
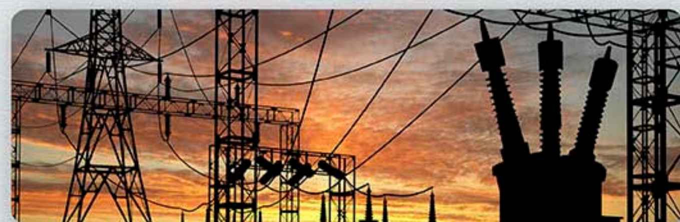


EPRI | ELECTRIC POWER RESEARCH INSTITUTE

California’s Energy Future:
The View to 2050

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CEF committee

Jane Long and Mim John, co-chairs

- Jeff Greenblatt, LBNL (portraits, building efficiency)
- Burt Richter, Stanford (nuclear power)
- Heather Youngs, UCB (biofuels)
- Max Wei, LBNL (industry efficiency)
- Chris Yang, UCD (transportation)
- Bryan Hannegan, EPRI (CCS, Renewables)
- Nate Lewis
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Maxine Savitz
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Chris Somerville
Dan Sperling
Jim Sweeney
Margaret Taylor
Carl Weinberg
John Weyant
Mason Willrich

Full Report at http://ccst.us

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 GT CO_2e today to 80 GT CO_2e in 40 years

Energy system portraits for 2050

- Technology assessment
- Existence proof: could we find systems that meet our needs and cut emissions 80%?
- Not an economic projection
- Assessment should
  - avoid leakage
  - and assume the rest of the world is doing what we are doing
- Can it be done? What are the barriers? What are the impacts? What is the state of technology required to do it?

Logic–> eliminate fossil fuels*

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

*unless the emissions are sequestered

Bottom-up study

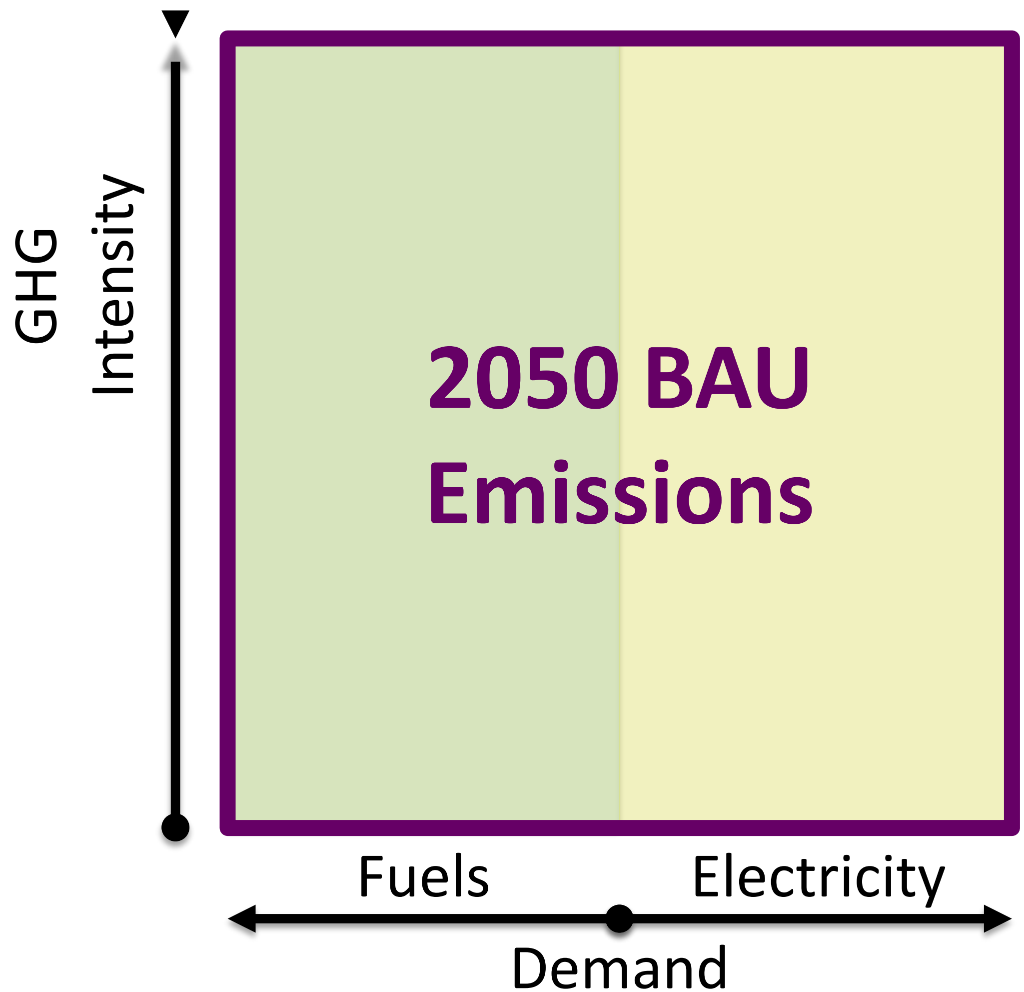
- Efficiency and Electrification in buildings and industry: Jim McMahon, Max Wei, Jeff Greenblatt
- Efficiency and Electrification in transportation: Chris Yang
- Nuclear power: Burt Richter
- CCS and renewables: Bryan Hannegan
- Fuel: Biofuel potential: Heather Youngs
- The energy system portraits for 2050; Jeff Greenblatt
- Game changers: Nate Lewis, Bill McClean

Technology bins

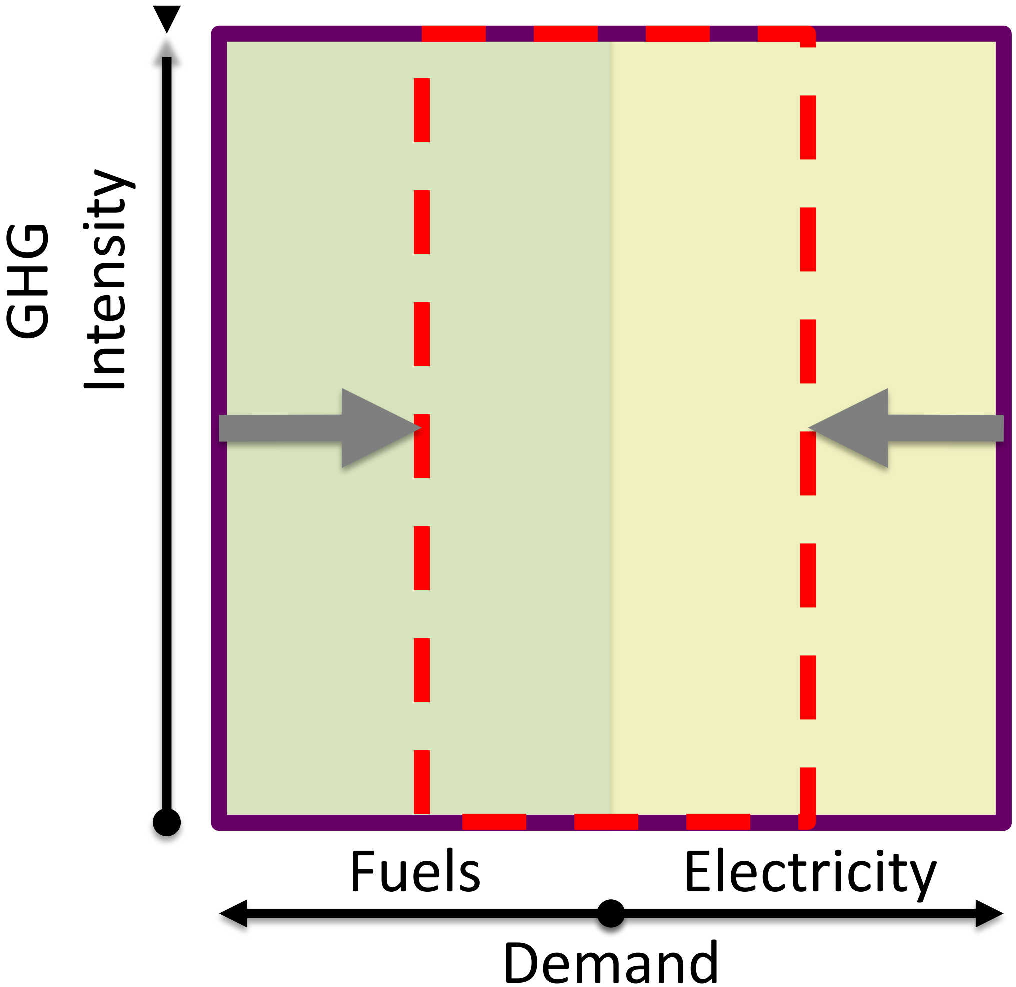
Bin 1:	**Deployed at scale now**
Bin 2:	Has been demonstrated, not available at scale
Bin 3:	In development
Bin 4:	Research concept

