



California's Energy Future - The View to 2050

Summary Report

**CHAIR'S LECTURE:
CALIFORNIA ENERGY
FUTURES STUDY
RESULTS**

July 15, 2011

Jane C. S. Long

California Council on Science and Technology
May 2011

California Context

- AB 32 Requires reducing GHG emissions to 1990 levels by 2020 - a reduction of about 25 percent,
- Governor's executive order S-3-05 (2005) requires an 80 percent reduction below 1990 levels by 2050.
- We must go from 480 mmT CO₂e today to 80 mmT CO₂e in 40 years

Approach

- **“Existence proof”**: Can it be done, and what needs to change to allow us to get there?
- **Focus on technology, GHG emissions** and other impacts, not economics

CEF committee

Jane Long and Mim John, co-chairs

Lead authors:

- Jeff Greenblatt, LBNL
(calculations, writing, building efficiency)
- Burt Richter, Stanford (nuclear)
- Heather Youngs, UCB (biofuels)
- Max Wei, LBNL (industry efficiency)
- Chris Yang, UCD
(transportation)
- Bryan Hannegan, EPRI (CCS, Renewables)

Nate Lewis, Caltech
(adv. tech.)
Bill McClean, ret,
Sandia (CA
innovation)
Jan Schori, SMUD
(nuclear)
Jim McMahon, LBNL
(building &
appliance efficiency)
Bob Budnitz
Bob Epstein
Joan Ogden
Lyn Orr, Stanford
(CCS)
Per Peterson

Linda Cohen
Chris Field
Peter Gleick
Nalu Kaahaaina
Dan Kammen
Maxine Savitz
Larry Papay
Ari Patrinos
George Shultz
Chris Somerville
Dan Sperling
Jim Sweeney
Margaret Taylor
John Weyant
Mason Willrich
Carl Weinberg

The short answer: **Yes, we can**

- We can achieve 80% cuts in emissions and still meet our energy needs.
- We can get ~60% of the cuts with technology we largely know about.
 - We basically know how to do this
 - A lot of this technology is in demonstration.
 - Deployment will depend on policy and innovation.
 - Note: We excluded extremely expensive technology
- We can get the rest of the cuts to 80% below 1990, but this will require new technology innovation and development.

Two major technology limitations will cause us to exceed the target:

- We don't have sufficient technology for load balancing without emissions
 - This is an especially big deal if we don't have baseload power
- We don't have enough technology choices “in the pipeline” for de-carbonizing fuel.
 - Need advanced biofuels, but it likely won't be enough
 - CCS may play a larger role in fuels than in electricity

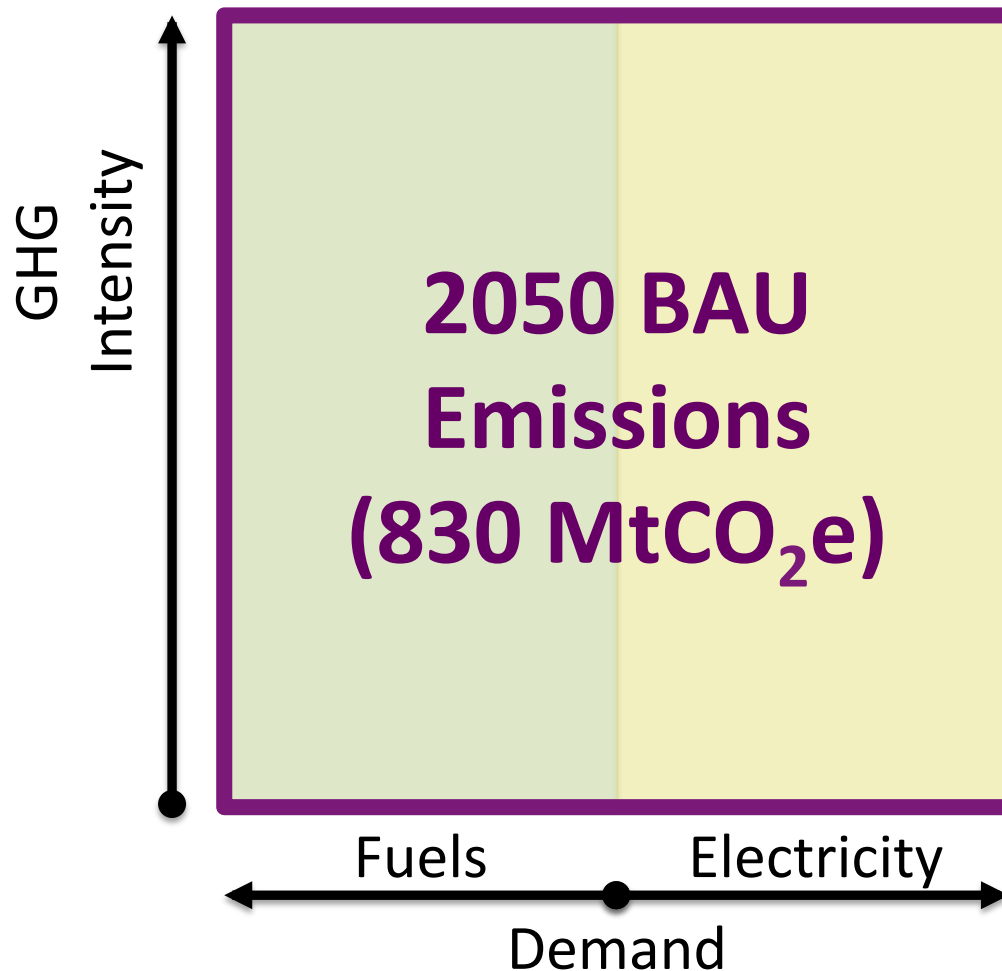
Logic→ eliminate fossil fuels*

1. How much can we control demand through efficiency measures? → Decrease need for electricity and fuel
2. How much do we electrify or convert to hydrogen fuel ? → Increase demand for electricity, decrease demand for fuel
3. How do we de-carbonize enough electricity to meet resulting electricity demand?
How do we balance load? → Nuclear, CCS, Renewables
→ Natural gas, energy storage, or demand management
4. How do we de-carbonize enough fuel (hydrocarbons or hydrogen) to meet remaining demand? → Biofuel, fuel from electricity?

