The Role of Carbon Capture and Sequestration in California's Energy Future

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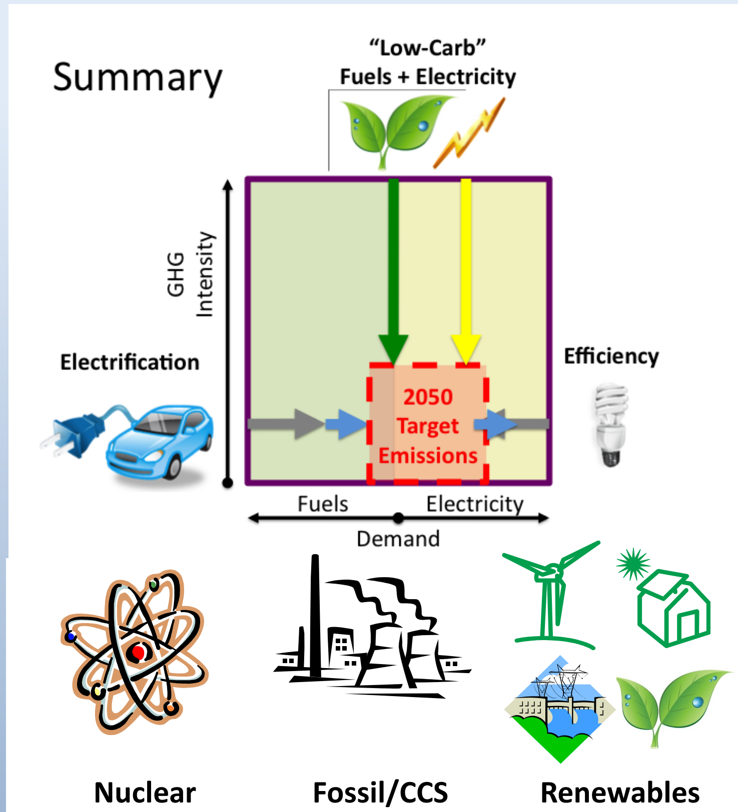
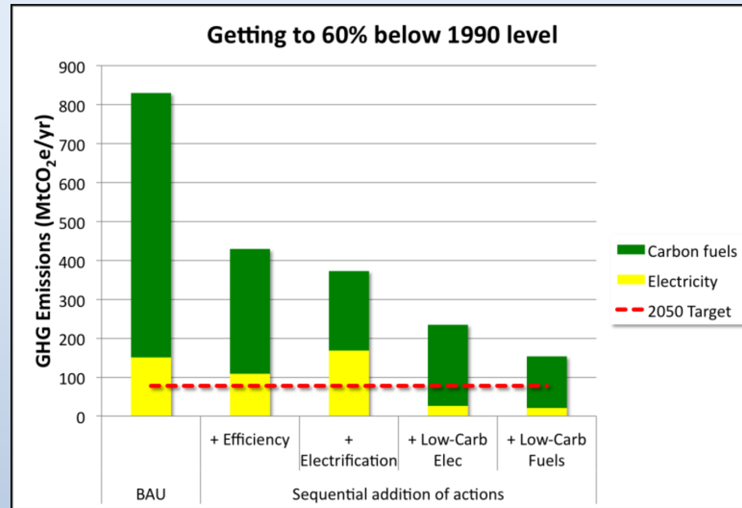
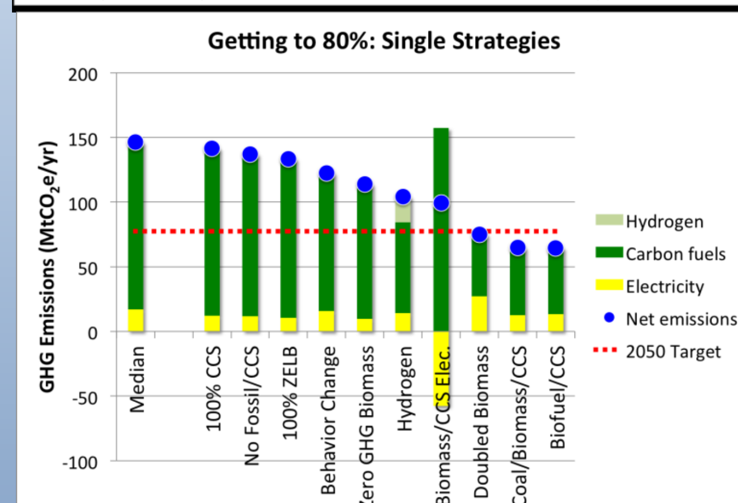
California’s Energy Future Project