Four Actions to Reduce Emissions

GHG Intensity-Demand Diagram



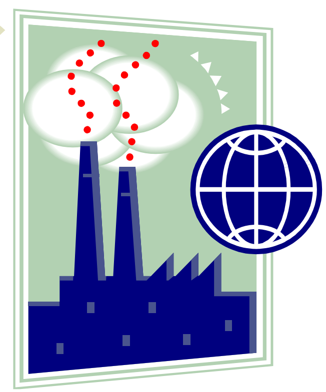
1. Efficiency



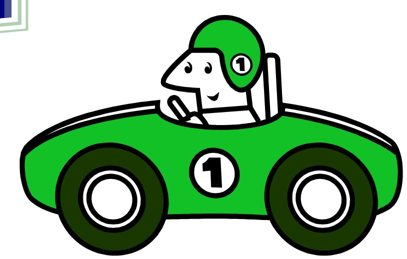
Three sectors of efficiency/ electrification

– Buildings

– Industry



– Transportation



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

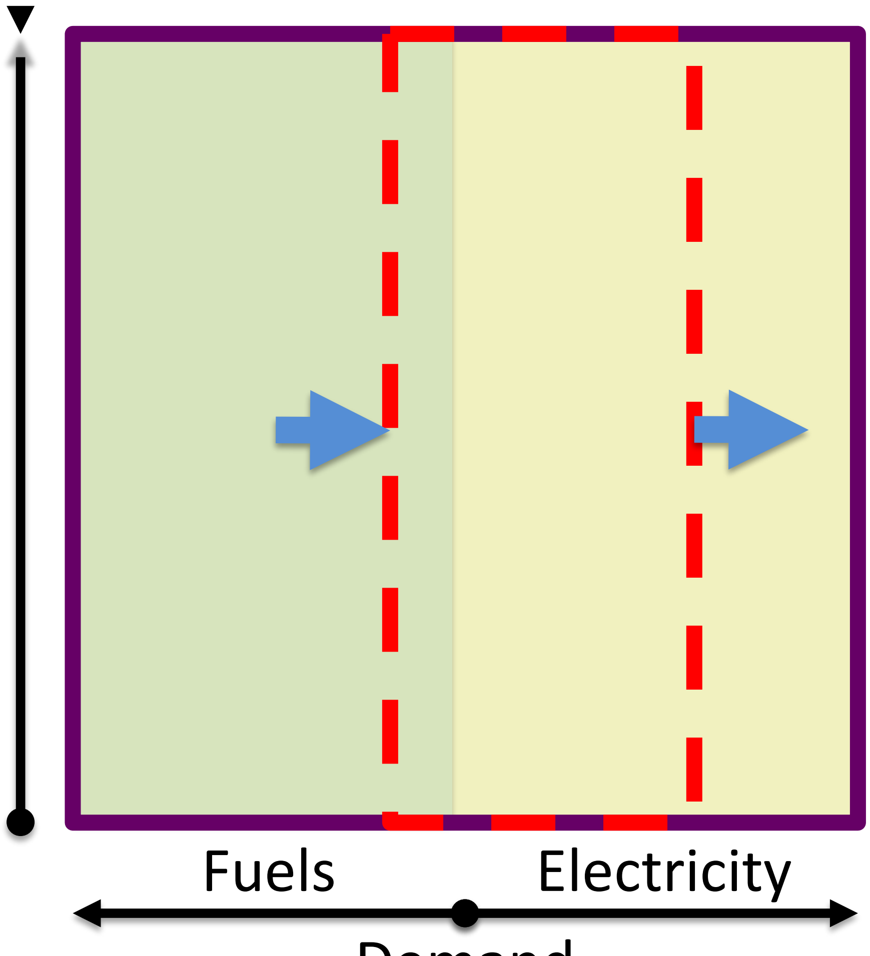
Bin	Light-Duty Vehicles	Charging infrastructure and management
1	Hybrid engines, lightweight materials, better aerodynamics, low-resistance tires	Low- and high-voltage charging hardware, simple charging (on-demand or timer)
2	Battery- electric and plug-in hybrids	“Smart” charging via signals from utility 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 Case
Electricity	TWh/yr	270	470	510
Fuels	bgge*/yr	36	64	27

*Billion gallons gasoline equivalent

2. Electrification

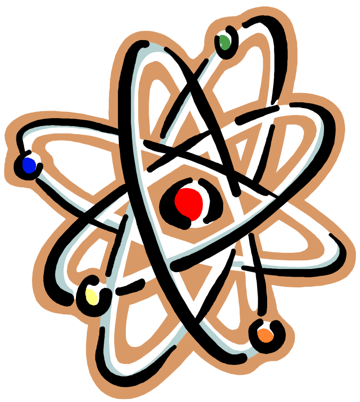


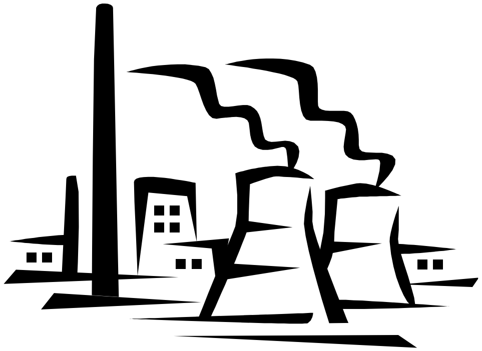
The realistic potential of electricity supply technologies in California

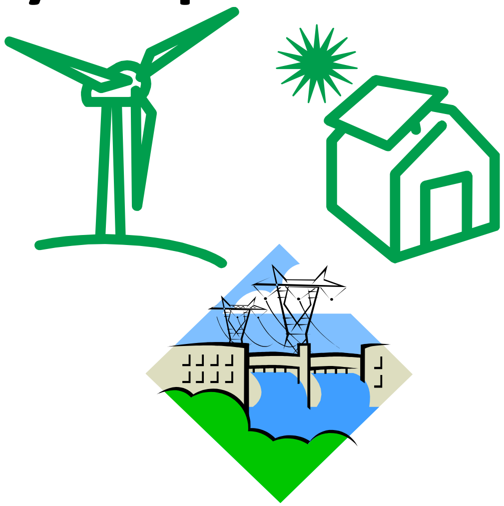
- Nuclear: GENIII technology
- Fossil fuel w/CCS: either coal or gas
- Renewables : 80% intermittent
- Load balancing: gas, storage, smart-grid