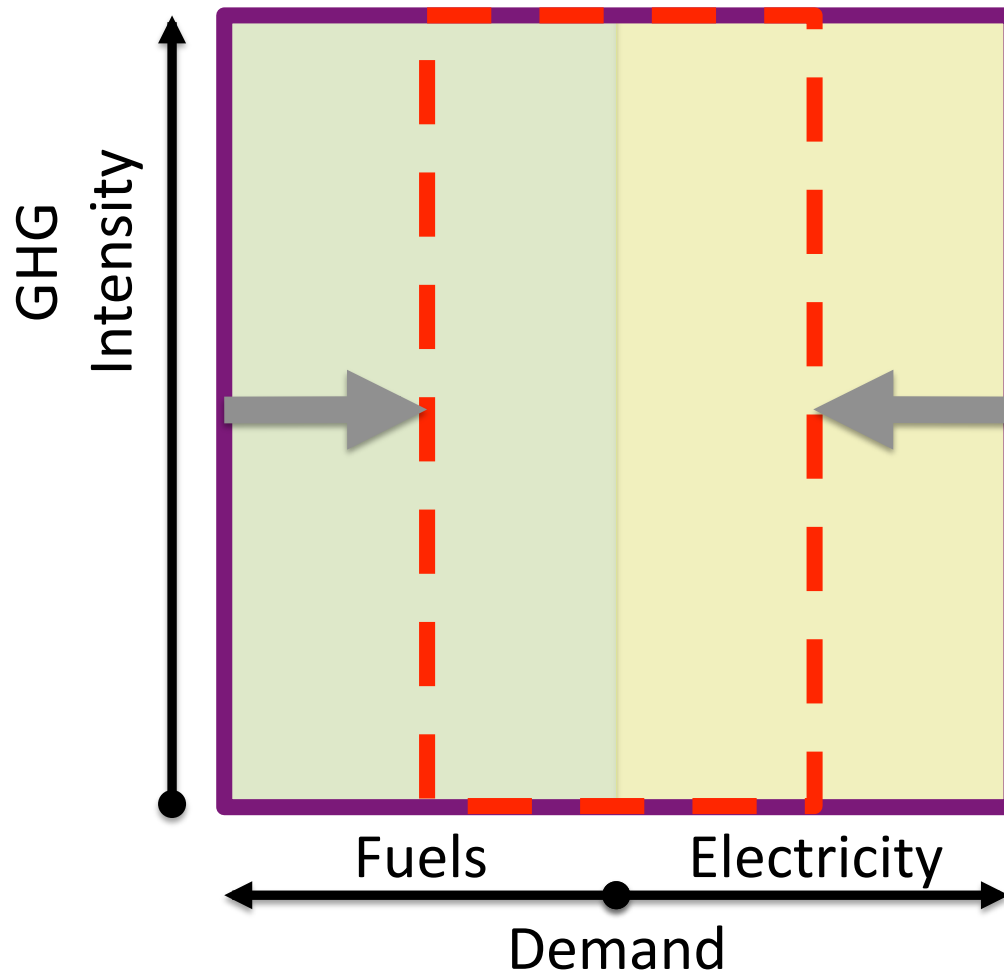
*unless emissions are sequestered

Four Actions to Reduce Emissions

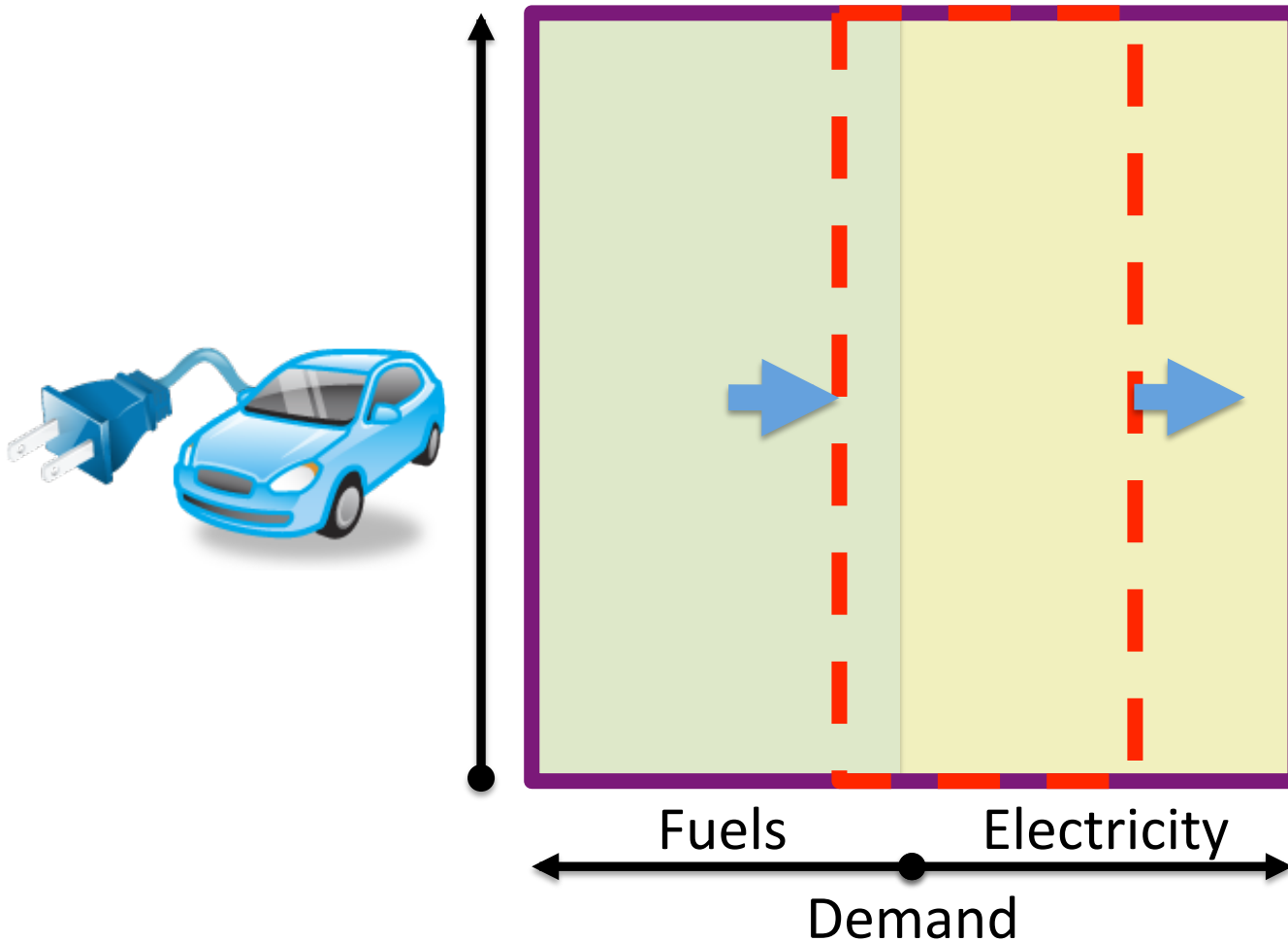
GHG Intensity-Demand Diagram



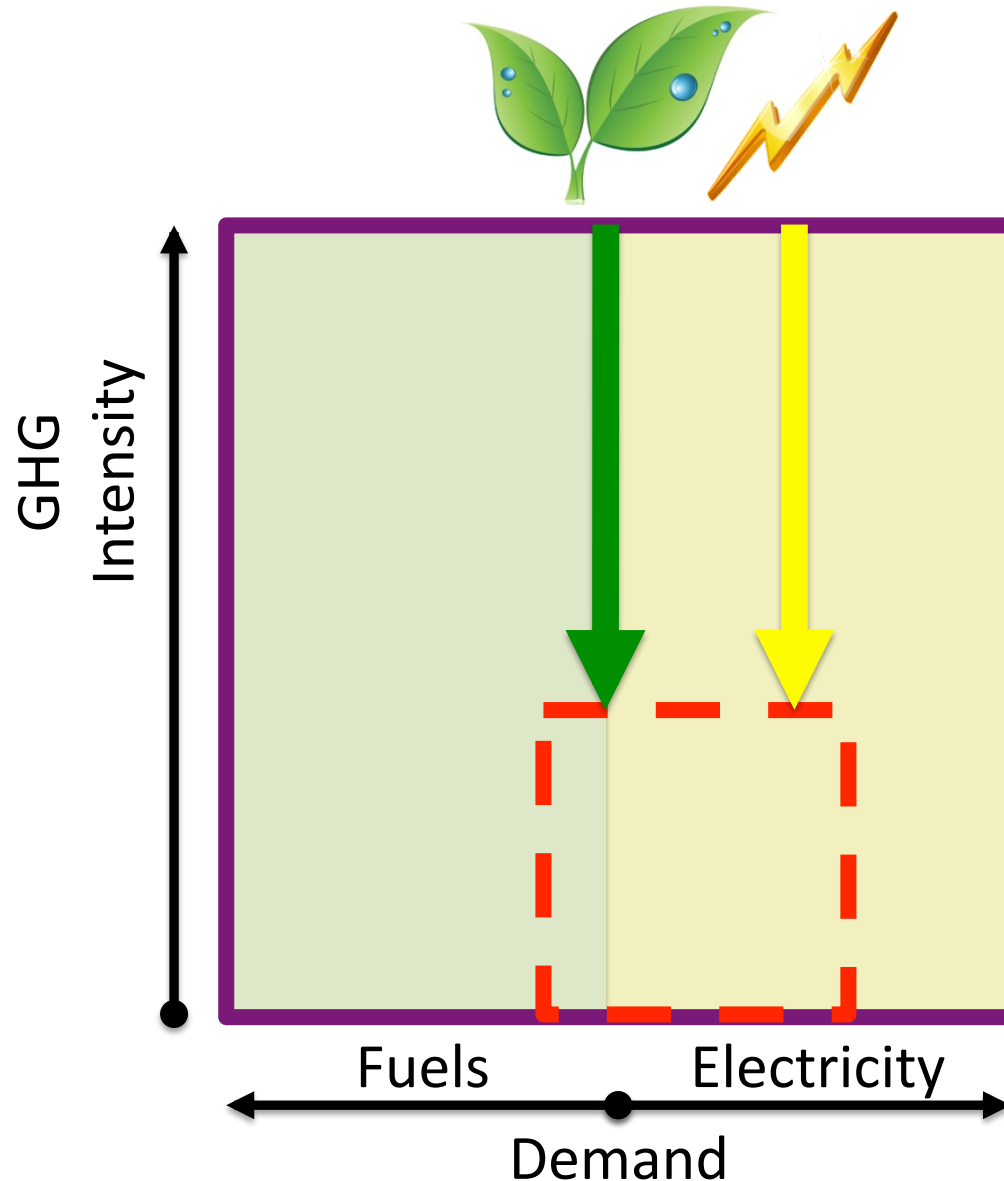
1. Efficiency



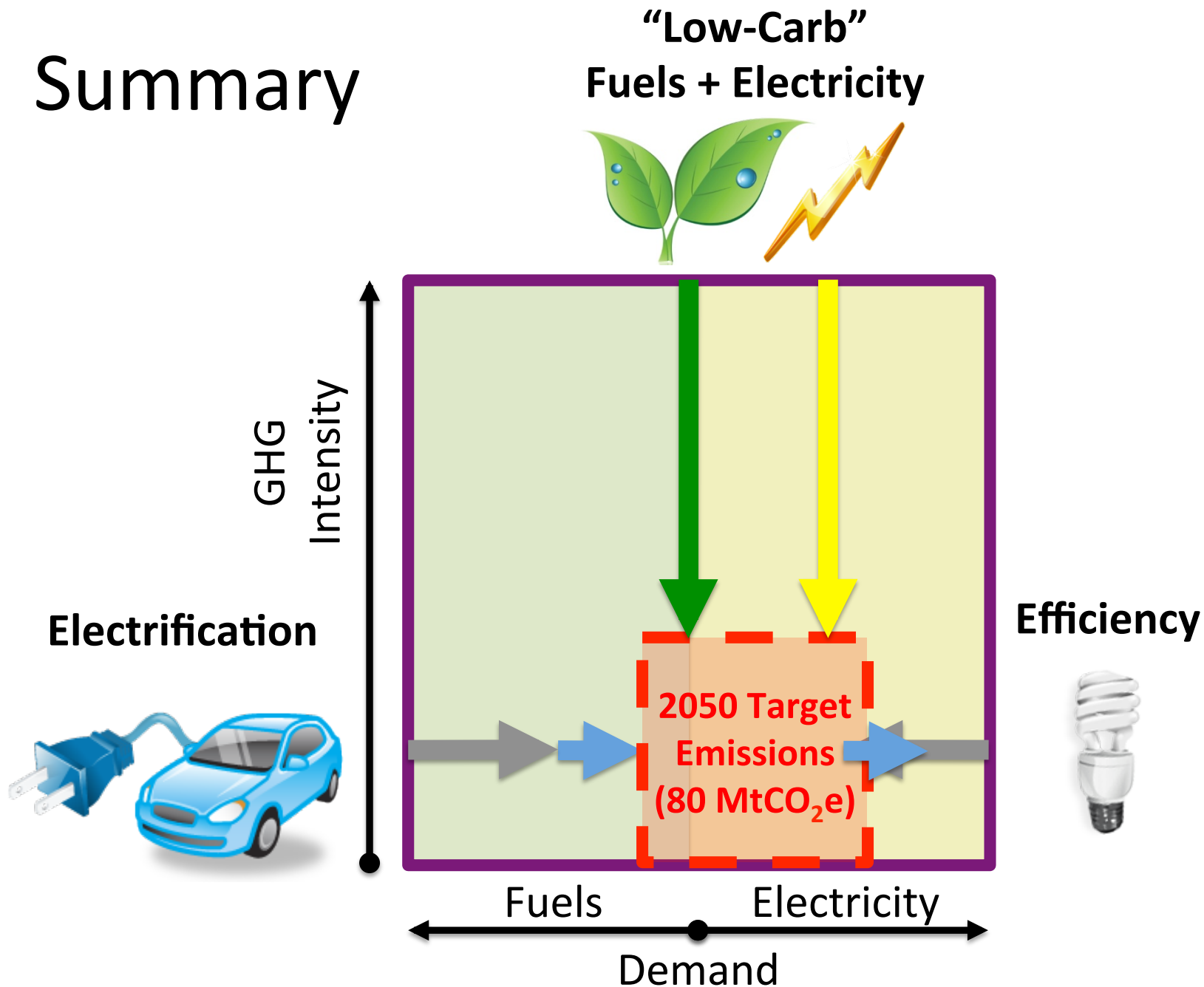
2. Electrification



3 + 4. “Low-Carb” Fuels + Electricity



Summary



Technology bins

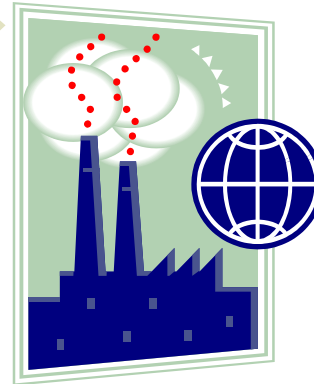
Bin 1:	Deployed at scale now
Bin 2:	Has been demonstrated, not available at scale
Bin 3:	In development
Bin 4:	Research concept

Three sectors of efficiency and electrification

– Buildings



– Industry

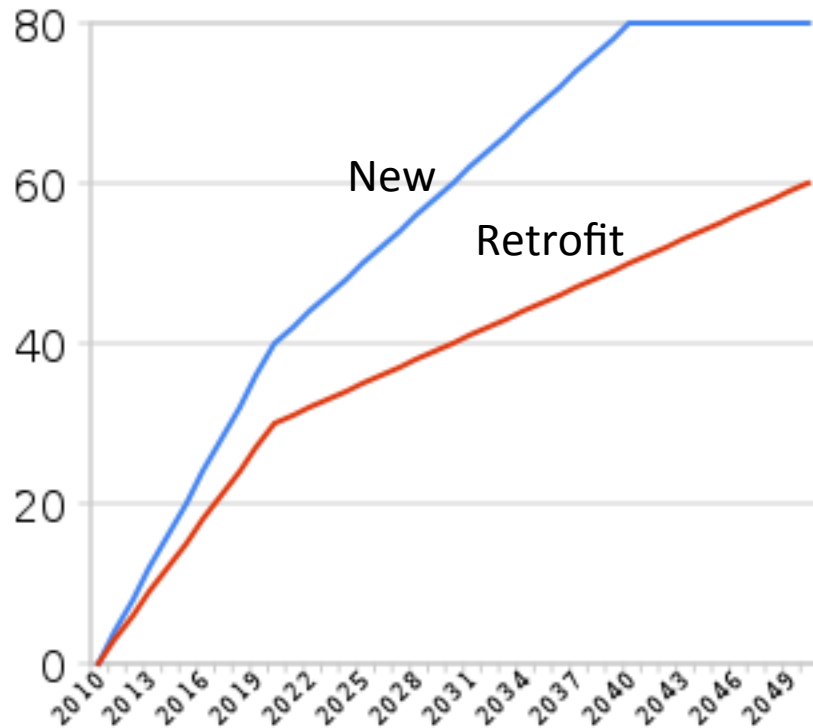


– Transportation

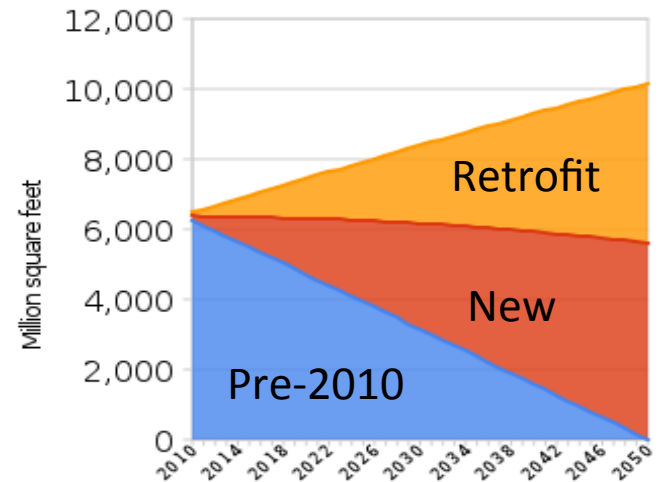


Building efficiency

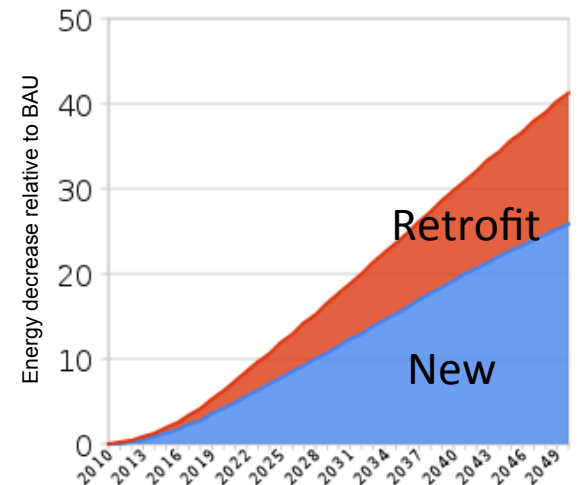
Efficiency decrease in energy from BAU



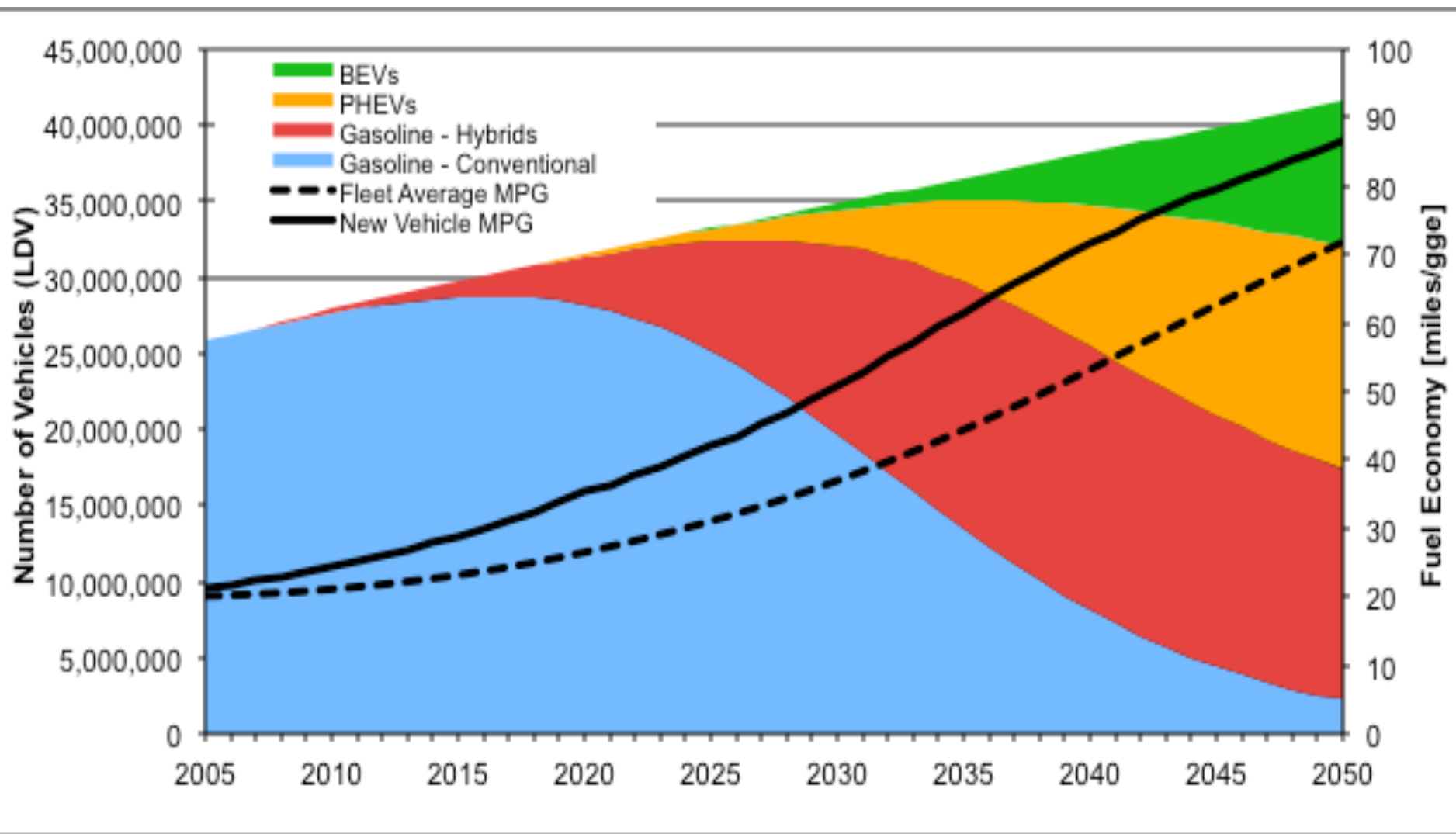
Building stock turnover



Cumulative energy decrease



Light-duty vehicle scenario



Efficiency Summary

Percent energy decrease from BAU



Buildings	40%	Cars	60%
Industry	0-15%*	Trucks	30%
* BAU 30-40% fr. 2005		Airplanes	50%
Electricity	31%	Bus, Rail	0%
Fuels	52%	Marine	40%

Electrification: Not just for cars!

Electrification saturation from BAU			
Buildings	70%	Cars	44%
Industry	12%	Trucks	18%
Change in demand		Airplanes	0%
Electricity	+56%	Bus, Rail	100%
Fuels	-33%	Marine	0%



Buildings efficiency technology

Bin no.	Space conditioning and building envelope	Water heating	Appliances	Electronics	Other
1	High efficiency furnaces (including heat pumps), high efficiency air conditioning equipment, occupancy sensors, fiberglass super-insulation, cool roofs	High efficiency water heaters, on-demand water heaters	Energy Star appliances (~20%), soil sensing clothes- and dishwashers, horizontal- axis clothes washers, high-spin clothes dryers	Automatic sleep mode, more efficient transformers	More efficient motors and fans, LED lighting, magnetic induction cooktops
2	Vacuum panel insulation, whole-building optimal energy management	Heat pump water heaters, solar hot water, waste heat recovery, whole-system integration	Higher efficiency appliances (~40-50%)	Network proxying	Organic LED lighting
3	Non-invasive insulation retrofits				
4			Magnetic refrigeration		

Industry technology maturity → complex

Bin	Technologies
1	Ultra high efficiency furnaces, controls and monitoring systems, waste heat recovery systems
2	Membrane technology for separations, super boilers, advanced/hybrid distillation, solar boiler systems
3	Integrated & predictive operations/sensors, advanced materials and processing, electrified process heating (e.g. microwave), process intensification
4	New membrane materials, advanced materials/coatings

