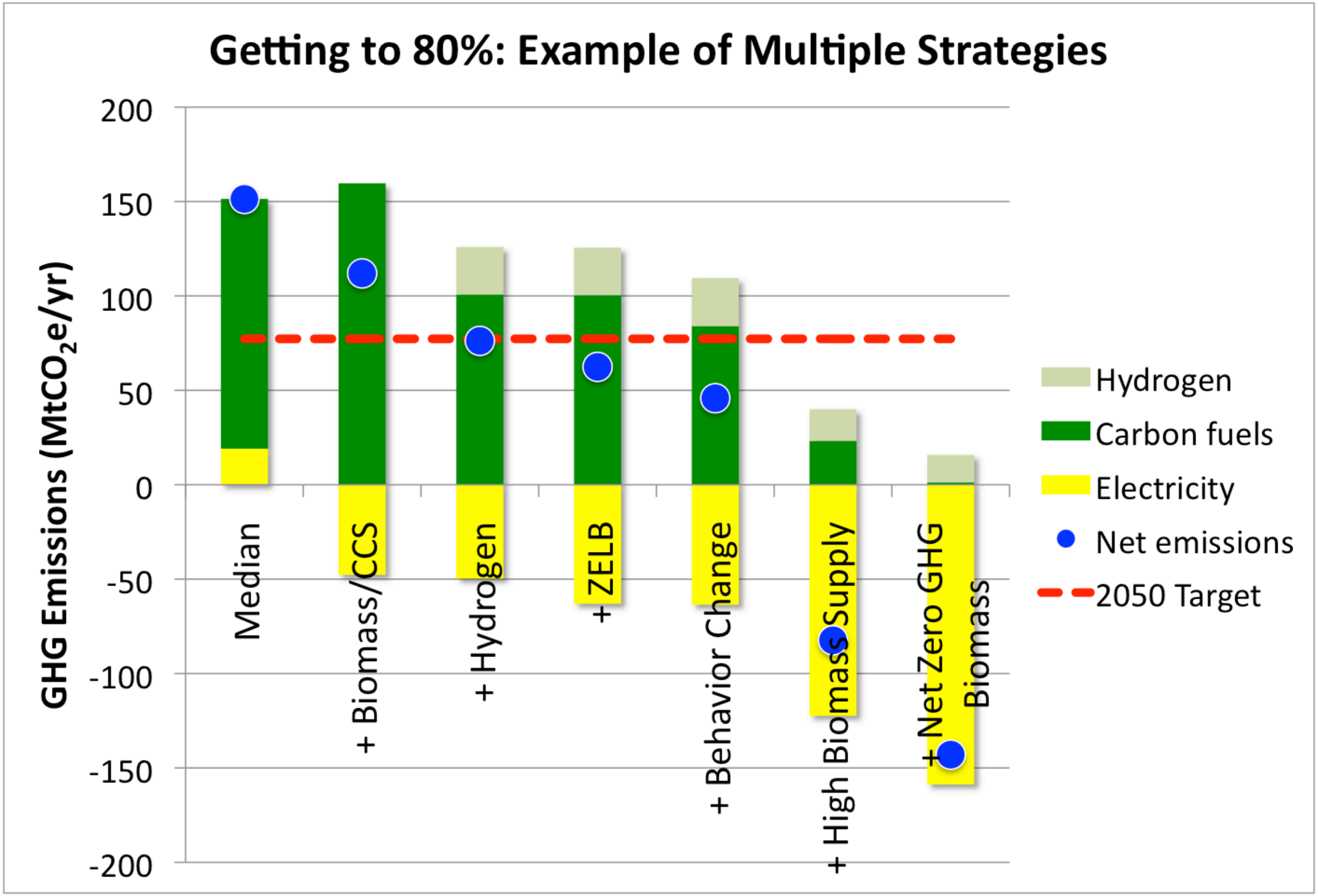
Doubling Biomass Supply



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
GHG Emissions (MtCO2e/yr)
200
150
100
50
0
-50
-100
-150
-200
Median
+ Biomass/CCS
+ Hydrogen
+ ZELB
+ Behavior Change
+ High Biomass Supply
+ Net Zero GHG Biomass
Hydrogen
Carbon fuels
Electricity
Net emissions
2050 Target

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)