- Any of these could supply all the electricity required – about 500TWh
- **The primary issue is emissions**
- Ancillary impacts, costs, barriers are issues too
- We assume at least 33% renewables in all cases

Low-Carbon Electricity Options







Nuclear
62% nuclear
43GW
33% renewable
5% natl gas
load following

Fossil/CCS
62% fossil/CCS
48 GW
33% renewable
5% natl gas
load following

Renewables
90% renewable
(70% intermittent)
150 GW
10% natl gas
following

Strategy	Assumed plant size	Total plant capacity needed in 2050	Build rate 2011-2050 (Plants/year)
Nuclear	1.5 GW	43 GW	0.7
Fossil/CCS	1.5 GW	48 GW	0.8
Renewables Mix			
- Wind	500 MW	57 GW	2.9
- Central Solar (CSP and PV)	500 MW	57 GW	2.9
- Distributed Solar PV	5 kW	25 GW	125,000
Biomass/CCS	500 MW	12 GW	0.6
CA Biofuels	50 Mgge/yr	6,500 Mgge/yr	3.2

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

Challenges of Fossil/CCS

- Massive new infrastructure
  - In-state: CO_2 pipeline network needed
  - Out-of-state ("coal by wire"): New transmission network throughout West
- Saline aquifer viability must be demonstrated
  - Oil/gas reservoir capacity alone severely limited
- Natural gas: Uncertainties in long-term production cost, competition from LNG imports
- Coal: Environmental impacts of mining remain

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 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

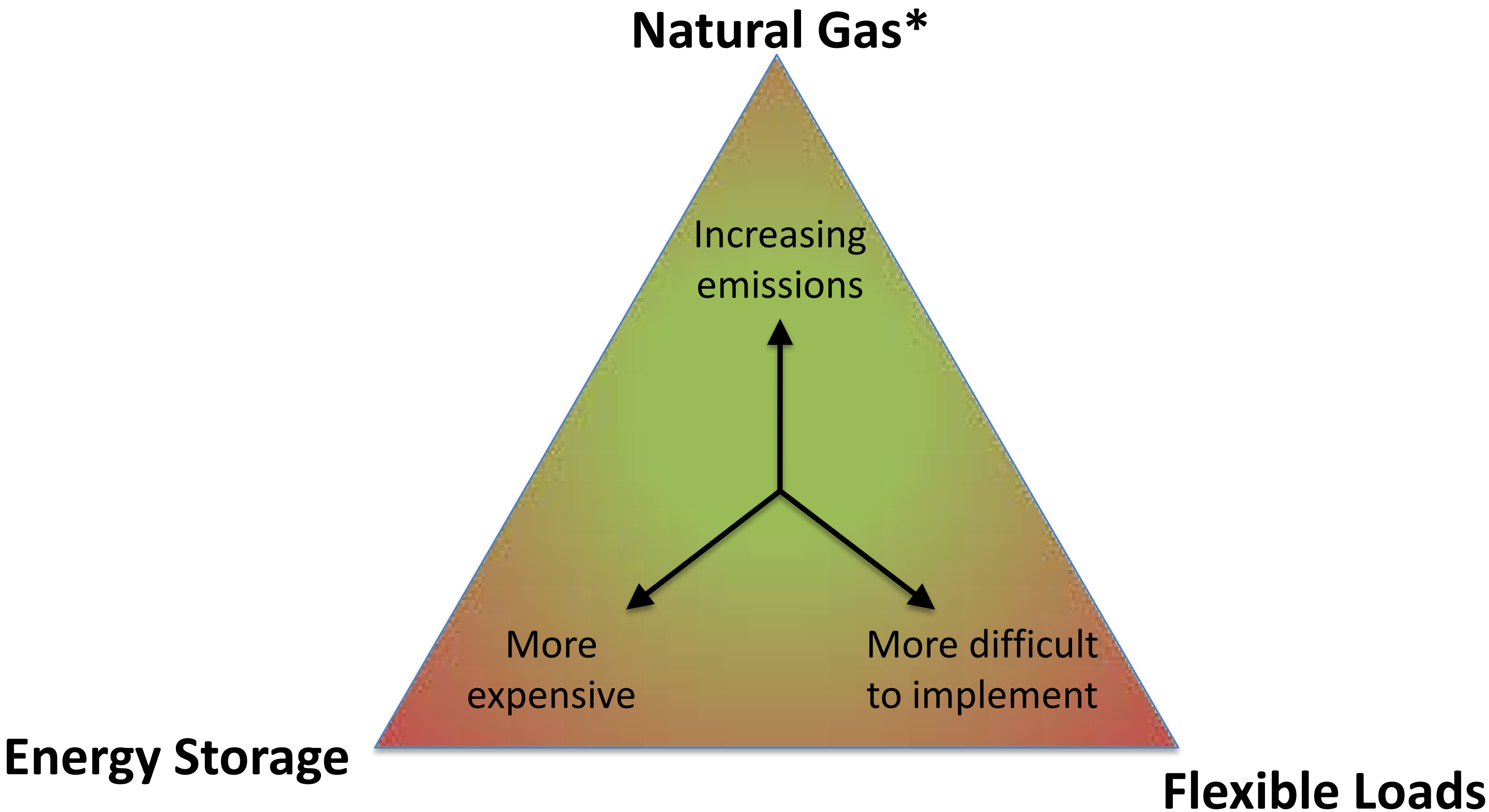
What is required for Renewables

- Improved technology costs and performance
  - Conversion technology,
  - O&M,
  - environmental controls
- Grid flexibility to balance out variability, particularly for wind, solar
  - Controllable loads, storage, transmission, demand response, electric vehicles
- Water resources for thermal cooling
- Land use and availability