Technology maturity light duty transportation

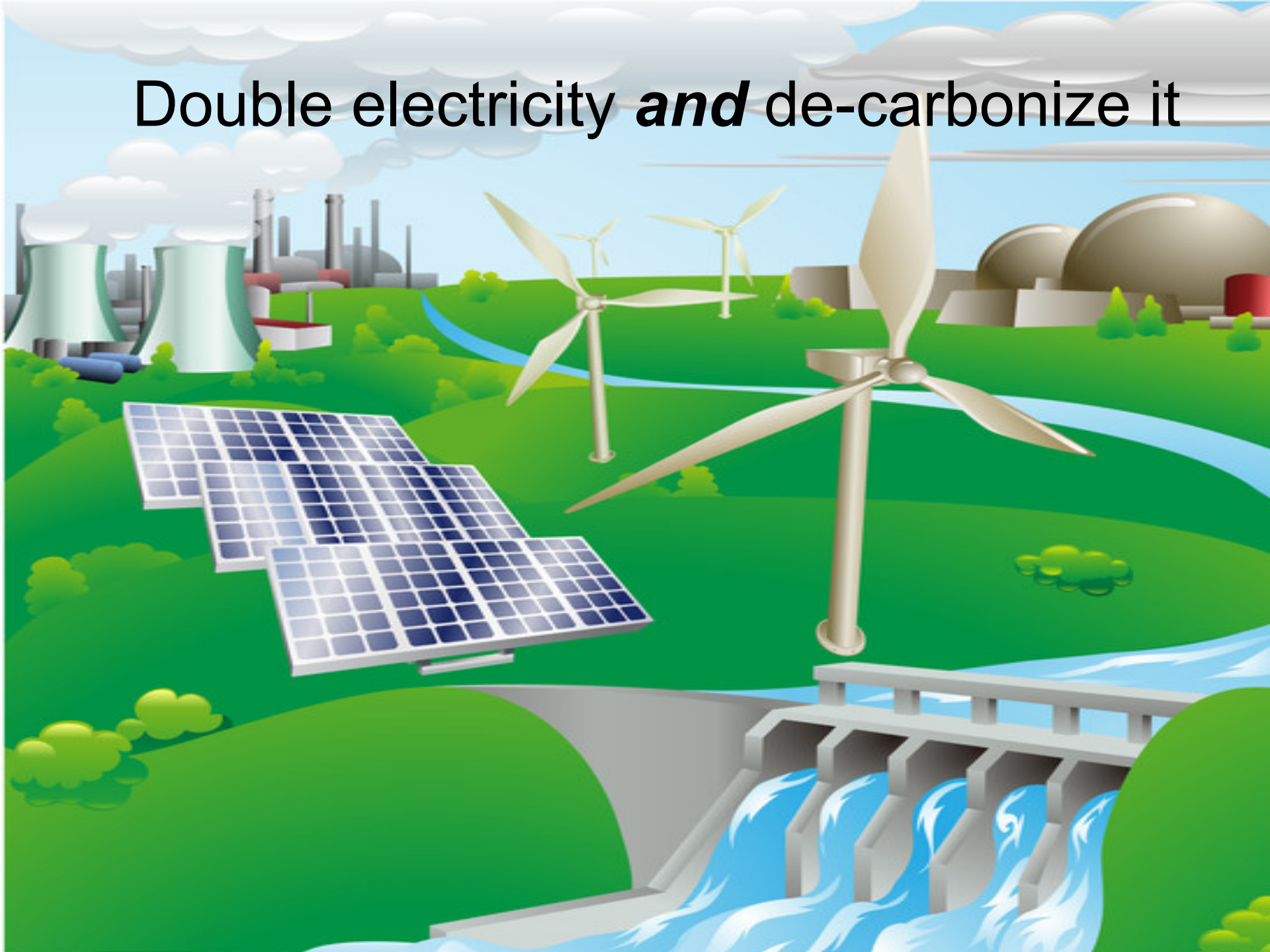
Bin	Light-Duty Vehicles	Charging infrastructure and management
1	Hybrid engines, lightweight materials, better aerodynamics, low-resistance tires	Low- and high-voltage charging hardware, simple charging (on-demand or timer)
2	Battery- electric and plug-in hybrids	“Smart” charging via signals from utility or control service
3	Advanced batteries	Two-way electricity flow (“Vehicle-to-grid”)
4	None	

Projected Energy Demands

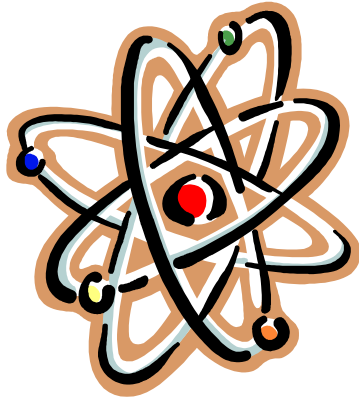
Energy Carrier	Units	2005	2050 BAU	2050 E1
Electricity	TWh/yr	270	470	510
HC Fuels	bgge*/yr	36	68	25

*Billion gallons gasoline equivalent

Double electricity ***and*** de-carbonize it



There are 3 Low-Carbon Electricity Options



Nuclear

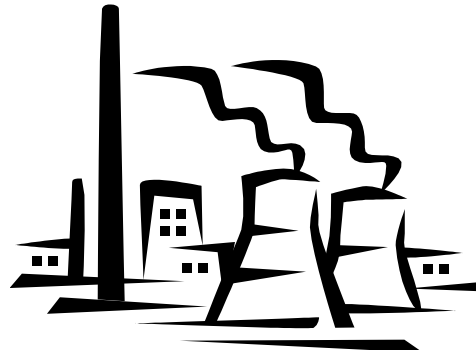
62% nuclear

44GW

33% renewables

5% natl gas

load balancing



Fossil/CCS

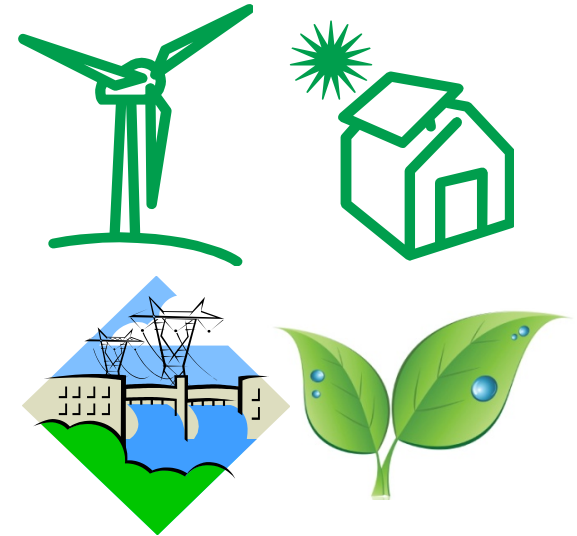
62% fossil/CCS

49 GW

33% renewables

5% natl gas load

balancing



Renewables

90% renewables

(70% intermittent)

160 GW

10% natl gas

load balancing

(Also use to make hydrogen)

Nuclear Electricity

- Mature technology
- Assume 62% nuclear, 33% renewables (RPS)
- Required build rate 2020-2050: 1.4 GW per year
- Adequate land, fuel, safety
- Cooling water: use air cooling?
- Cost Estimates
 - Estimates range from 5-6 to 18 ¢/kWh (levelized)
 - Best estimate: 6-8 ¢/kWh, similar to fossil/CCS and renewables
- Challenges of Nuclear
 - Waste disposal (CA law)
 - Public acceptance
- Fukushima –what happened, what does it mean for CA?

Coal or Gas with CCS has emissions

- **Coal or gas with CCS can provide 100% of projected 2050 energy demand assuming full electrification and aggressive energy efficiency 48 GW.**
- **Emissions:** At 90% capture rate, residual emissions =
 - 28 mmt CO₂e – for coal – about 1/3 the total budget
 - 13 mmt CO₂e --- about 1/6th the total budget
- Using gas without saline reservoirs, about ~60 years capacity exists in state
- Massive new infrastructure required with high transportation costs

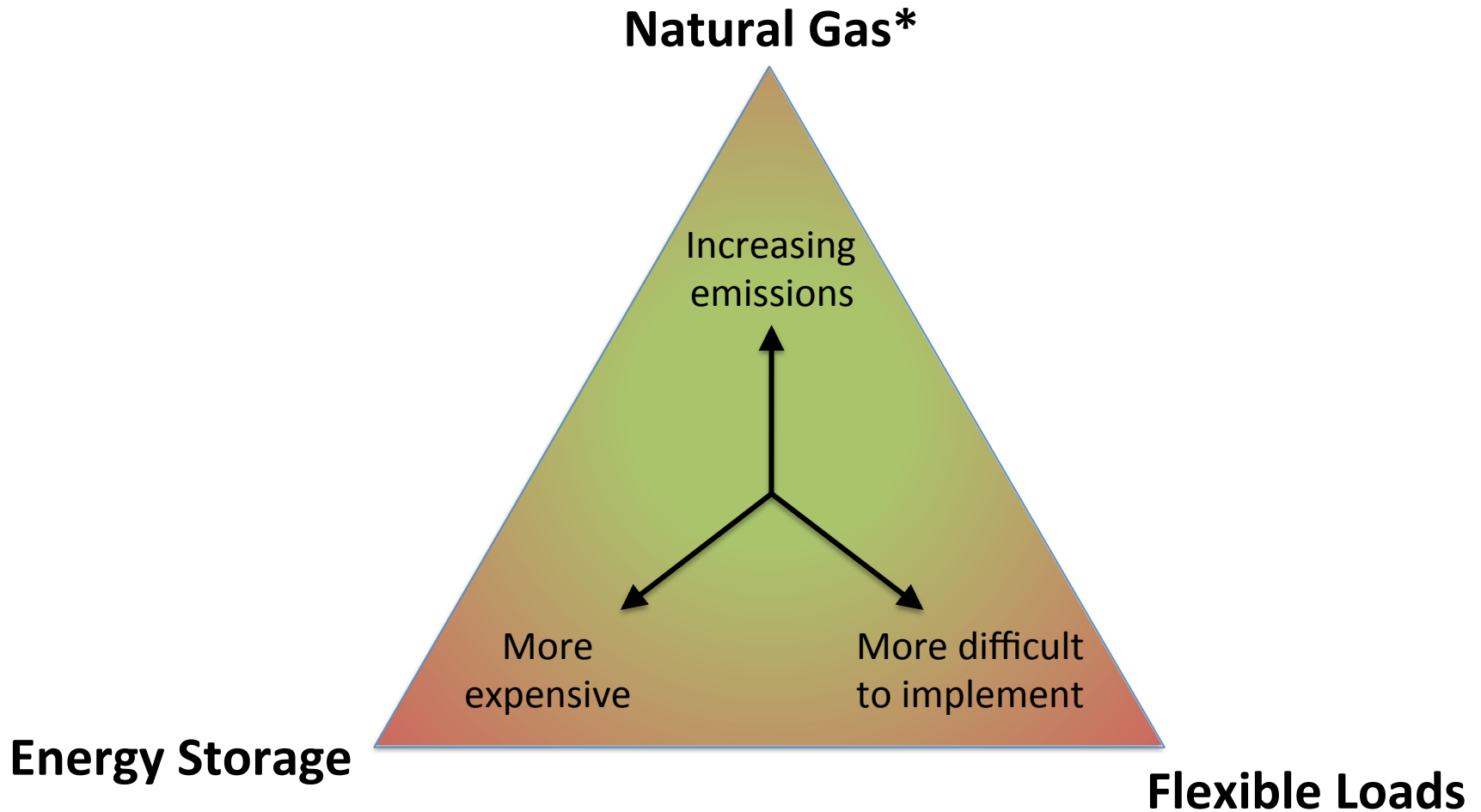
Renewable Electricity

Type	Share of Total Supply	Realistic Case Supply (GWh)	Capacity Factor	Generation Capacity Required in 2050 (GW)	CEC Resource Upper Limit (GW)	Fraction of Total Resource Consumed	Displaced land area (km ²)
Wind - onshore	30%	159,000	40%	45.4	150	30%	11,470 (230)*
Wind - offshore	10%	53,000	40%	15.1	293	5%	3,820 (80)*
Concentrated Solar Power (CSP)	20%	106,000	27%	44.8	1061	4%	1,620
Centralized Photovoltaic (PV)	10%	53,000	27%	22.4	17,000	0.1%	1,960
Distributed PV	10%	53,000	27%	22.4	78	29%	1,960 (0)*
Biomass	5%	26,500	85%	3.6	10.7	33%	35,600 (0)*
Hydroelectric	5%	26,500	30%	10.1	24	42%	1,430
Geothermal	10%	53,000	90%	6.7	25	27%	400
Total	100%	530,100		170.5			58,250 (5,710)*

*About 1.4% of California land area

Strategy	Assumed plant size	Total plant capacity needed in 2050	Build rate 2011-2050 (Plants/year)
Nuclear	1.5 GW	44 GW	0.7
Fossil/CCS	1.5 GW	49 GW	0.8
Renewables Mix		160 GW	
Wind	500 MW	59 GW	3
Central Solar (CSP and PV)	500 MW	57 GW	3
Distrib'd. Solar PV	5 kW	19 GW	100,000
Biomass/CCS	500 MW	7 GW	0.3
CA Biofuels	50 Mgge/yr	5,500 Mgge/yr	3
H₂ (onsite NG)	0.5 Mgge/yr	800 Mgge/yr	40
H₂ (central plant)	440 Mgge/yr	7,200 Mgge/yr	0.4

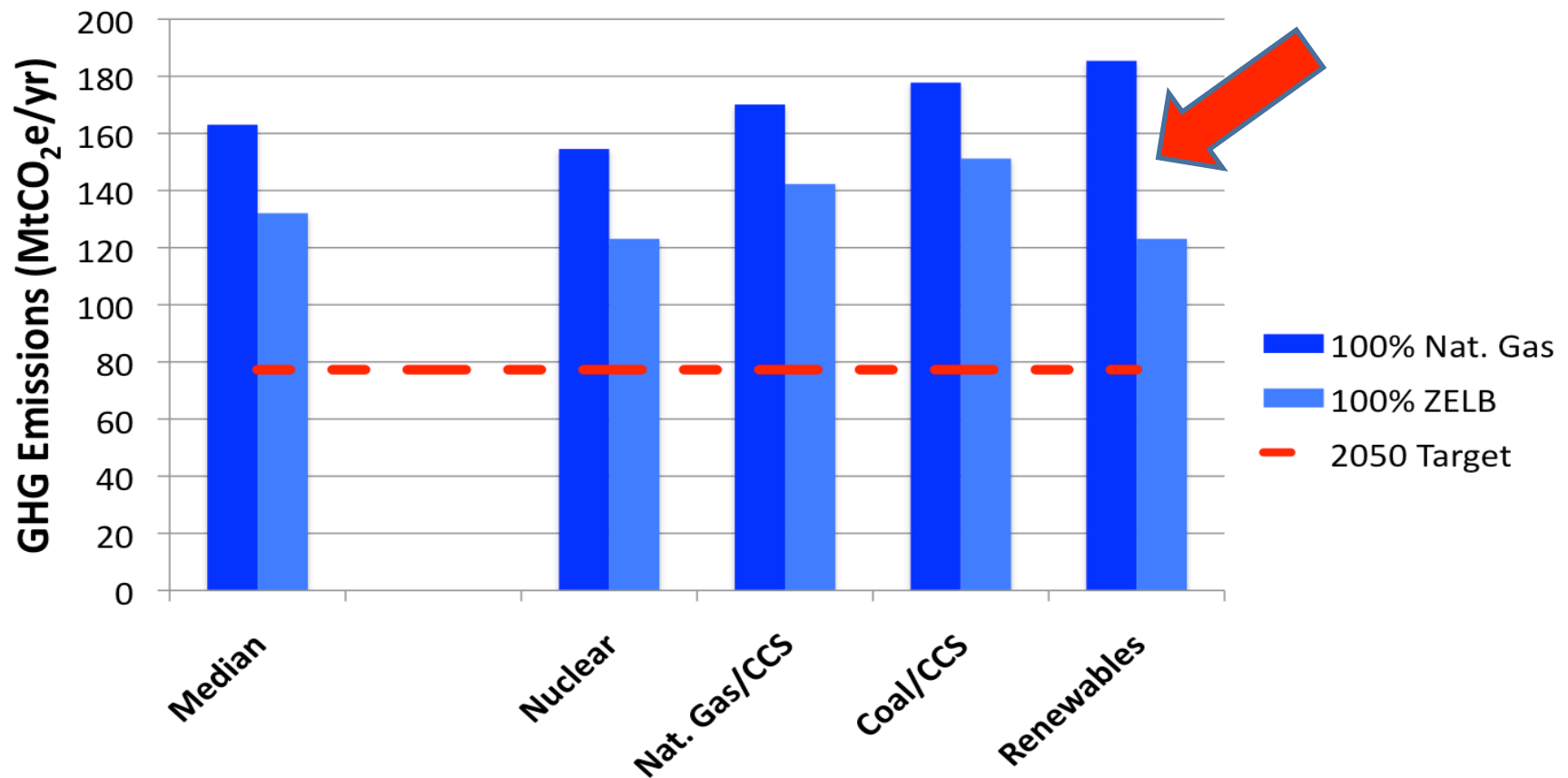
Load balancing can add emissions:



** May be possible with CCS in future*

Zero-Emission Load Balancing (ZELB)

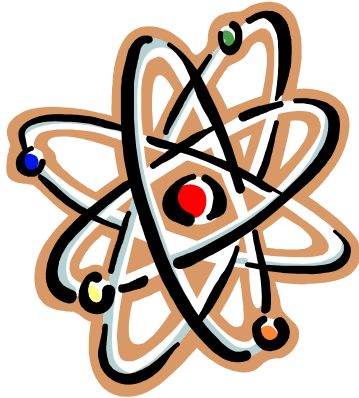
GHG Impact of Zero-Emissions Load Balancing (ZELB)



ZELB

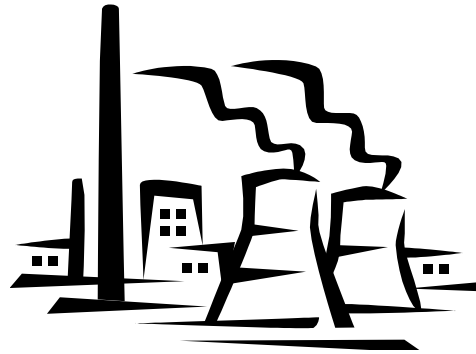
- More challenging for the maximum renewables case
 - GW-days of storage needed
 - Smart grid solution is a challenge
 - Smart meter fiasco
 - Completely change business model to demand follows load vs load follows demand
 - Need whole different system of system control – but will this ever solve the GW-day problem?
- Would be easier to have significant baseload power
 - No more hydro likely
 - Renew interest in geothermal energy
 - Choose nuclear or CCS

Summary: Electricity



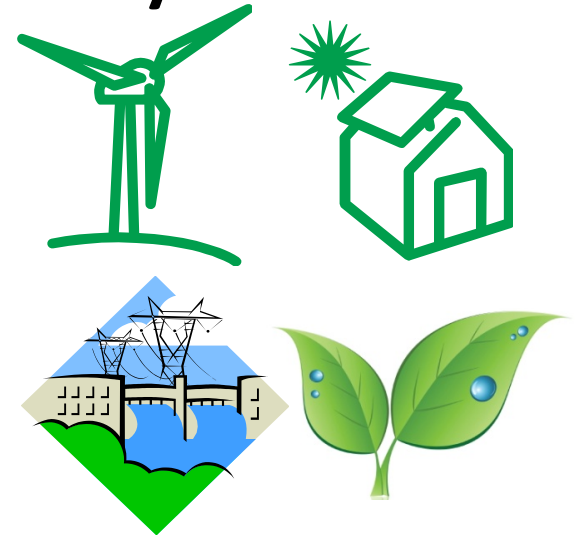
Nuclear

Fewest plants
Less load balancing
Existing laws,
safety, public
opinion, waste, etc.