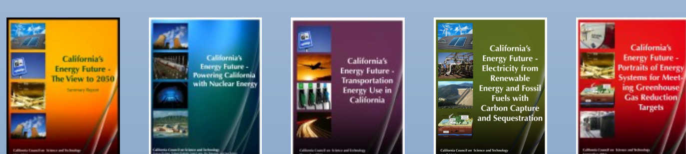
Sponsored by California Council on Science & Technology (CCST)

- Several pathways identified to achieve 60% reduction below 1990 by 2050
- Additional research necessary to achieve 80% reductions (low-GHG fuels and zero-emission load balancing are key)
- Achieving post-2020 goals will require new policies, infrastructure and regional coordination
- CCS plays a prominent role in several energy technologies





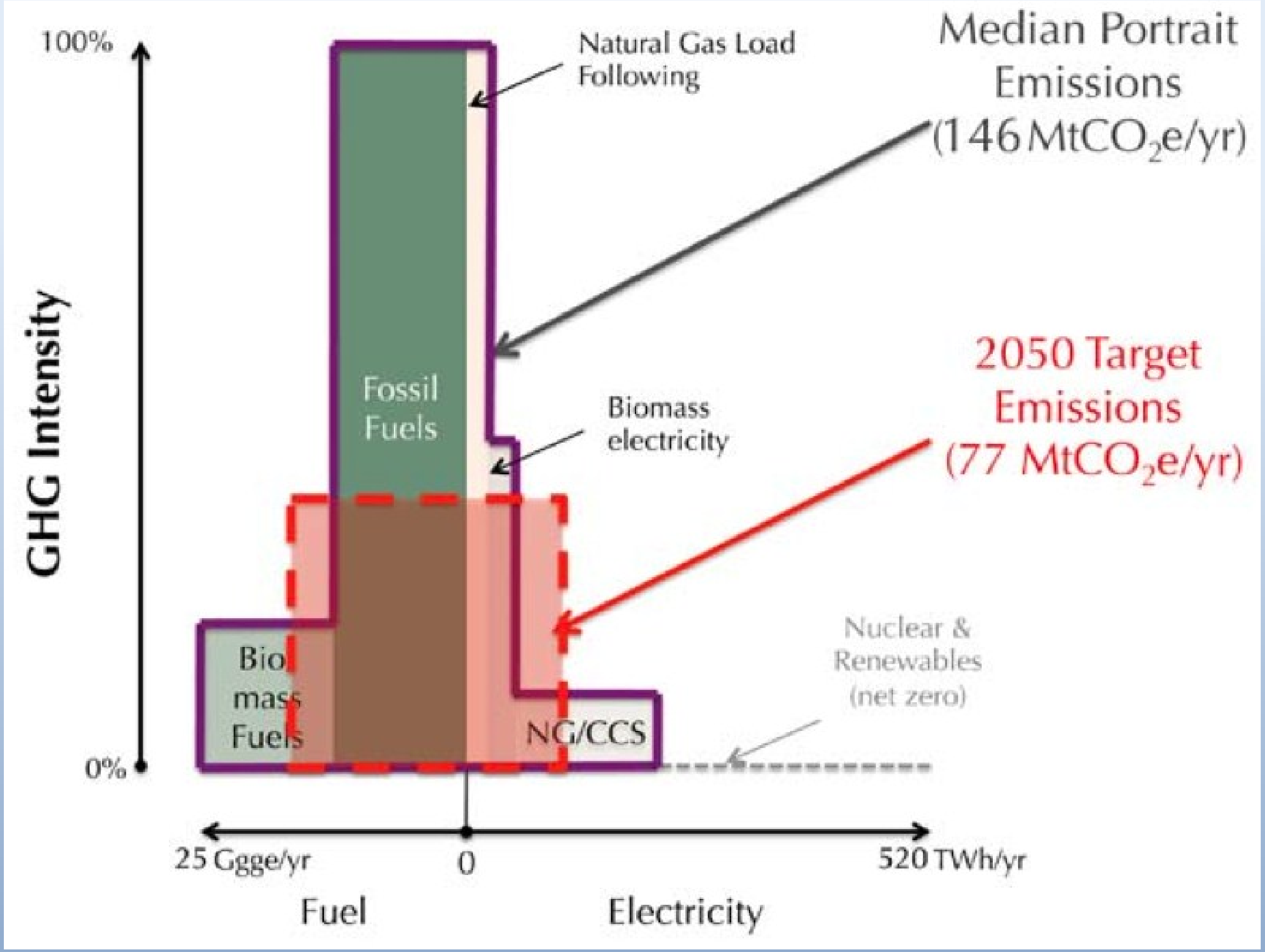




Building and Industrial Efficiency (in press)

Biomass Energy (in preparation)