Renewable technology bins

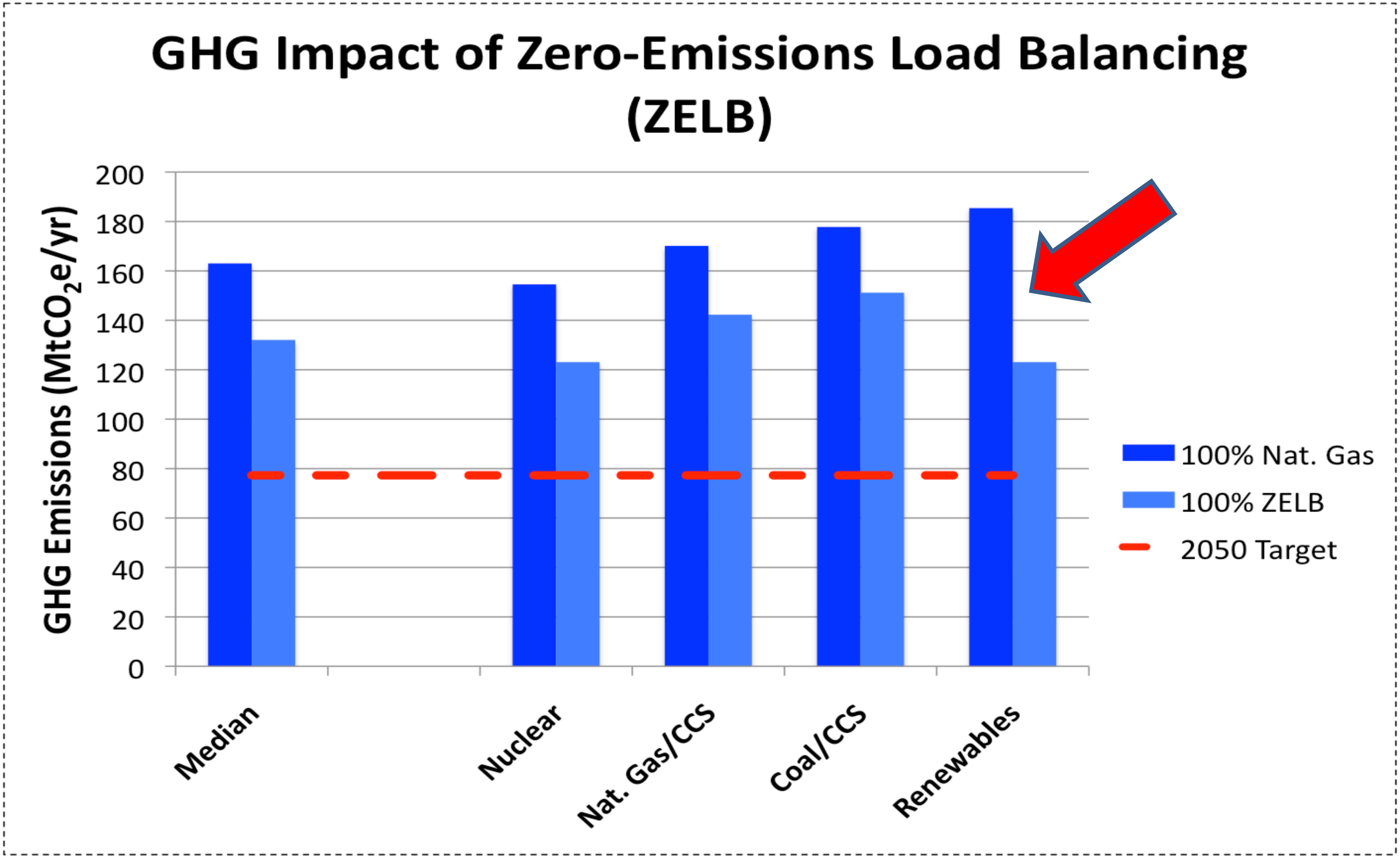
Bin	**Wind**	**Concentra-ted Solar Power (CSP)**	**Solar Photovol-taic (PV)**	**Geothermal**	**Hydro and Ocean**	**Biomass**
1	Onshore, shallow offshore turbines	Parabolic trough, central receiver	Silicon PV, Thin-film PV, Concen-trating PV	Conventional geothermal	Conven-tional hydro	Coal/bio-mass co-firing, 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)		

The load following triangle



** May be possible with CCS in future*

Zero-Emission Load Balancing (ZELB)



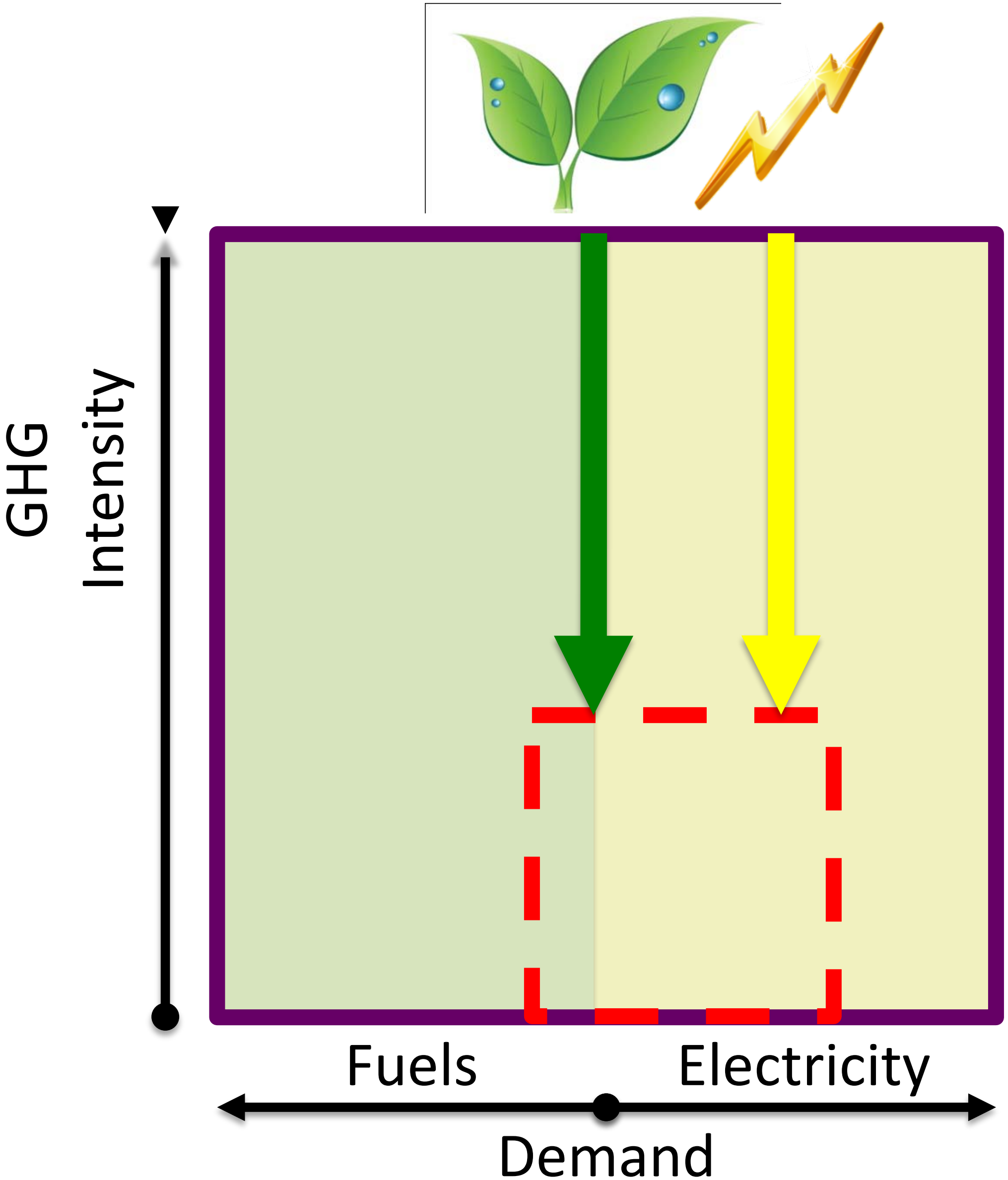
Load following technology bins

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 portrait

- For the sake of examining the whole energy system (ie adding in an understanding of fuels) these three electricity portraits are not exactly equal.
  - If we have 100% renewables, the requirement for ZELB increases
  - ZELB could be accomplished with carbon neutral fuel.
  - So this scenario increases the demand for carbon neutral fuel – which we will see is already in short supply.
- Two electricity portraits:
  - Median case
    - 33% renewables
    - 31% CCS
    - 31% nuclear
    - 5% gas for load following
  - 90% renewables + 10% natl gas for load following