Fossil/CCS

Similar to nuclear,
CO₂ infrastructure
Reserve CCS for
decarbonized fuel?
Has emissions: 90%
capture



Renewables

3x plants as baseload
(160 vs. 50 GW)
More load balancing
and commitment to
ZELB

Are we going to have base load power?

- If yes, then:
 - Do we want to deal with the issues of nuclear power or
 - Can we do CCS /fossil for baseload?
- If no, then
 - Accept the emissions associated with load balancing with natural gas?
 - Commit to completely restructure the electric utility?)
 - Will there be a major breakthrough in energy storage technology to handle GW-days of demand?
 - Should we decide to give up on electricity reliability?

Nuclear and CCS technology bins

Bin	Nuclear Technology	Coal or Natural Gas CO2 Capture	CO2 Storage
1	Generation III+ reactors	High-efficiency coal gasification, high-efficiency natural gas combined cycle, ultra-supercritical pulverized coal combustion, solid-oxide fuel cell (SOFC), solvent separation	Injection into oil/gas reservoirs
2	Small modular reactors (LWR)	Post-combustion CO2 capture technologies with 90% capture efficiency, integrated gasification systems with CCS, amine solvent separation	Saline aquifer injection
3	Generation IV (including small modular Na-cooled reactors)	New capture methods with >90% effectiveness, lower cost CO2 capture technologies of all kinds, metal-organic framework separations, membrane separation	Coal bed injection
4	None	None	Shale injection

Renewable technology bins

Bin	Wind	Concentrated Solar Power (CSP)	Solar Photovoltaic (PV)	Geothermal	Hydro and Ocean	Biomass
1	Onshore, shallow offshore turbines	Parabolic trough, central receiver	Silicon PV, Thin-film PV, Concentrating PV	Conventional geothermal	Conventional hydro	Coal/biomass co-firing, direct fired biomass
2		Dish Stirling				Biomass gasification
3	Floating (deepwater) offshore turbines		"Third generation" PV		Wave, tidal and river turbines	
4	High-altitude wind			Enhanced geothermal systems (EGS)		

Load balancing technology bins

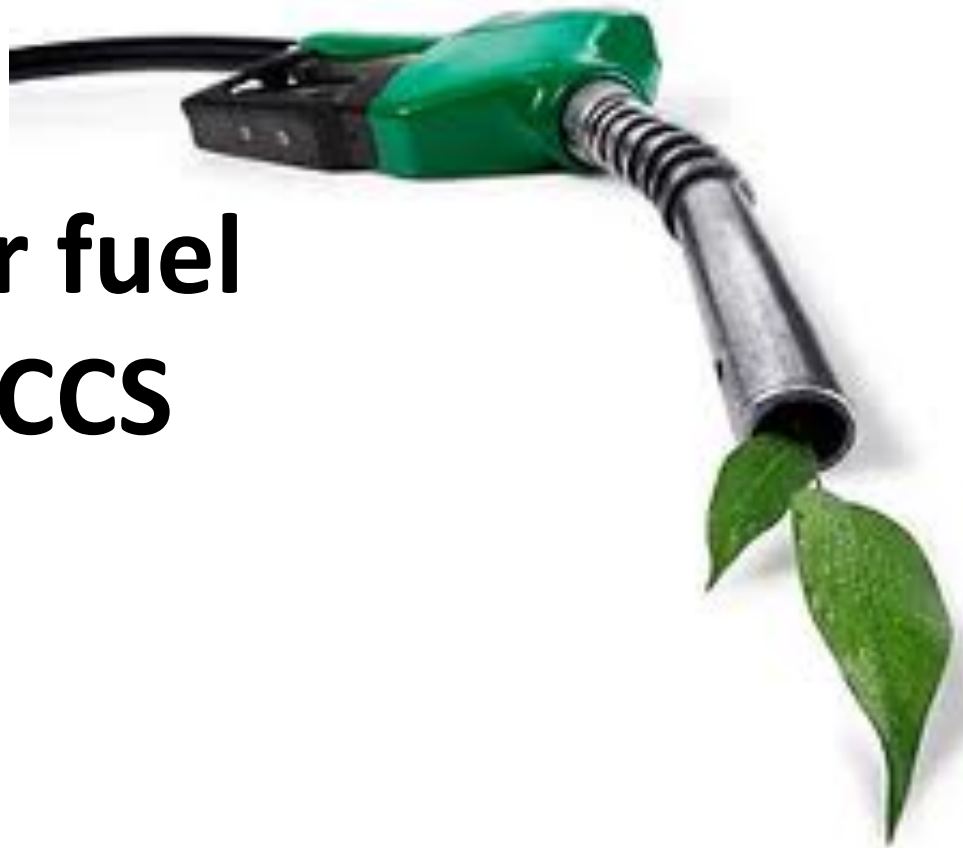
Bin	Natural Gas	Storage*	Demand Side Management
1	Combustion turbine	Pumped hydro	Commercial-scale critical peak demand response
2		“First generation” compressed air energy storage (CAES), battery technologies (Na/S, advanced Pb/Acid, Ni/Cd, Li ion as found in electric vehicles)	Commercial time-of-use demand-side management
3	Variable fossil generation with CCS	Battery technologies (some advanced Pb/Acid, Vanadium redox, Vanadium flow, Zn/Br redox, Zn/Br flow, Fe/Cr redox, some Li ion), flywheel, “second generation” CAES	Residential time-of-use demand-side management

The median electricity case

- About equal parts of nuclear/renewable/CCS
- A robust choice
- Meets current RPS, but doesn't exceed it
- ZELB "WAG": Assume
 - ½ load balancing is without emissions
 - ½ is with natural gas
- Almost all emissions from electricity are from load balancing

Still need 27 billion gge/yr fuel that can't have CCS

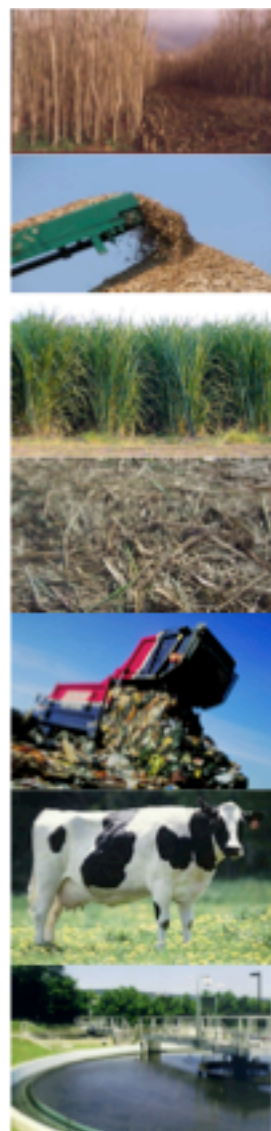
- Can't electrify
 - Heavy duty transport
 - Airplanes
- Plus fuel for
 - Load following
 - High quality heat
- Biofuels are the choice in the pipeline
 - How much biomass?
 - How green?



Meeting the demand for fuel

- **Total demand: 37 billion gge/yr**
- **About 10 billion gge/yr are for gas based electricity generation with CCS**
- **27 billion gge/yr can not have CCS**
 - **Heavy duty transport**
 - **Airplanes**
 - **Load following**
 - **High quality heat**

California Biomass



Woody energy crops

(0-20 mtons/yr)*

Woody residues

(17-24 mtons/yr)

Herbaceous energy crops

(4.5-21 mtons/yr)

Crop residues

(4-7 mtons/yr)

MSW

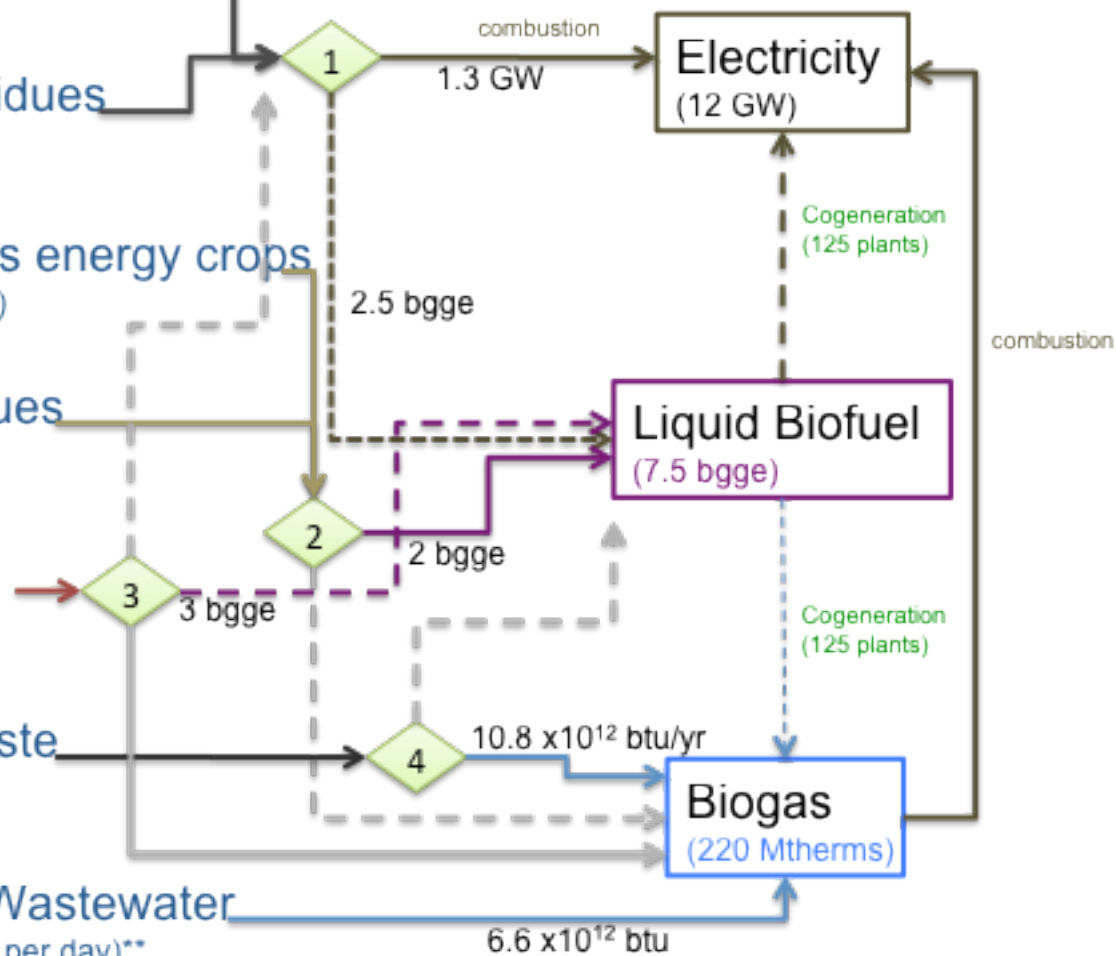
(10-40 mtons/
yr)

Animal Waste

(5.5-9 mtons/yr)

Municipal Wastewater

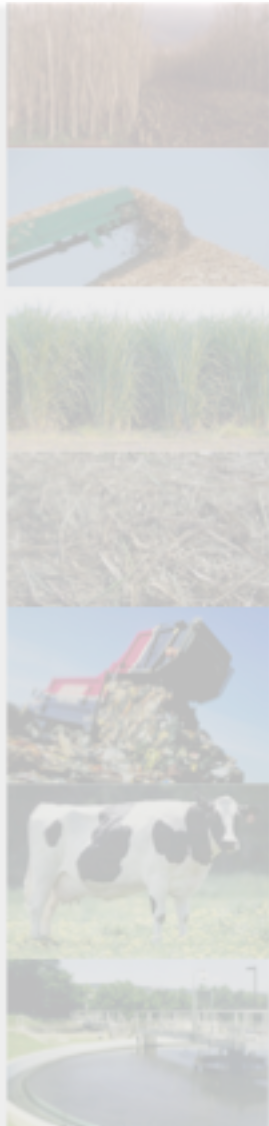
(3 billion gallons per day)**



*technical recoverable yield (50-80% of gross biomass production depending on type)

**not currently used for energy production

California Biomass



Woody energy crops
(0-20 mtons/yr)*

Woody residues
(17-24 mtons/yr)

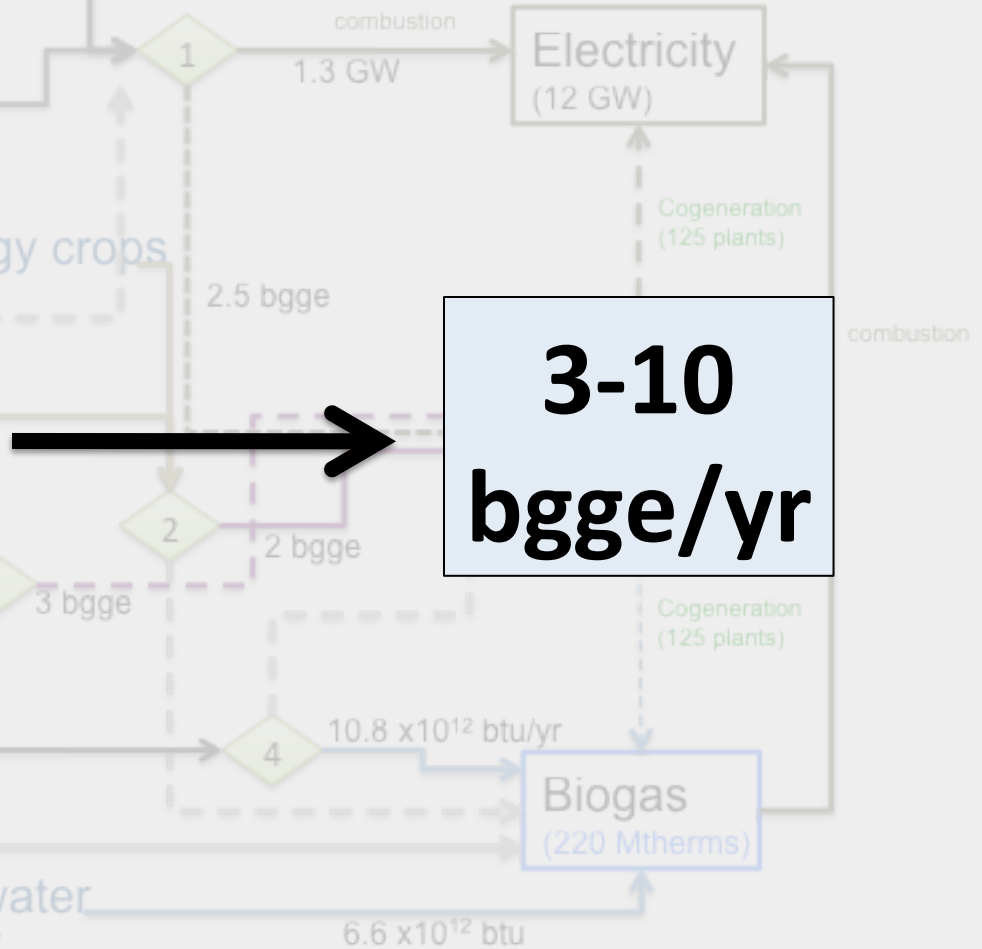
Herbaceous energy crops
(4.5-21 mtons/yr)