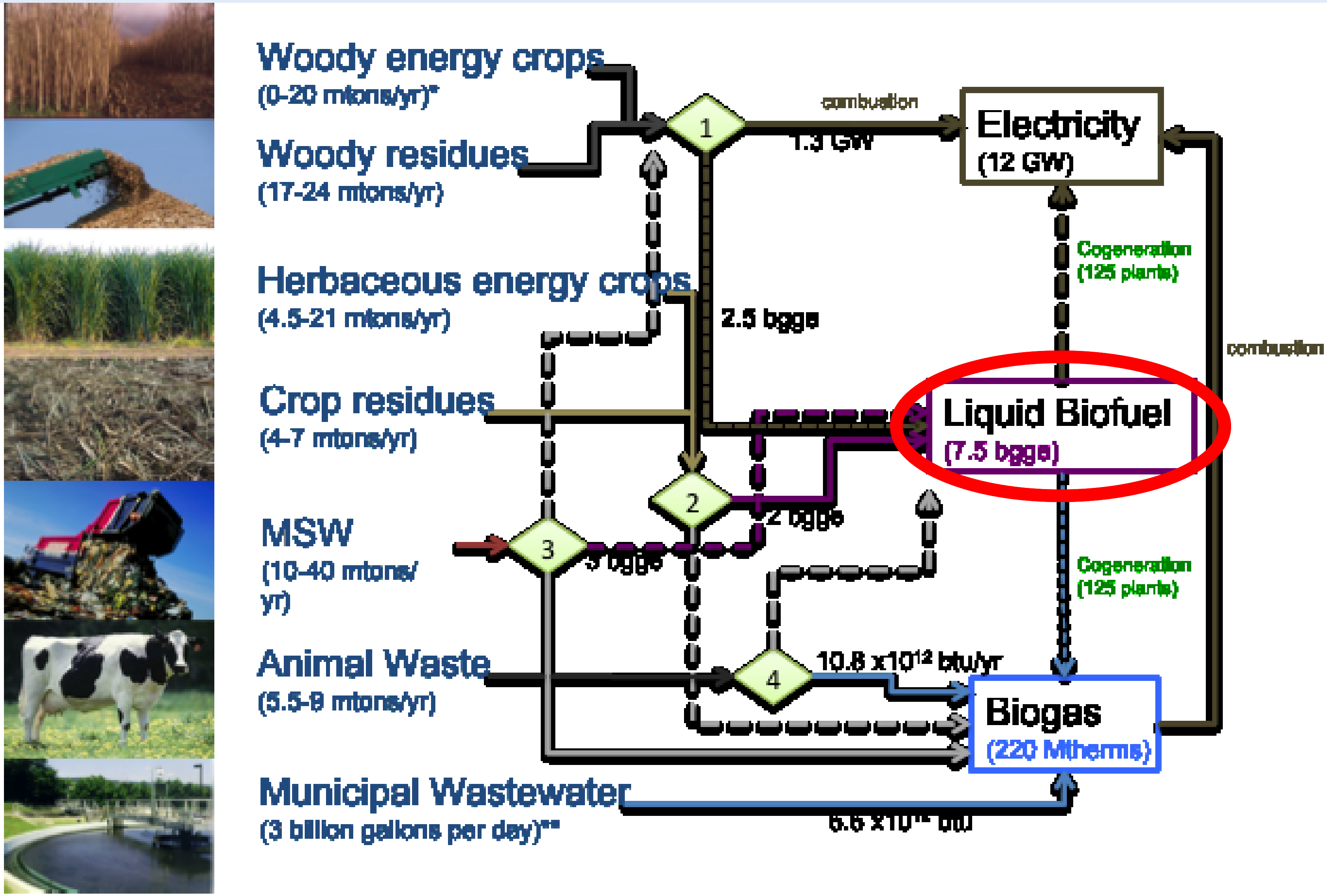
Getting to 80% GHG Reduction



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. Behavior Change (10% reduction in demand) 5. Net-zero GHG biomass 6. Hydrogen from fossil/CCS 7. Biomass/CCS electricity (offsets GHG from fuels)	Moderate
8. Double biomass supply 9. Coal/Biomass/CCS fuels (low GHG emissions) 