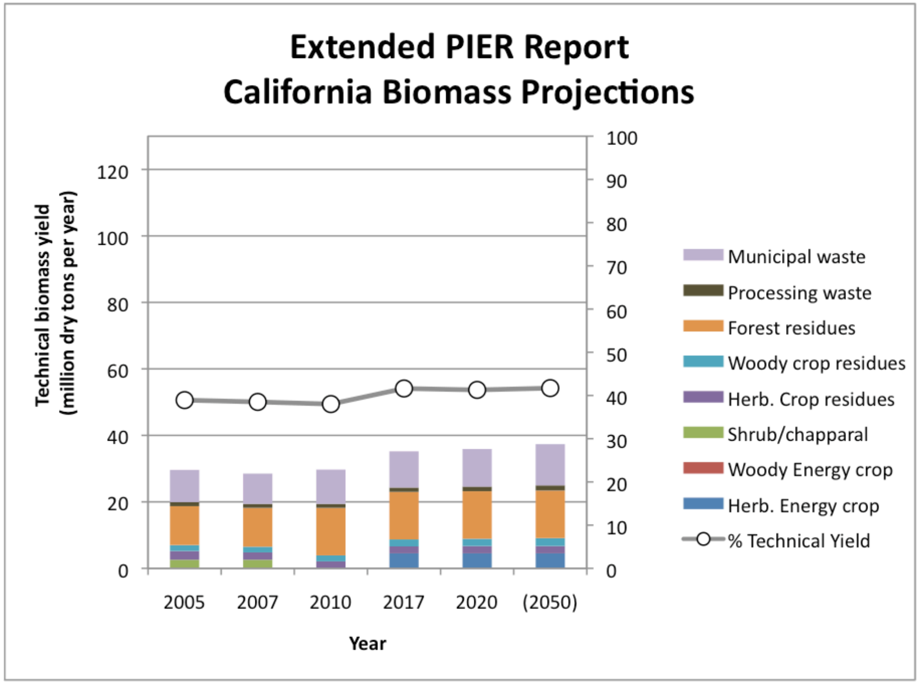
3 + 4. "Low-Carb" Fuels + Electricity

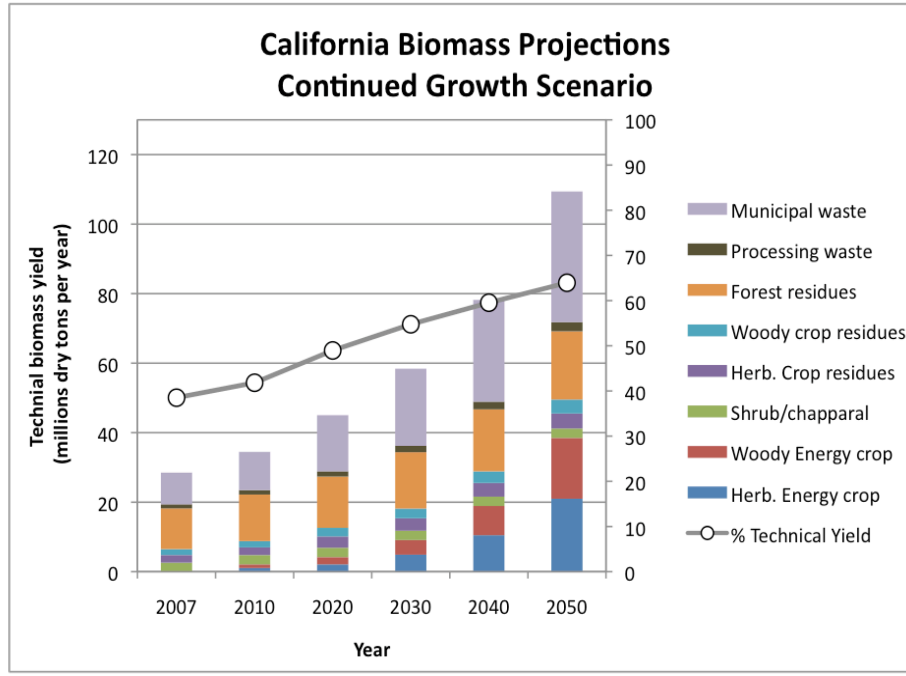


Will still need about 75% of the fuel we use today

- Use biomass to make carbon-neutral fuel.
- Quantity of available biofuels is highly uncertain and may not be adequate.
  - 3 to 12 bgge/yr from low impact sources in CA
  - This estimate is based on sources with no food, fuel or fertilizer issues, but need to insure biofuel actually is limited to these sources if biofuel becomes a commodity
  - Demand for fuel in California in 2050 is more than twice the high end estimate of the availability of CA bio- energy.
- Carbon signature of current biofuels is about 50% on average but could lower this to 20% by 2050.
- If we use a median estimate for the amount of biomass that could be used for energy and include some imports—we can thus displace about half of the remaining the fossil fuel demand.
- **The residual fuel demand alone exceeds the target emissions**

California Biomass Scenarios





Scenario Differences

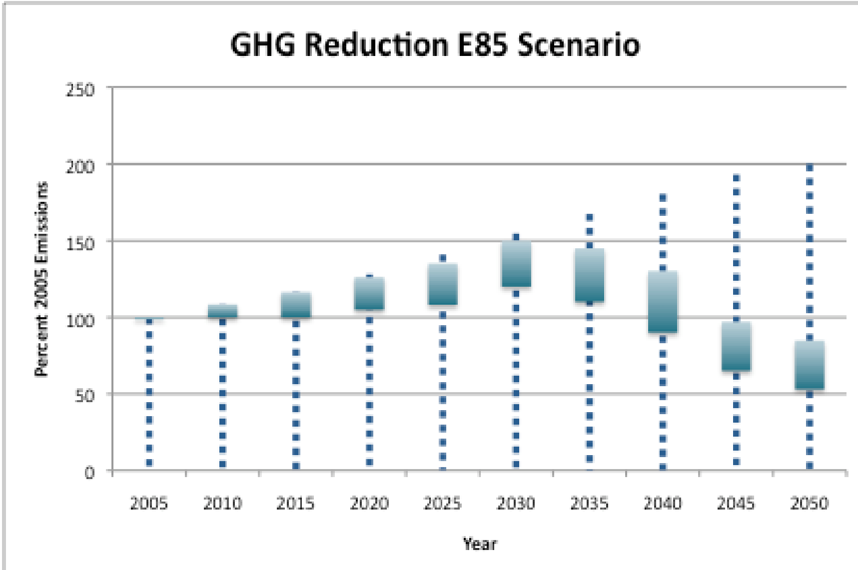
- Improved residue recovery (up to 62% from 40%
- Increase in MSW production with population growth
- Growth of additional energy crops
    -(woody and herbaceous)
    -on abandoned ag. and non-productive forest lands