**41-121
mdt/yr**

(10-40 mtons/
yr)

Animal Waste
(5.5-9 mtons/yr)

Municipal Wastewater
(3 billion gallons per day)**

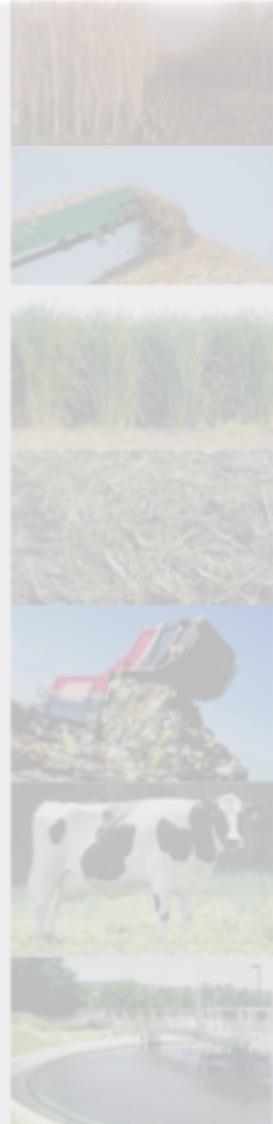


**3-10
bgge/yr**

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Median Case



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**41-121
mdt/yr**

(10-40 mtons/
yr)

Animal Waste
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Municipal Wastewater
(3 billion gallons per day)**

Imported

3 GW

(2.0 bgge/yr)

+ Cogeneration
(125 plants)

5.5

bgge/yr

+ Cogeneration
(125 plants)

7.5

bgge/yr

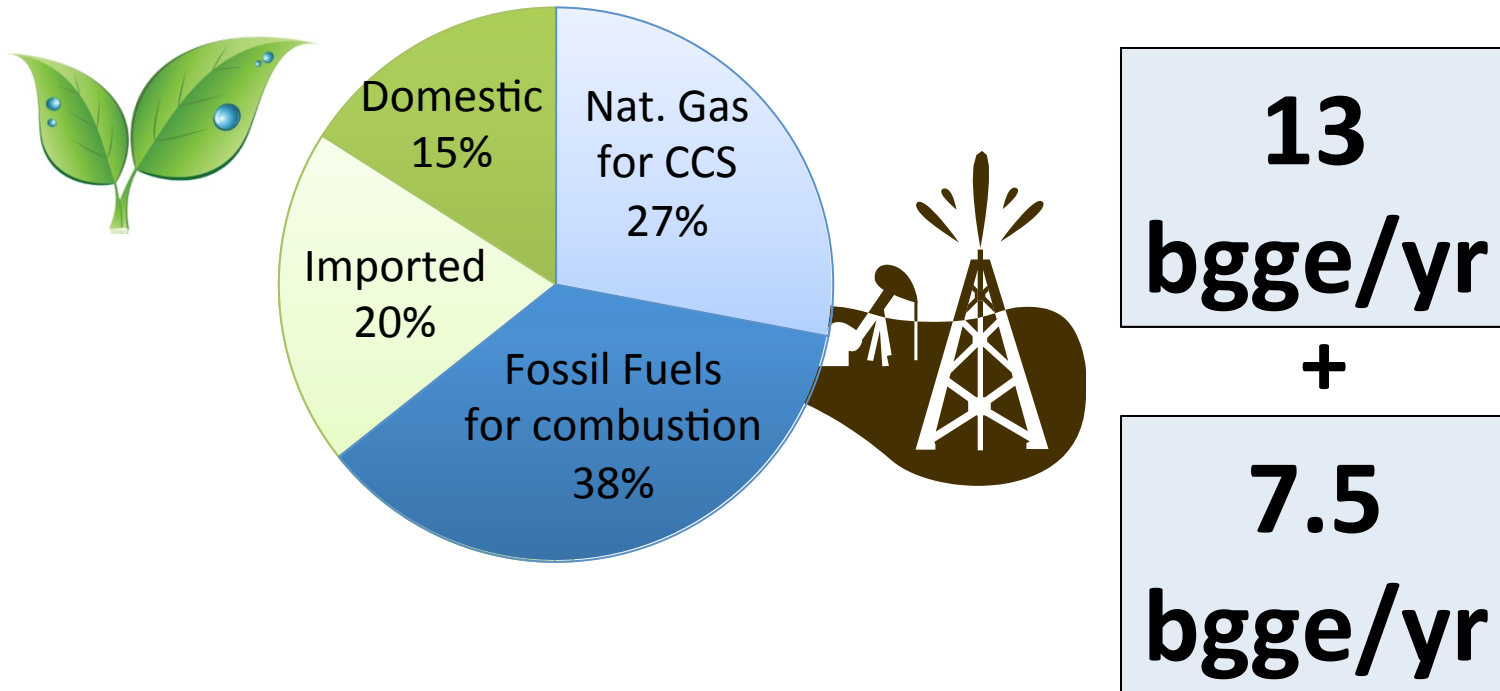


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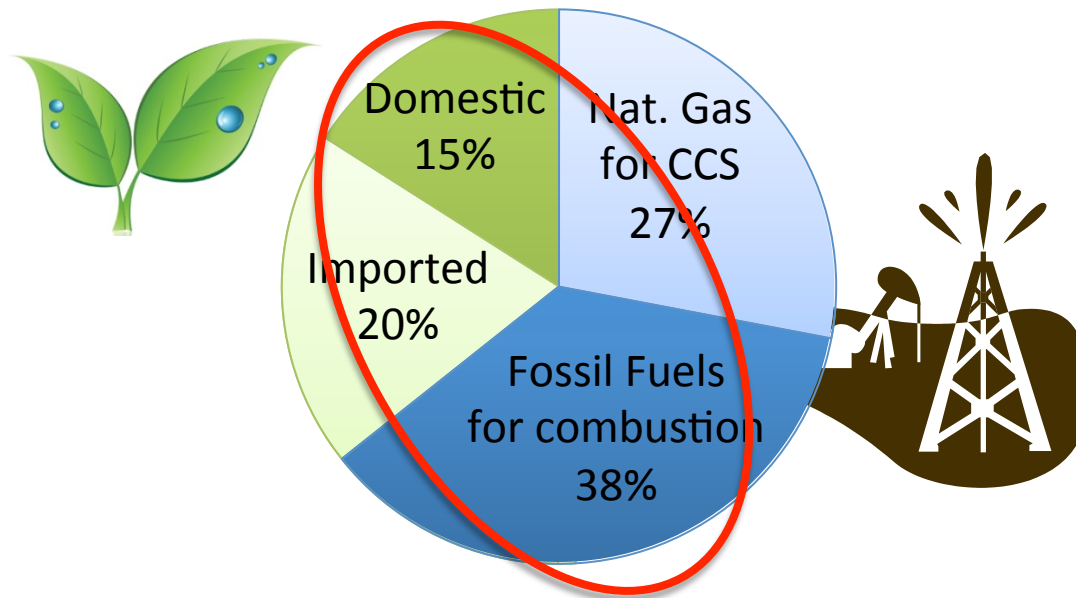
Median Case

**Total demand:
37 billion gge/yr**



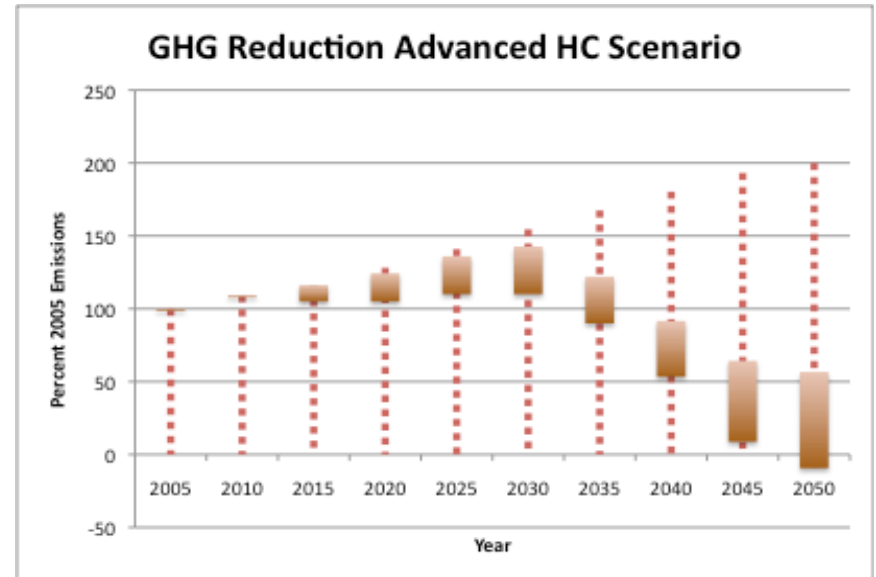
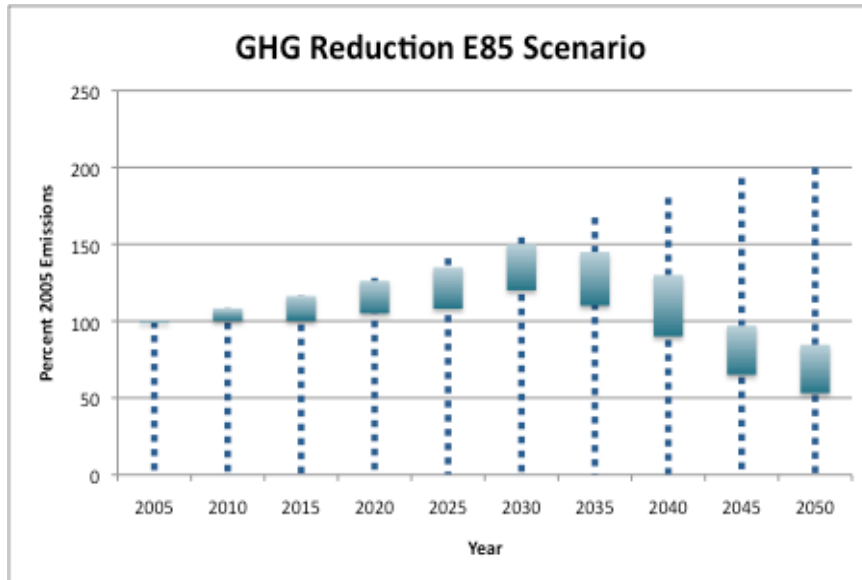
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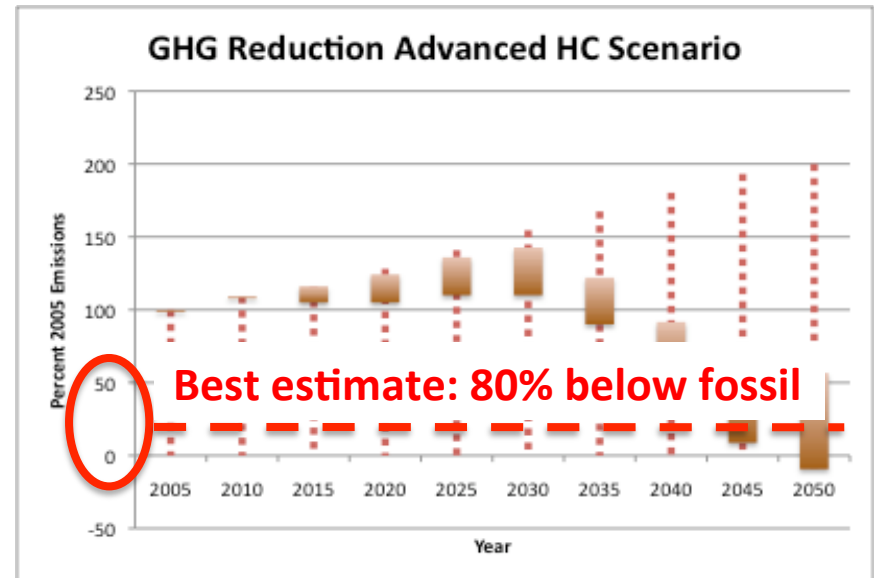
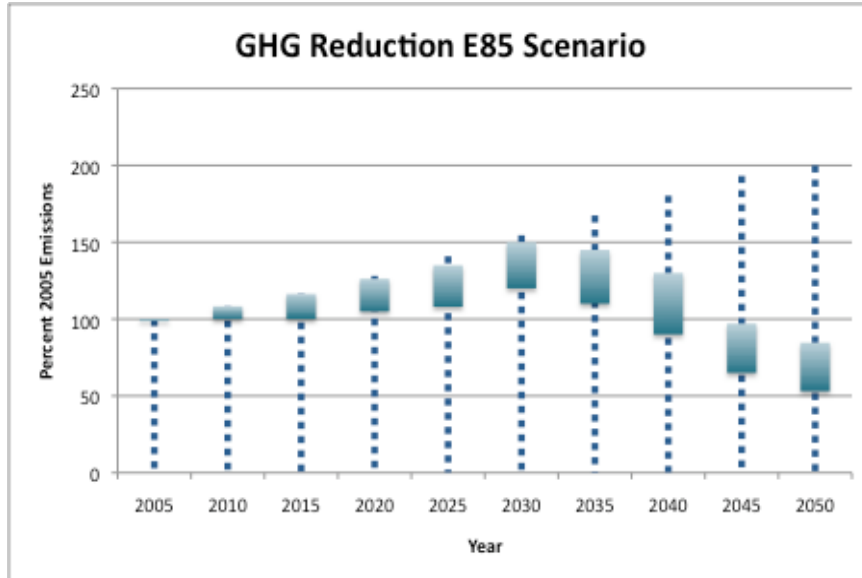
We might expect biomass to provide about ½ the fuel demand (27 bgge/yr) where CCS is not possible
including 2 bgge/yr for load balancing)