10. Biomass/CCS fuels (negative GHG emissions)	Large
11. Fuel from sunlight (need net-zero carbon source) 12. Fusion electricity or others?	Trans-formative

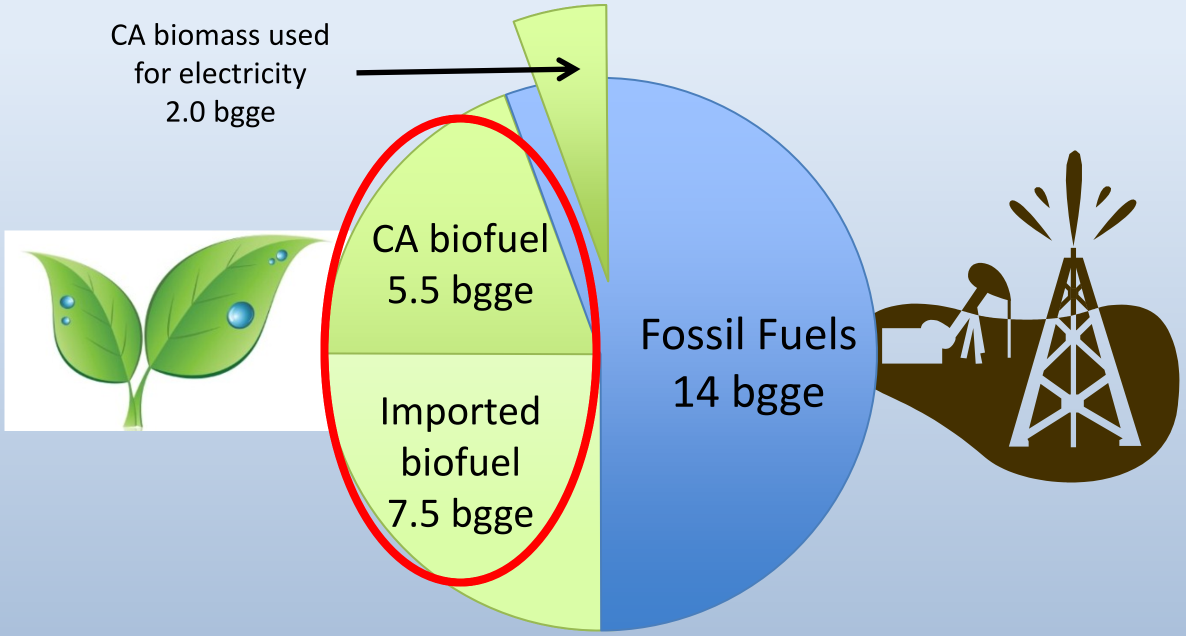
California Biomass



*technical recoverable yield (50-80% of gross biomass production depending on type)
**not currently used for energy production