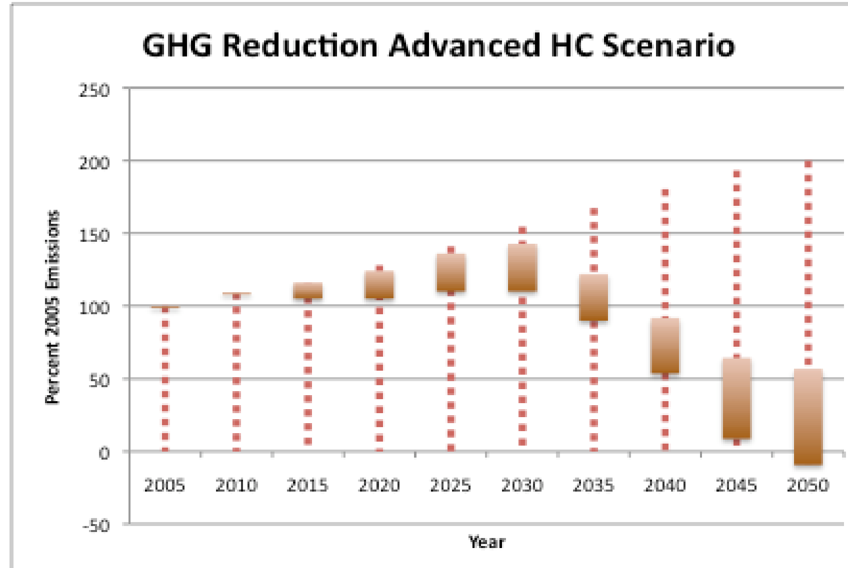
Fuel Yield

3-12 billion gallons gasoline equivalent

40-100 mtons = 3.2-8 bgge residues
5-40 mtons = 0.5-3.2 bgge energy crops

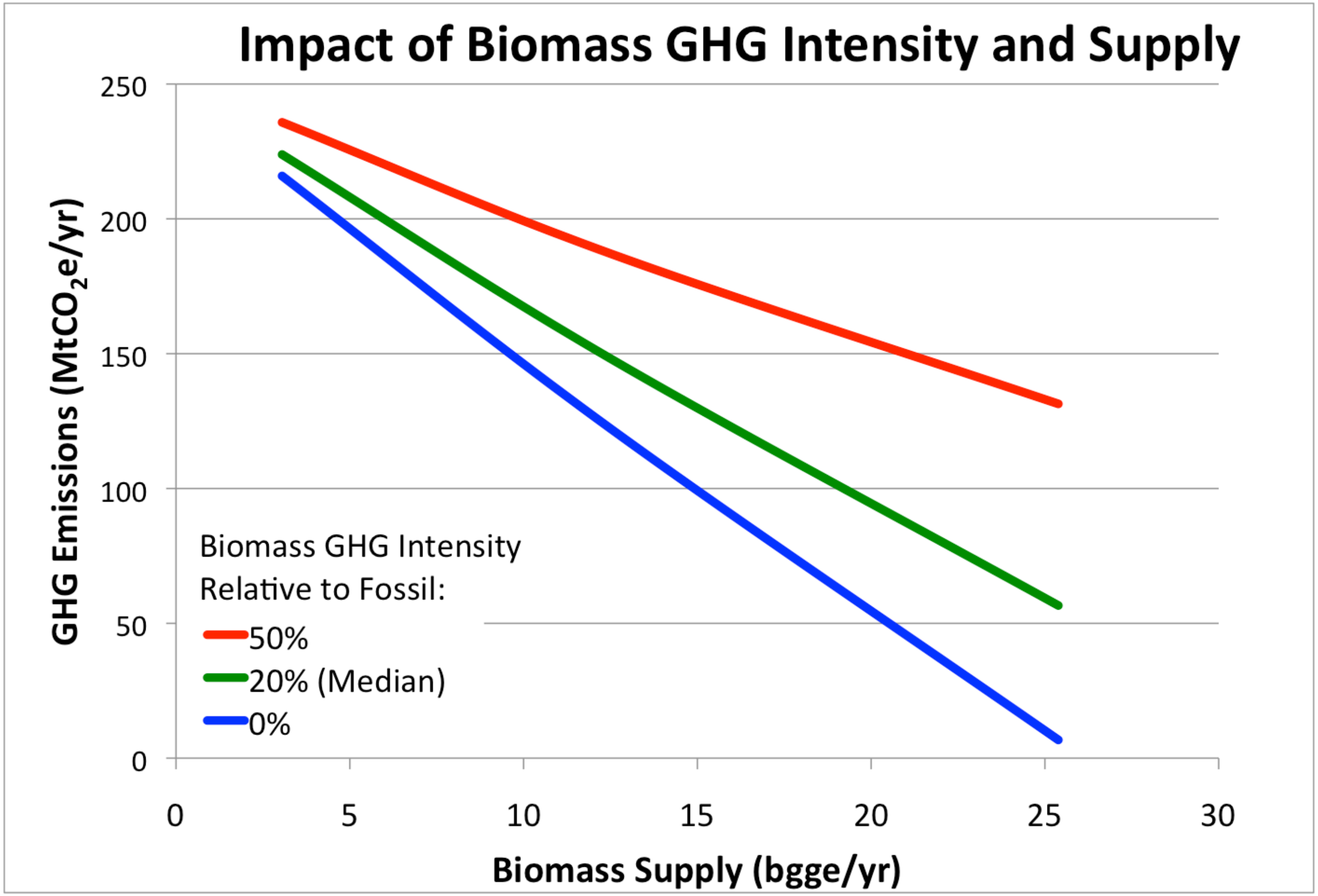
GHG reductions



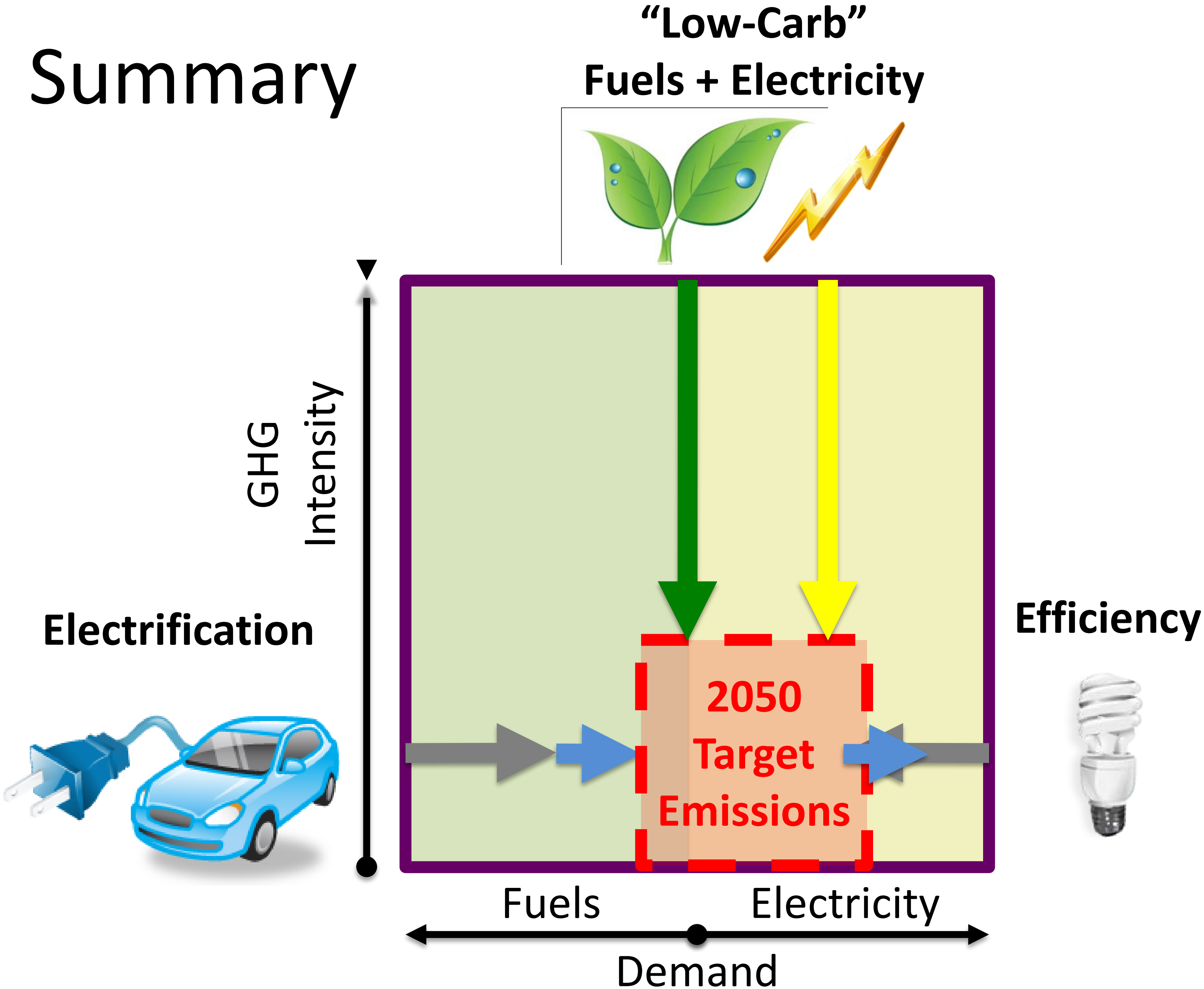


- Cellulosic E85 Falls Short (E100 could go farther)
  - Remaining petroleum footprint is high
  - Limitations on waste oil push biodiesel footprint higher (oil crops needed)
- Advanced Hydrocarbons have a chance to meet the goal
  - Direct replacement for diesel, gasoline and jet fuel with large GHG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