Biomass GHG reductions



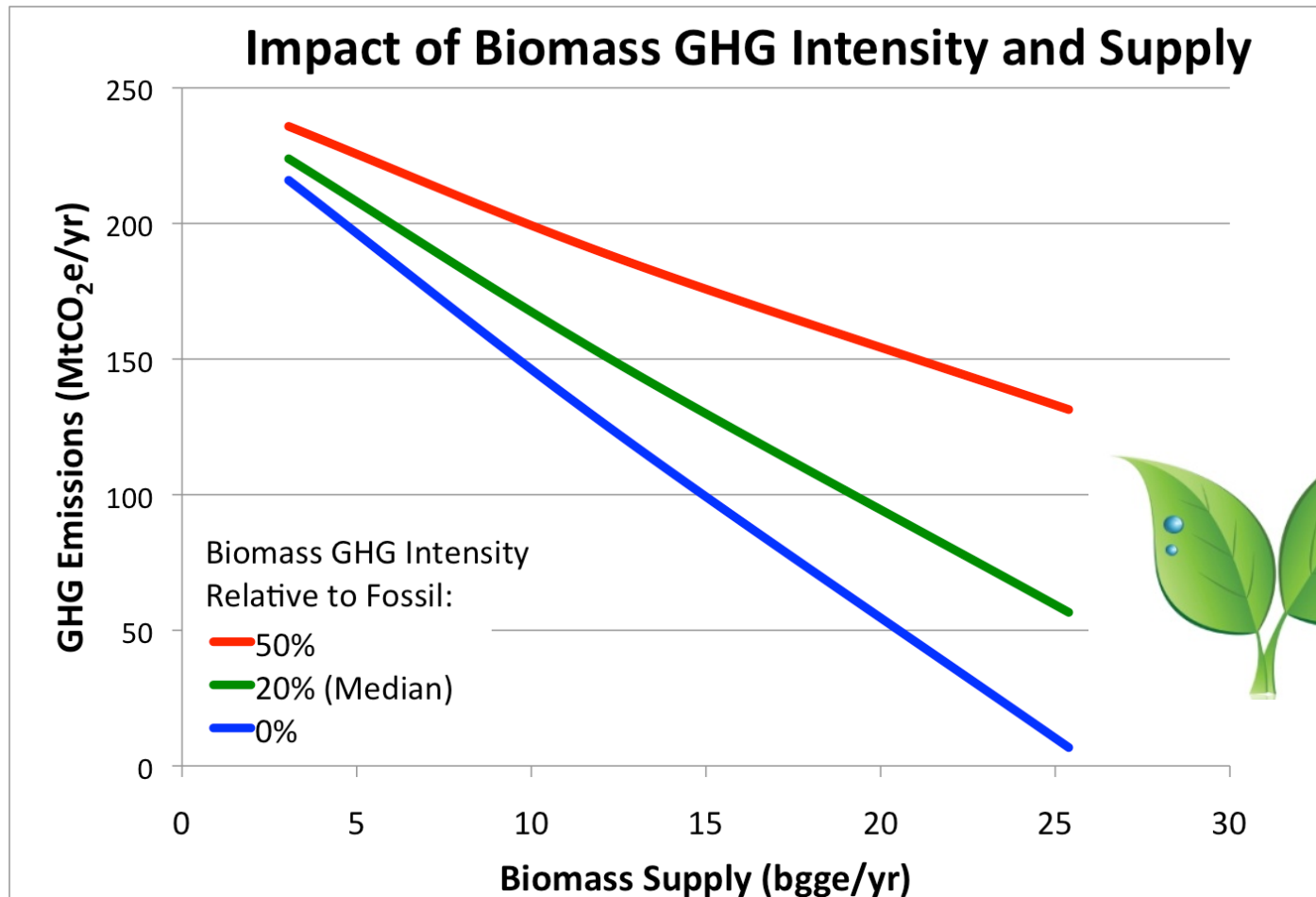
- Cellulosic E85 Falls Short (E100 could go farther)
 - Remaining petroleum footprint is high
 - Limitations on waste oil push biodiesel footprint higher (oil crops needed)
- Advanced Hydrocarbons have a chance to meet the goal
 - Direct replacement for diesel, gasoline and jet fuel with large GHG reductions

Biomass GHG reductions

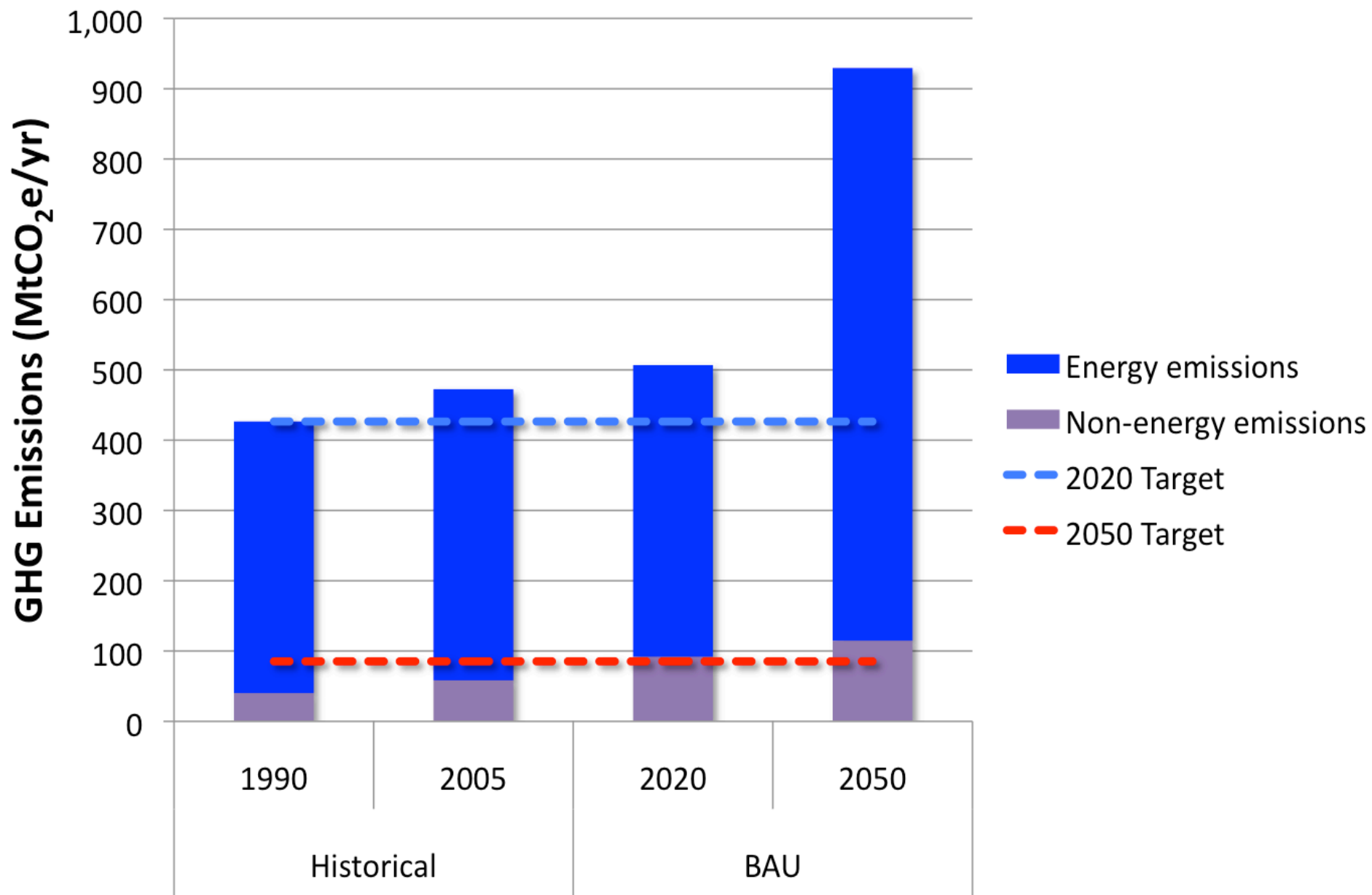


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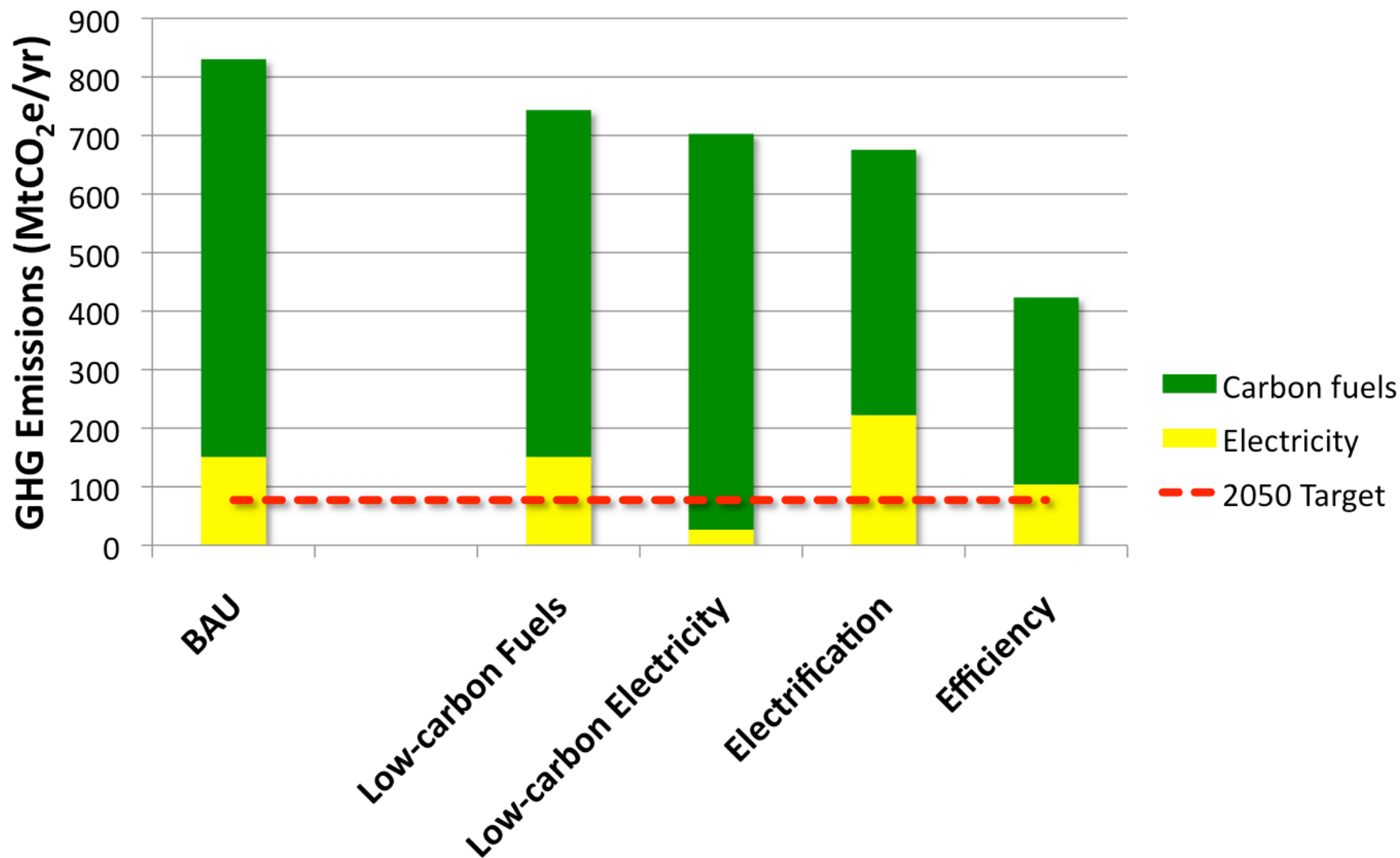
Biomass GHG Intensity and Supply