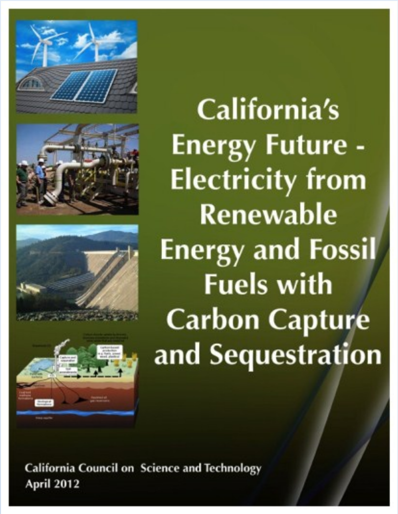
California Biomass

Total demand: 27 billion gge/yr



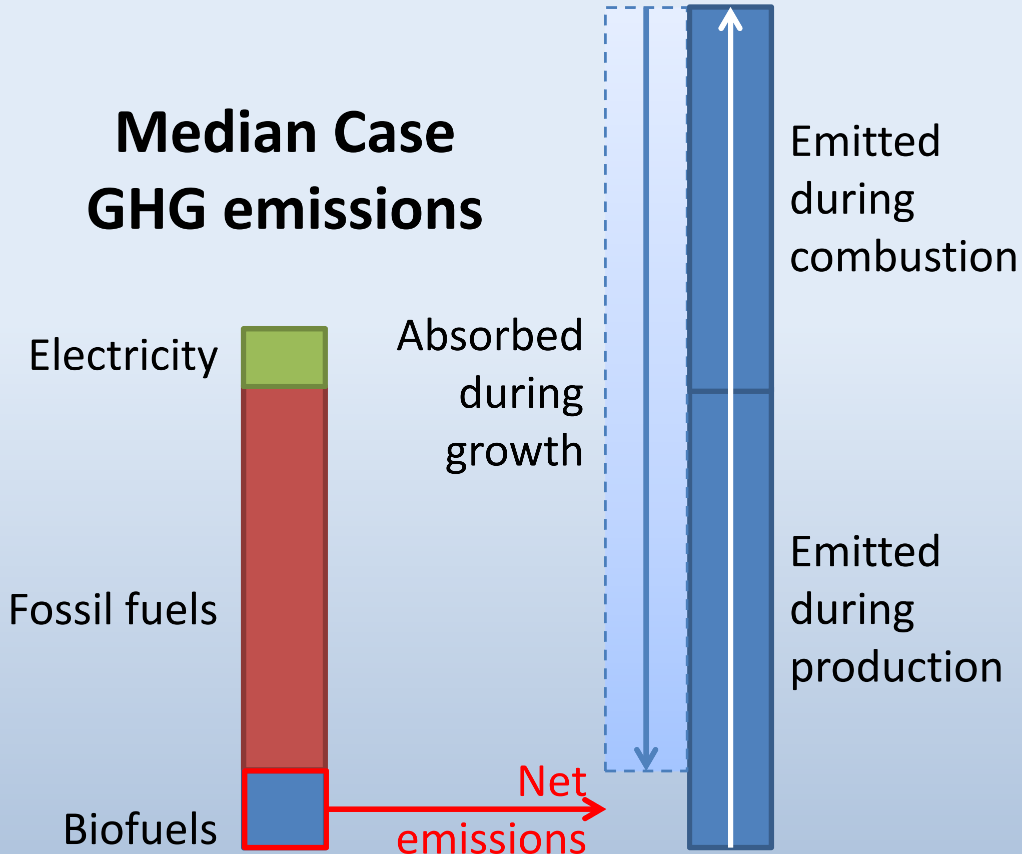
If we import as much as we grow in California, we might provide about ½ the fuel demand where CCS is not possible