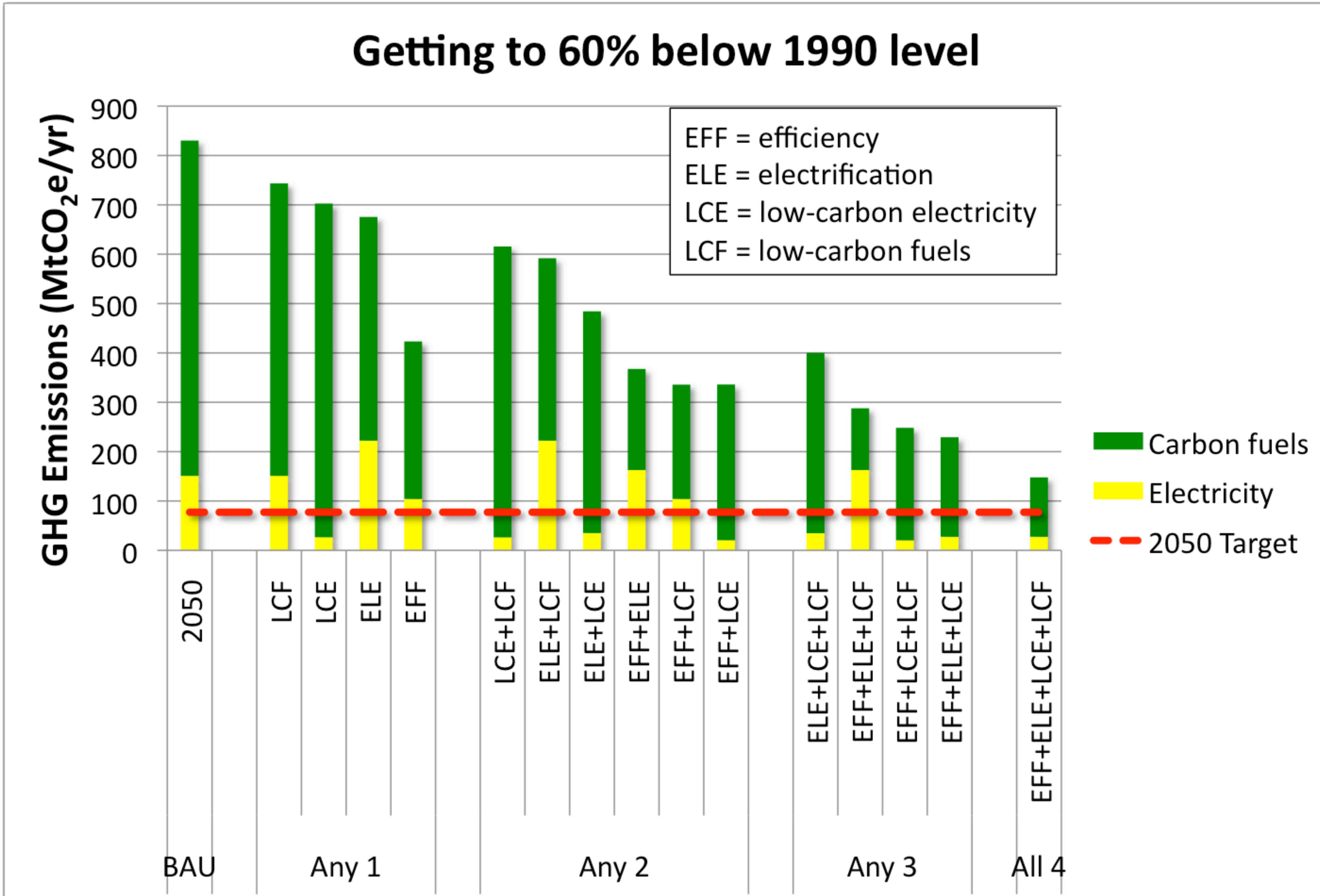
Biomass GHG Intensity and Supply



Summary



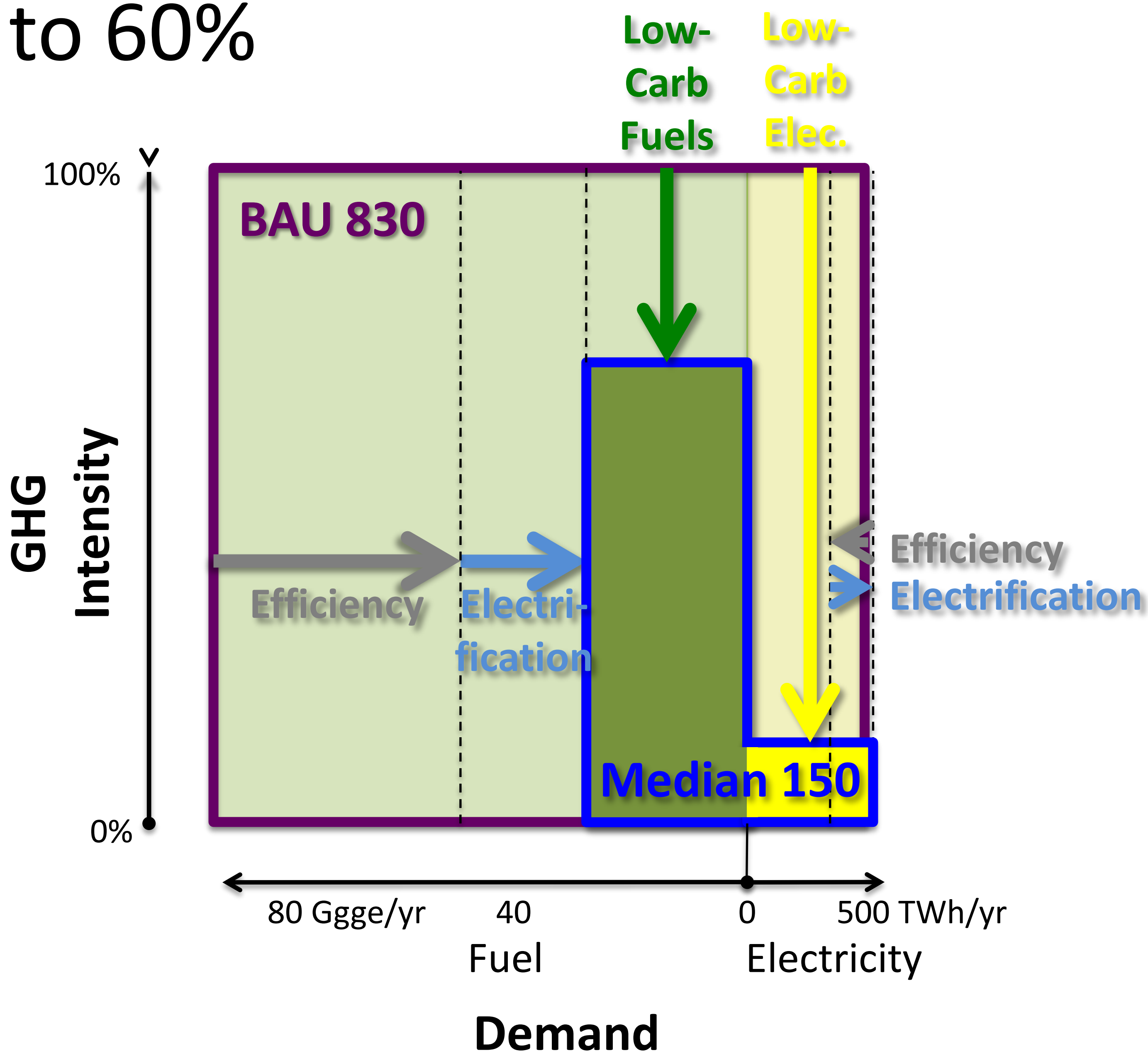
"Low-Carb"
Fuels + Electricity
GHG
Intensity
Electrification
Efficiency
2050
Target
Emissions
Fuels
Electricity
Demand