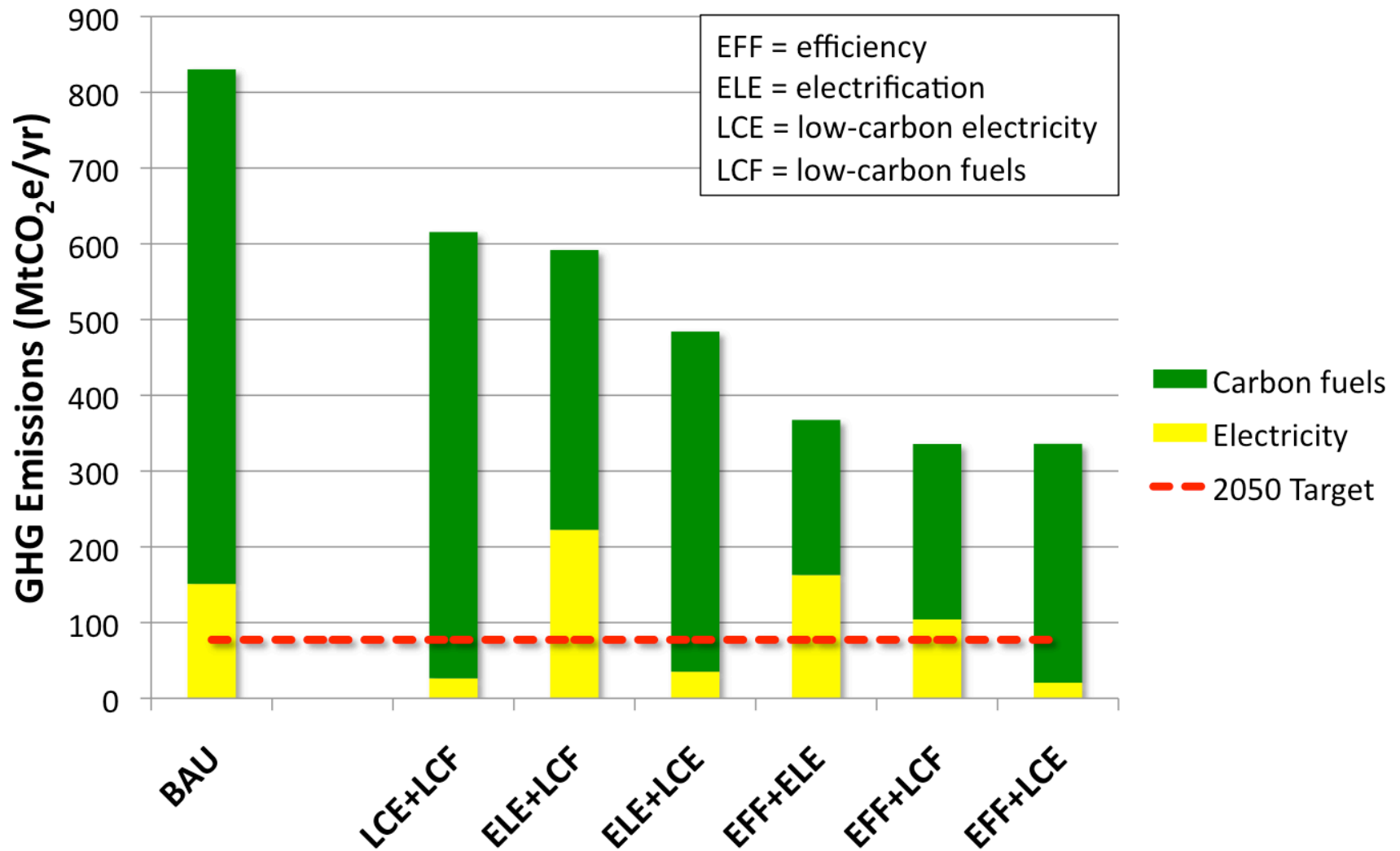
Historical and BAU Emissions



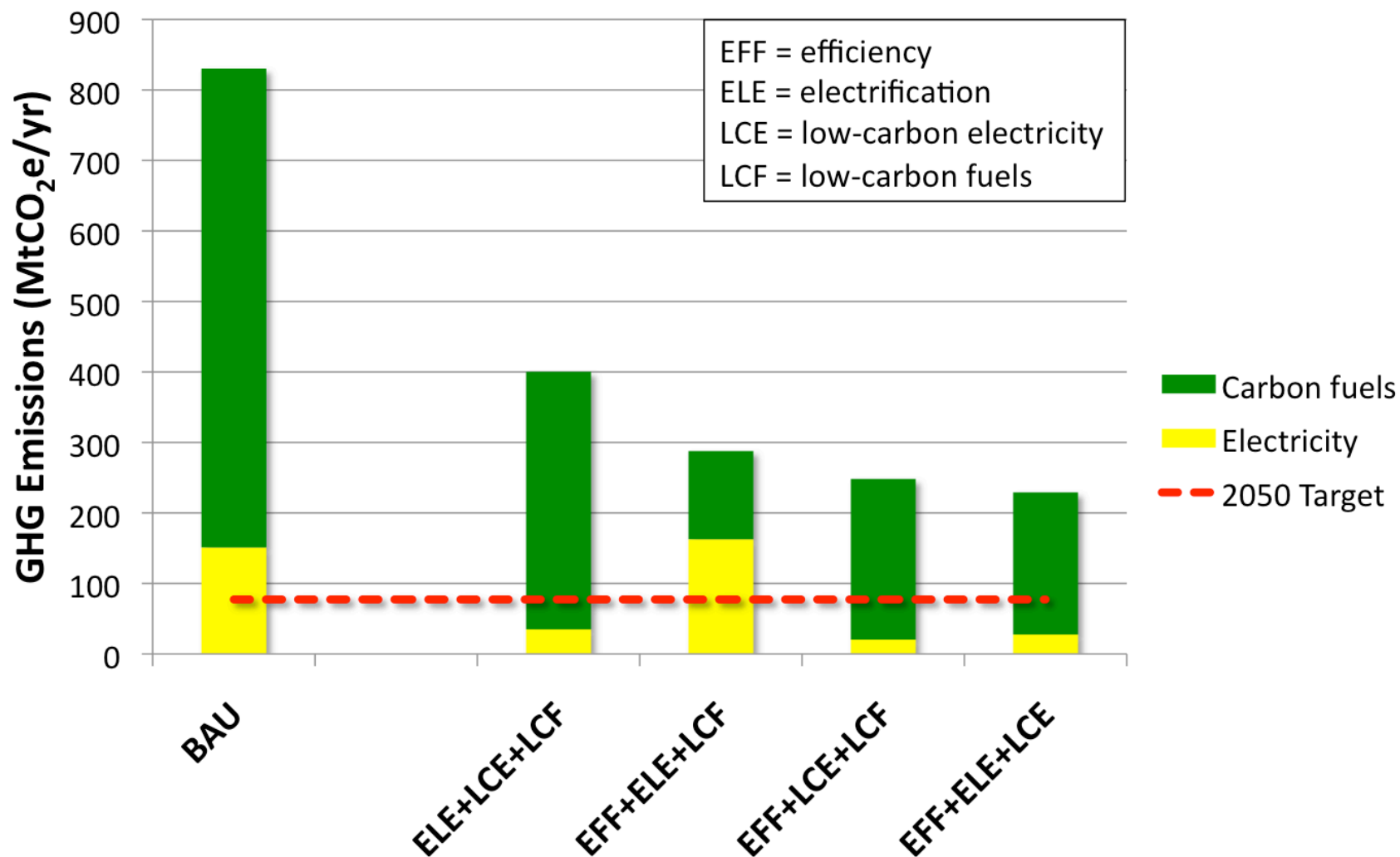
GHG Reductions with a Single Strategy



GHG Reductions with Two Strategies

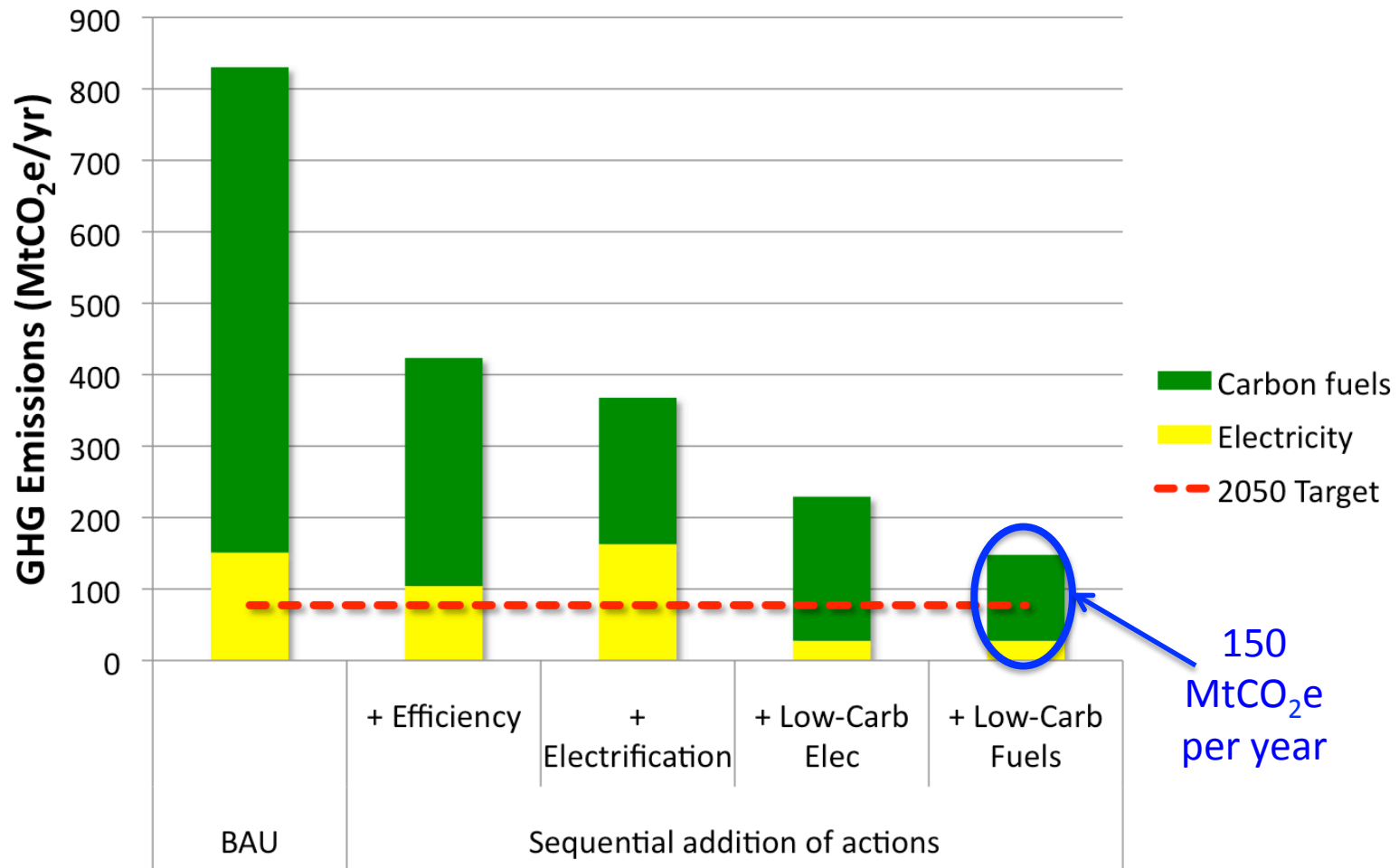


GHG Reductions with Three Strategies



Getting to 60%: All 4 Actions

Getting to 60% below 1990 level



Components of a 60% solution

Efficiency

Percent energy decrease from BAU

Buildings	40%	Cars	60%
Industry	0-15%*	Trucks	30%
*BAU 30-40% fr. 2005		Airplanes	50%
Electricity	31%	Bus, Rail	0%
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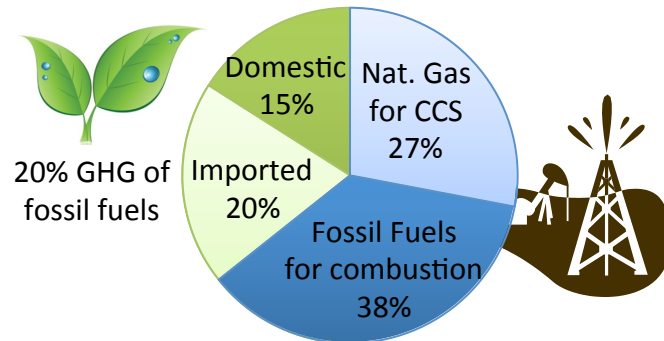
Electrification

Electrification saturation from BAU

Buildings	70%	Cars	44%
Industry	12%	Trucks	18%
Change in demand		Airplanes	0%
Electricity	+56%	Bus, Rail	100%
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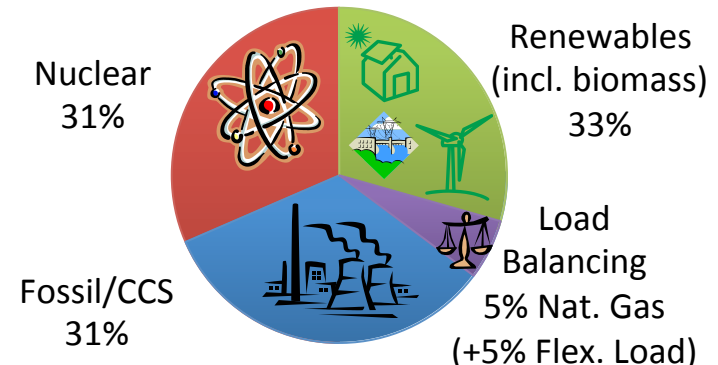
Low-Carb Fuels

Total demand: 37 billion gge/yr



Low-Carb Electricity

Total demand: 520 billion kWh/yr



Population: 50% increase from 2005 to 2050

GDP: 2.8% per year growth from 2005 to 2050

Strategies for Getting to 80%

1. 100% effective CCS
2. Eliminate fossil/CCS (use nuclear instead)

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)

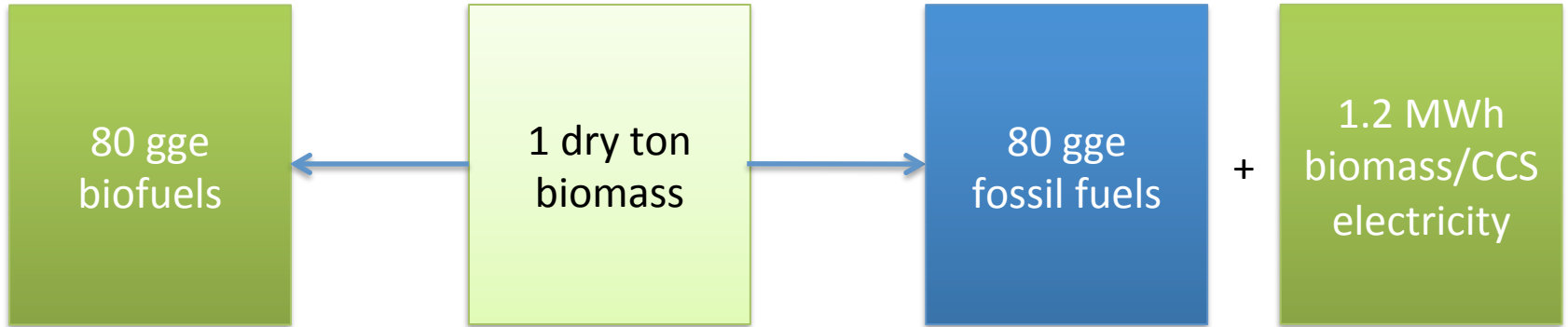
8. Double biomass supply
9. Biomass/Coal/CCS (make fuels + electricity)

10. Fuel from sunlight (need net-zero carbon source)
11. Fusion electricity
12. Others?

Biofuels

vs.

Biomass/CCS



0.11 tCO₂

**Net GHG:
0.1 tCO₂**

0.62 tCO₂

-0.73 tCO₂

**Net GHG :
-0.1 tCO₂**

Projected Energy Demands

Energy Carrier	Units	2005	2050 BAU	2050 E1	2050 H1 E1 plus H2
Electricity	TWh/yr	270	470	510	470
Fuels HC/H2	bgge*/yr	36/0	68/0	25/0	18/8

*Billion gallons gasoline equivalent

H₂

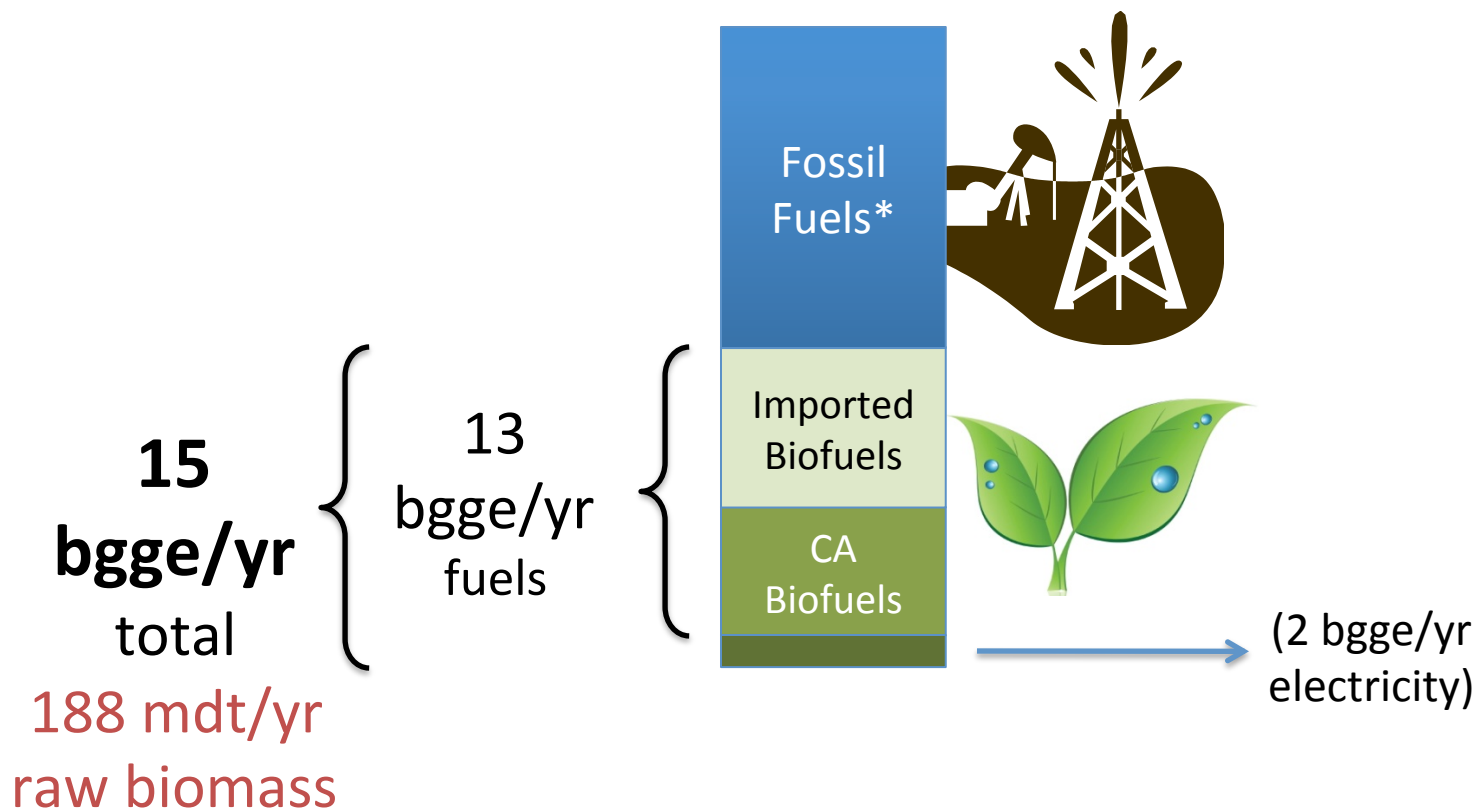
Hydrogen case

H₂

H₂ demand rel. to median case

Buildings	0%	Cars	22%
Industry	21%	Trucks	9%
Fuel shifts		Airplanes	0%
Electricity	-49 TWh	Bus	100%
Fuels	-7.7 bgge	Rail	0%
Hydrogen	8.0 bgge	Marine	0%