Carbon Capture and Sequestration

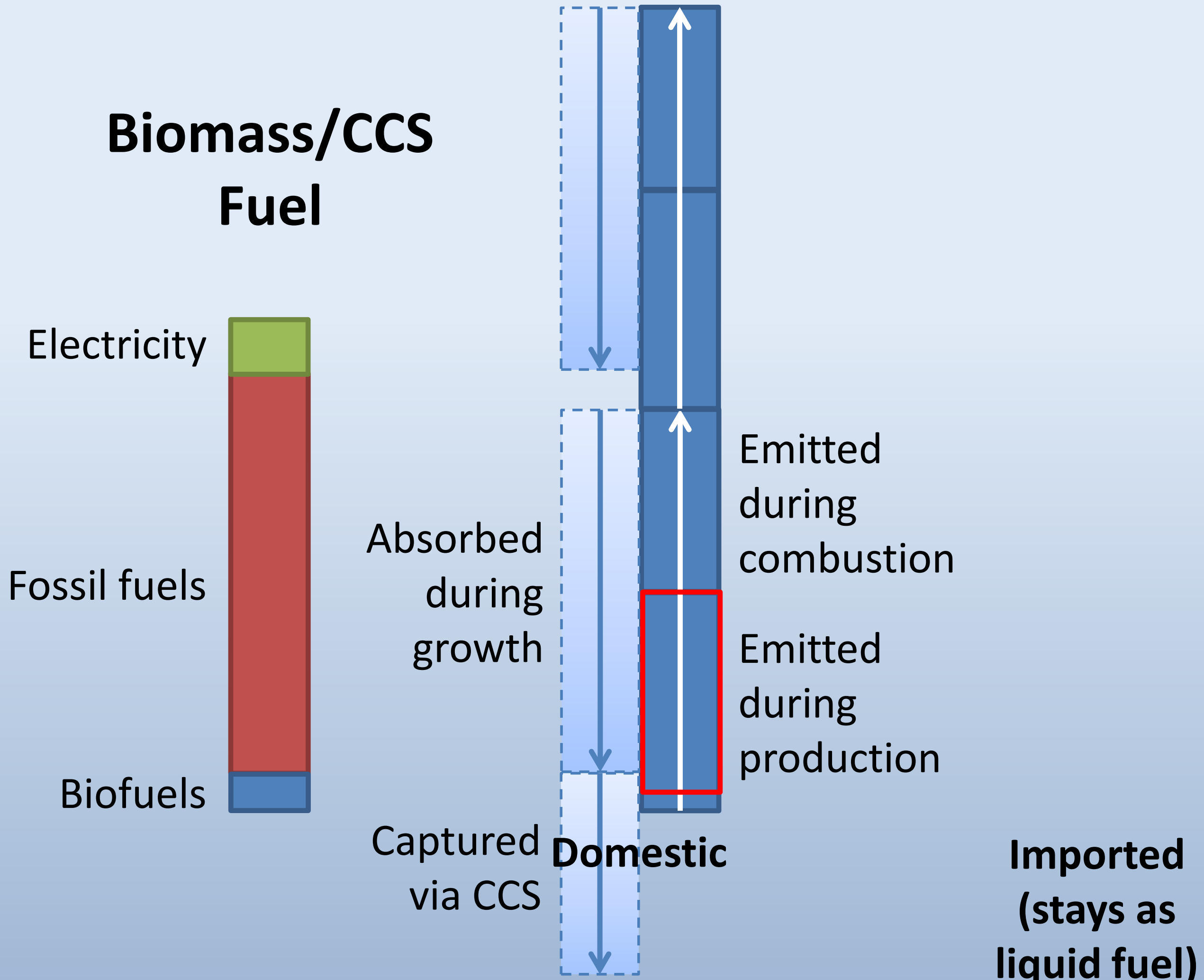


- Important technology for electricity generation
- Key strategy for achieving economy-wide low-carbon fuels:
  - Biomass/CCS electricity
  - Biofuel production with CCS
  - Biofuels from biomass + fossil with CCS
  - Hydrogen from fossil with CCS