Getting to 60% below 1990 level
GHG Emissions (MtCO2e/yr)
900
800
700
600
500
400
300
200
100
0
EFF = efficiency
ELE = electrification
LCE = low-carbon electricity
LCF = low-carbon fuels
Carbon fuels
Electricity
2050 Target
2050
LCF
LCE
ELE
EFF
LCE+LCF
ELE+LCF
ELE+LCE
EFF+ELE
EFF+LCF
EFF+LCE
ELE+LCE+LCF
EFF+ELE+LCF
EFF+LCE+LCF
EFF+ELE+LCE
EFF+ELE+LCE+LCF
BAU
Any 1
Any 2
Any 3
All 4

We can achieve 60% cuts in emissions below 1990 levels

- With aggressive electrification and efficiency and
- An electricity portfolio that is roughly equal parts nuclear, natural gas with CCS, and renewable,
- Half of the ZELB problem solved and the rest is managed with natural gas, and
- A median estimate for the amount of available sustainable biomass

BAU to 60%

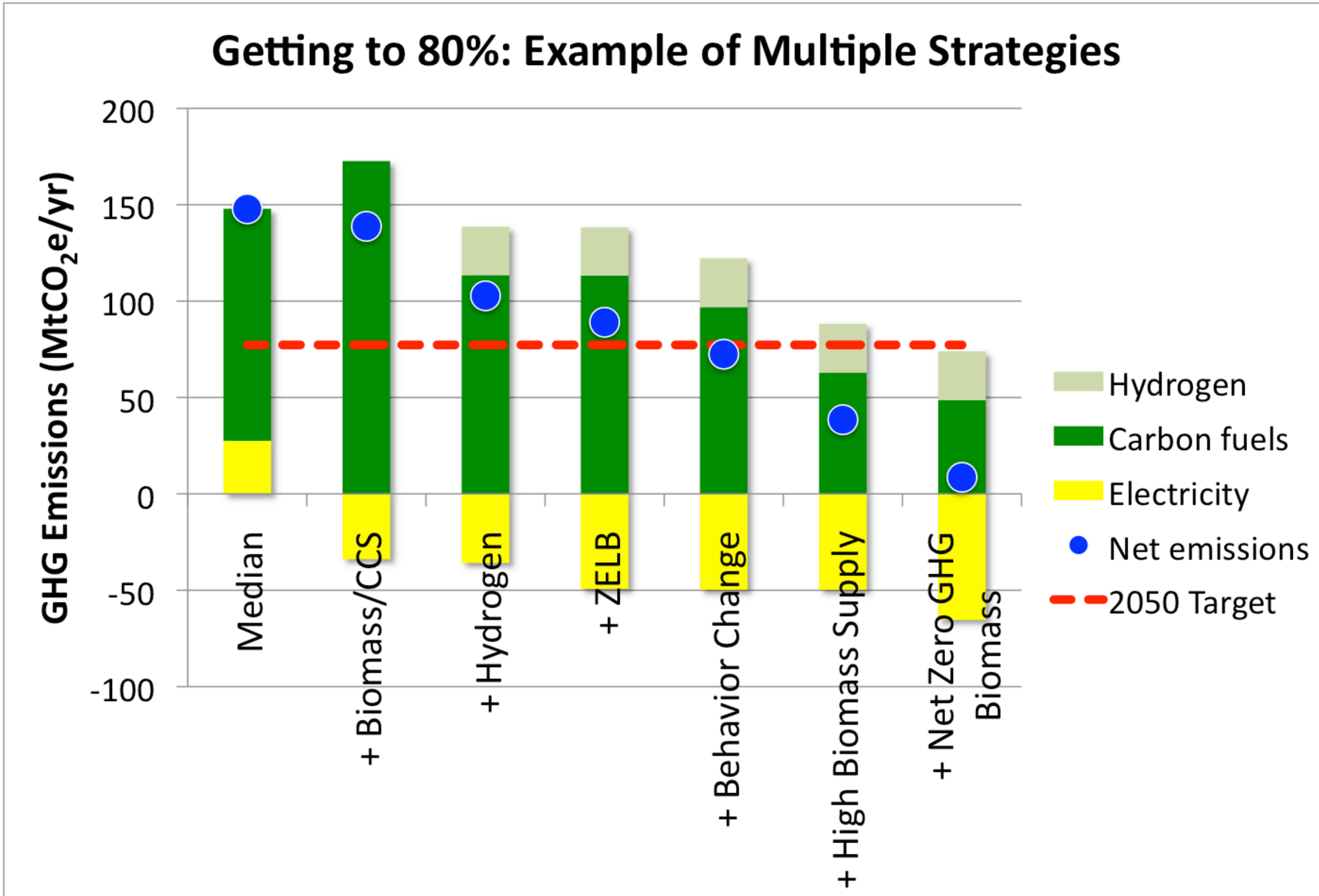

Low-Carb Fuels
Low-Carb Elec.
100%
0%
GHG Intensity
BAU 830
Efficiency
Electri-fication
Efficiency
Electrification
Median 150
80 Ggge/yr
40
0
500 TWh/yr
Fuel
Electricity
Demand

The median 60% portrait

- Efficiency + Electrification:
  - 40% more efficient building stock
  - 70% shift to electrified heating
  - 60% plug-in light-duty vehicles
  - 50% reduction in truck and aviation fuel use
  - 30% reduction in liquid fuel, 50% reduction in gaseous fuel
  - Approximately double today's electricity use
- Low-carbon electricity: ~530TWhr/yr
  - 31% nuclear, 31% natural gas/CCS, 33% renewables
  - Load balancing: 5% natural gas, (5% ZELF)
- Low-carbon fuels for transportation, heat and load balancing:
  - Carbon fuel demand: 27 billion gallons gasoline equivalent (Ggge/yr)
  - Biomass supply: 13 bgge/yr, 20% GHG intensity of fossil fuels

7 Example Strategies for Getting to 80%

1. Increase biomass supply (17 bgge)
2. Hydrogen use where efficacious (8 bgge)
3. Net-zero GHG biomass
4. Behavior Change
5. 100% ZELB for load balancing
6. Biomass/CCS (no biofuels): negative GHG electricity, offsetting fossil fuel use
7. 100% effective CCS (or eliminate fossil/CCS electricity)
8. Eliminate fossil/ccs option (use nuclear instead)



Getting to 80%: Example of Multiple Strategies
GHG Emissions (MtCO2e/yr)
200
150
100
50
0
-50
-100
Median
+ Biomass/CCS
+ Hydrogen
+ ZELB
+ Behavior Change
+ High Biomass Supply
+ Net Zero GHG Biomass
Hydrogen
Carbon fuels
Electricity
Net emissions
2050 Target

Summary

- 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.
  - Technology in use today or in demonstration.
  - Deployment will depend more on policy.
- We can get the rest of the cuts to 80% below 1990, but this will require new technology innovation and development.

Final comment: The CEF Approach

- Committed to the math
- Meta study
- Expert judgment of large committee
- Not the final word!