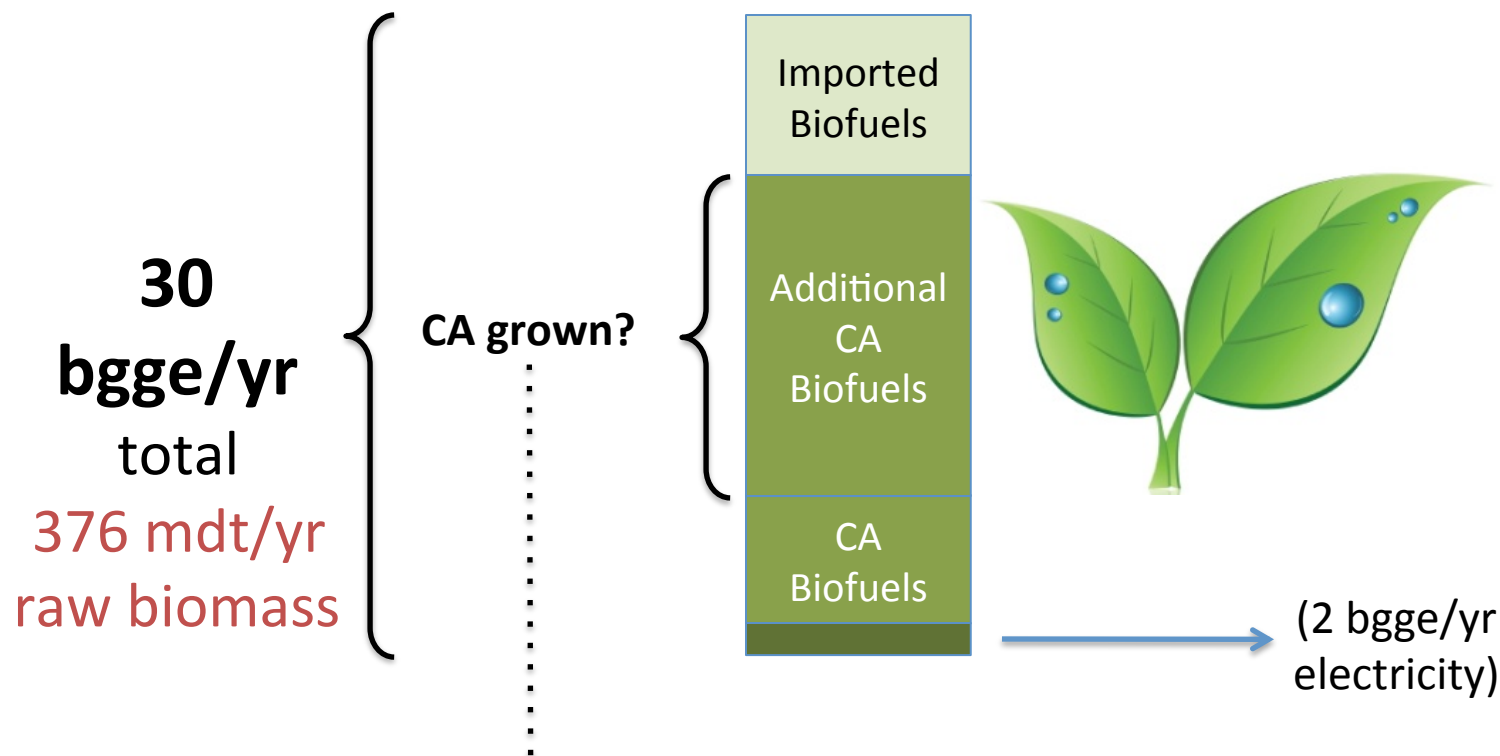
Doubling Biomass Supply



Median case

*Not including natural gas for CCS

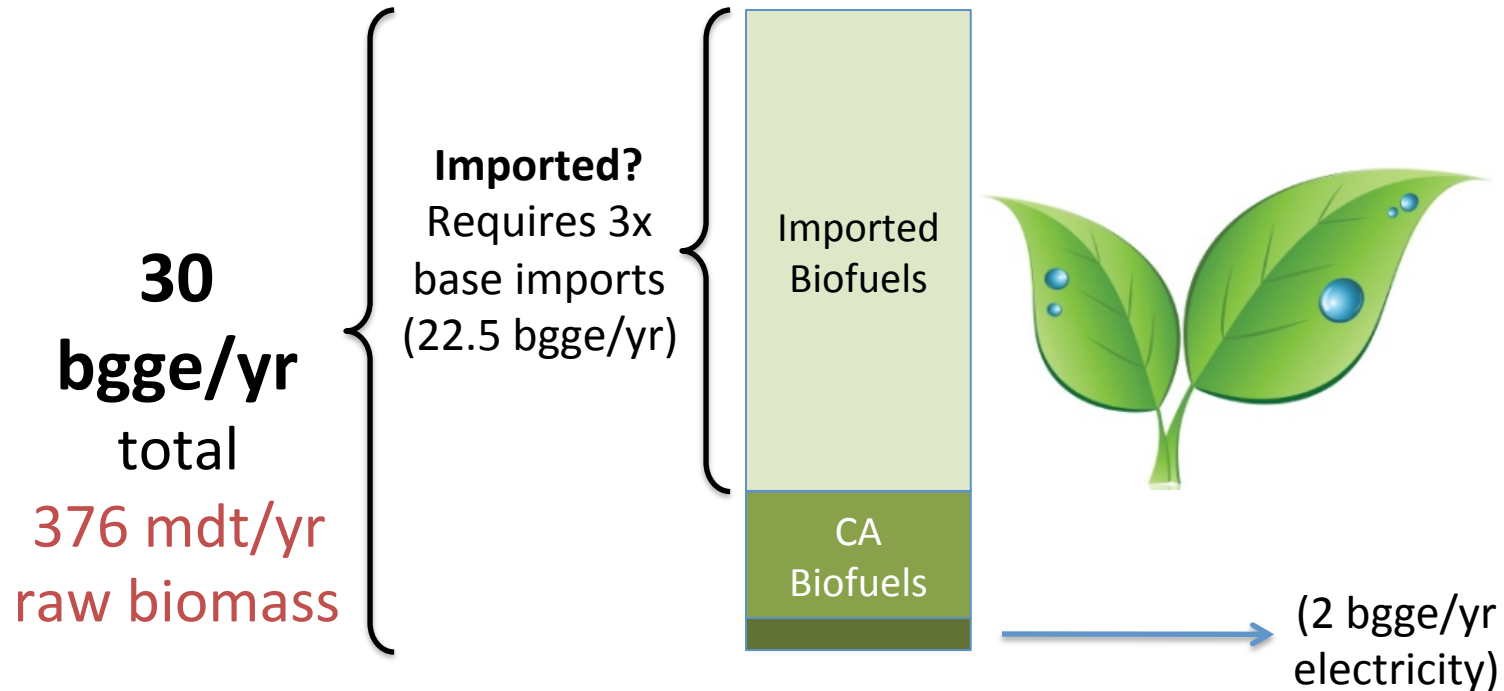
Doubling Biomass Supply



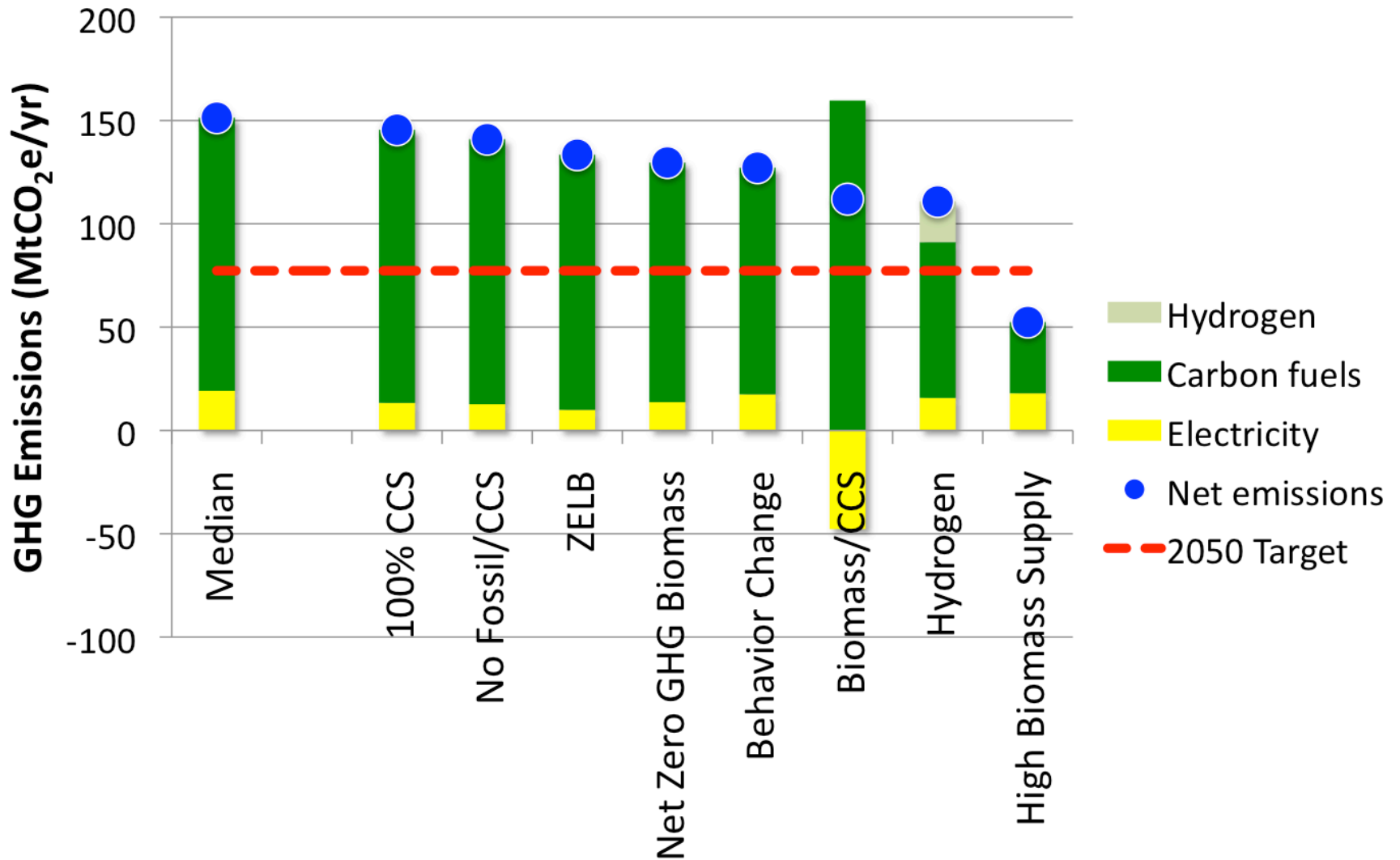
Where could this land come from?

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

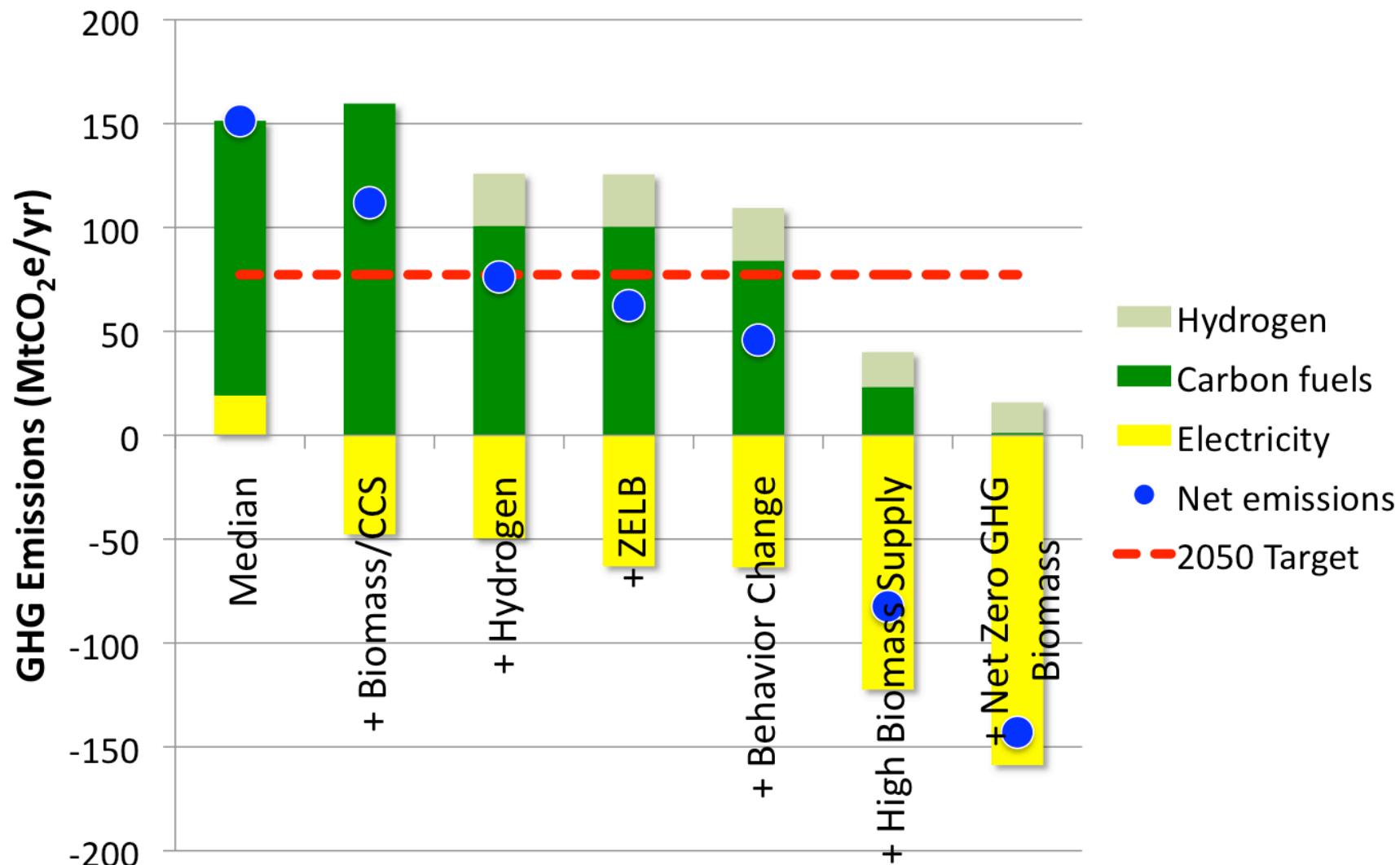
Doubling Biomass Supply



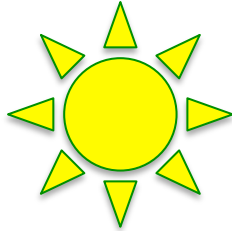
Getting to 80%: Single Strategies



Getting to 80%: Example of Multiple Strategies

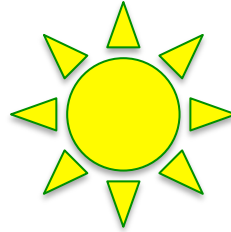
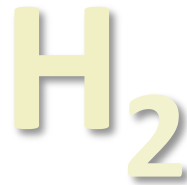


Advanced Technologies



- Fuel from sunlight
- Fusion: *Really* cheap electricity?
- What else could help?

Getting to 80%: Conclusions



- Biofuels are a promising, but risky, bet
- Alternative fuel pathways needed, e.g.,:
 - Hydrogen
 - Fuel from sunlight (or *cheap* electricity = fusion)
 - Probably others
- Other high-impact items important, e.g.,:
 - Zero-emissions load balancing (ZELB)
 - Behavior change
- Multiple strategies required to get to 80%

Conclusions

- **Yes, we can:** Achieve 60% below 1990 level with technologies we largely know about
 - The magnitude of the changes required and the pace of implementation will not occur without sustained and substantial capital investment and policy interventions.

Key challenges:

- Need aggressive efficiency and electrification– not a technology issue
- Base load: Nuclear power and Fukushima incident vs CCS
- Load balancing without emissions needed
 - Especially for predominant without baseload
 - Storage and smart grid technology gaps
- Biofuels are important and uncertain, and probably not sufficient
- Getting to 80% below 1990 level requires advanced approaches especially for fuel

Extra slides

Recommendation #1:

Achieving more than a 20% reduction

- **Strengthen existing AB32-related laws and rules**
- Ensure that aggressive performance standards are aligned with price signals to customers
- Ensure that the electricity infrastructure (*e.g.* vehicle recharging facilities and distribution transformers)
- Continually examine the low carbon fuel standard to ensure that it adequately addresses potential impacts on water, land, food, biodiversity, and perhaps social impacts (especially for biofuels imports).

Recommendation #2

Getting to a 60% reduction

- Ensure that all existing buildings are retrofit or replaced
- Effect rapid and ubiquitous electrification
- Ensure that new clean electricity is being developed at a rate of about 1.5 GW/yr (baseload) or 4.5 GW/yr (intermittent)
- Decide whether to develop this de-carbonized electric generation system with, or without, nuclear power
- Fill the low-carbon fuel gap with multiple strategies
- Advance carbon capture and storage, especially as a technology that supports low-carbon fuel production.
- Develop a plan for emission-free reliable electric load balancing

Recommendation #3

Monitor the implementation rate

- **Monitor the rate of actual implementation for efficiency, electrification, clean electricity generation and de-carbonized fuel production, and provide an annual report of progress against plan, with a listing of the specific actions that are required to keep progress on target.**
- The state needs to almost double the production of electricity by 2050, and at the same time decarbonize this sector. So, we need an average of 1.5 GW (baseload) or 4.5 GW (intermittent) near-zero carbon electricity generation every year from now until 2050.
- In 2050, the state will also need about 70% as much fuel as we use today.
- A standard part of the Integrated Energy Policy Report (IEPR) should look at the rate of new construction and implementation compared to the needed rate and remove barriers that can be eliminated without risk to public health and safety.

Recommendation #4:

Support the innovation needed to achieve an 80% reduction

- The State of California should foster, support and promote an innovation ecosystem in energy including
 - universities,
 - national laboratories,
 - small business,
 - innovation hubs,
 - regional clusters, etc.
- The California delegation should support federal funding for this activity

Recommendation #5:

Put in place the structure needed to inform future portraits

- **Consider the potential utility of the energy system-wide analytical tools (such as those developed for this project) in strategic planning and evaluate how to manage the future use of such tools to inform strategic decisions and investments.**
- Keep track of all end-use requirements, sources of energy, energy delivery mechanisms and associated emissions – no cheating!
- The assumptions used in this report are very likely to change over time
- The tool can help to show the system-wide effects of policy choices.

Recommendation #6:

Maintain a long-term plan

- Determine the most desirable 2050 energy system configurations from a combination of economic, policy and technology perspectives.