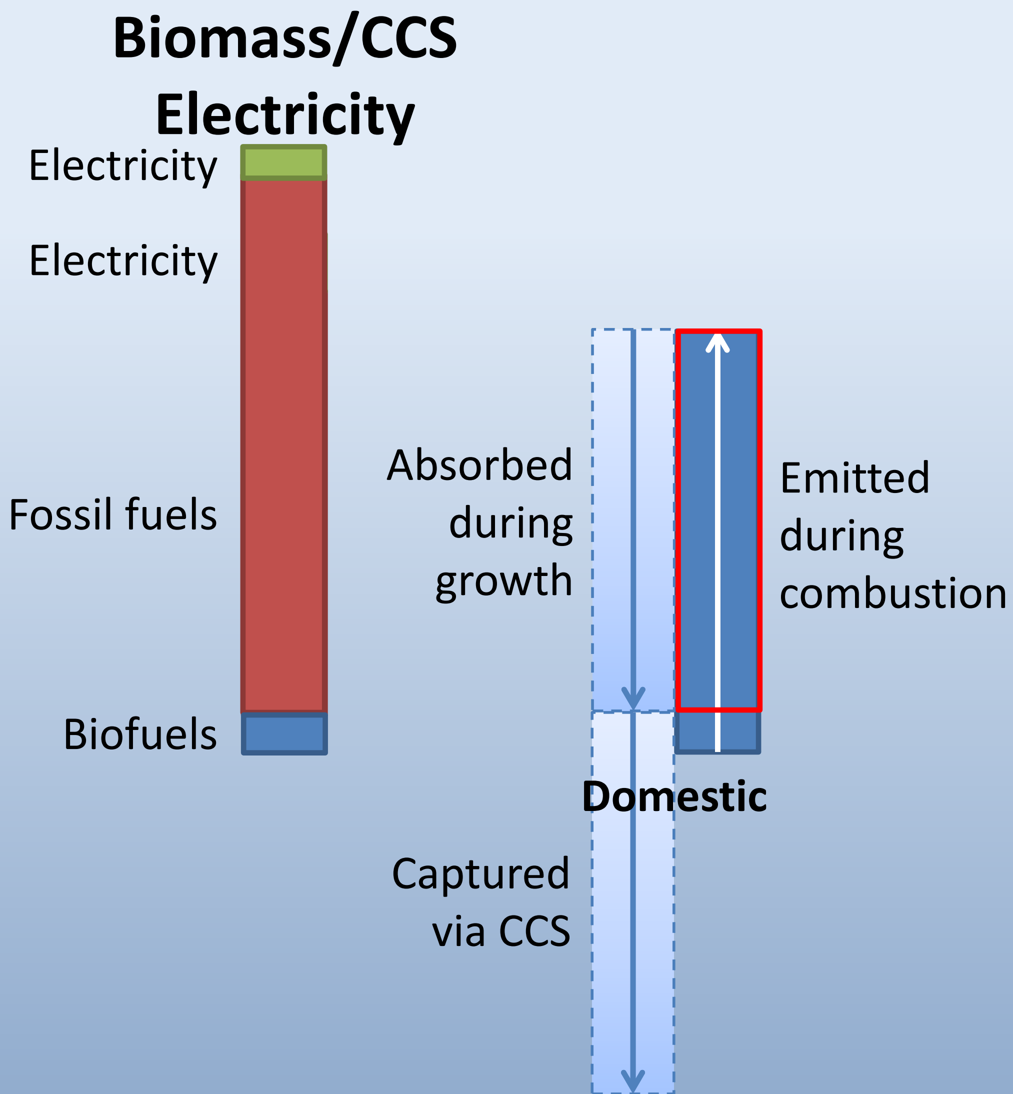
Combining Biomass with CCS



Combining Biomass with CCS



Combining Biomass with CCS



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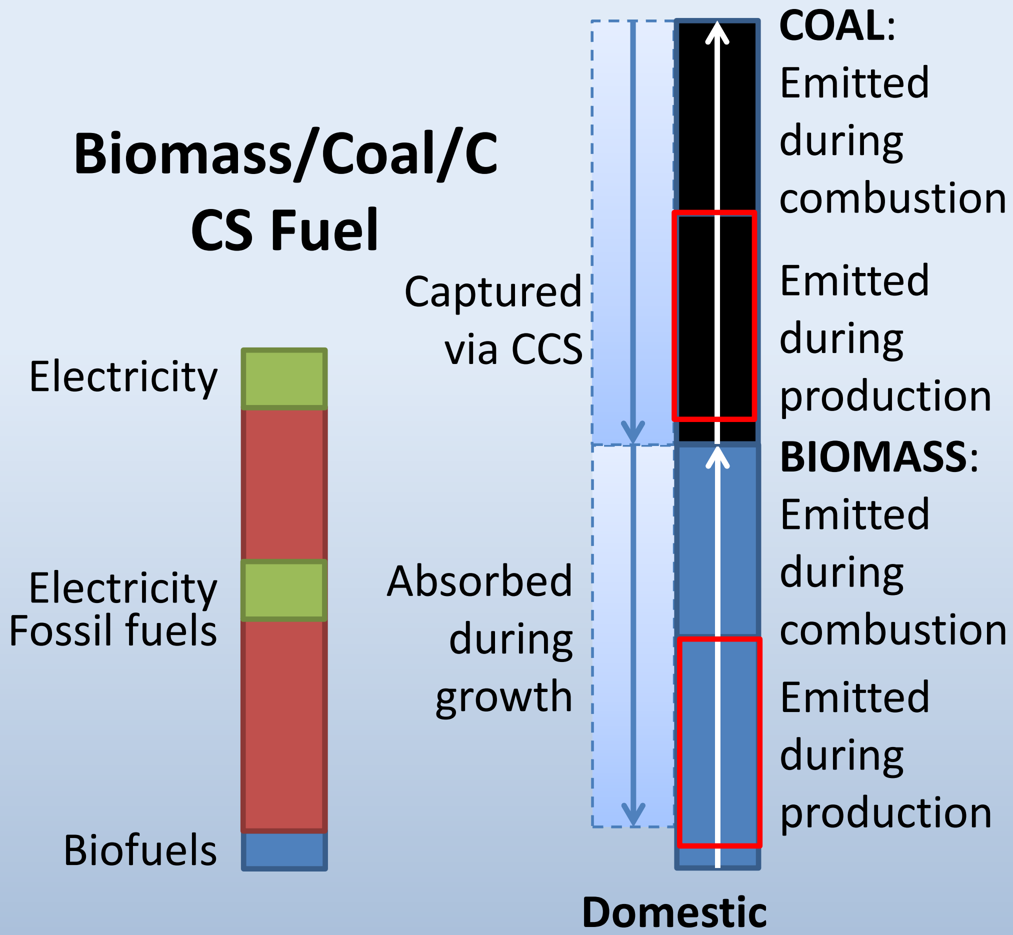

Combining Biomass with CCS

	Units	Median Case	Cases with CCS		
			Biomass Electricity	Biomass Fuels*	Biomass/Coal Fuels*
Biomass Supply					
Domestic	Mdt/yr	94	94	94	94
Imported	Mdt/yr	94	94	94	94
Total	Mdt/yr	188	188	188	188
Biomass-based Outputs					
Fuels	Bgge/yr	13.0	7.5	12.2	19.0†
Electricity	TWh/yr	25	95	27	26†
Fuel demand met**	%	53%	30%	49%	80%
Fuel GHG intensity	$kgCO_2e/gge$	2.19	2.37	-3.77††	1.12††
GHG emissions					
Statewide	$MtCO_2e/yr$	146	99	65	65

Hydrogen from Fossil/CCS

Sector*	Fraction of 2050 demand			Hydrogen efficiency	Hydrogen demand (GgH_2/yr)
	Carbon fuels	Electricity	Hydrogen		
Industry	51%	27%	21%	20% better than HC fuels	3,160
Light-duty vehicles	22%	22%	56%	79 mpgge	4,230
Heavy-duty vehicles	82%	9%	9%	25 mpgge	170
Buses	0%	0%	100%	70 seat-mpgge	420
TOTAL					**7,980**

- About 30% of fuel demand could be replaced with hydrogen
- Like fossil/CCS electricity, hydrogen is near net-zero GHG

CO_2 Storage Required

	Median	Biomass/CCS Electricity	Biomass/CCS Fuels	Biomass/Coal/CCS Fuels	Hydrogen from Nat. Gas/CCS	Natural Gas/CCS Electricity
Rate in 2050 ($MtCO_2$/yr)	44	117	83	137	40	111
Cumulative ($MtCO_2$)	454	N/A	N/A	N/A	N/A	1,146

- Beyond 2050, saline aquifers may be required (above ~5,000 $MtCO_2$ in-state storage)

Conclusions

- Getting to 80% GHG reductions in California by 2050 will require technologies focused on low-GHG fuel production
- CCS may play a prominent role in several technologies beyond low-carbon fossil-based electricity, including:
  - Negative-GHG biomass electricity
  - Negative-GHG biofuels
  - Zero-GHG fuels from biomass + fossil
  - Zero-GHG hydrogen
- All will require substantial CO_2 in-state storage capacity in 2050, with saline aquifers required by end of century

Questions?

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