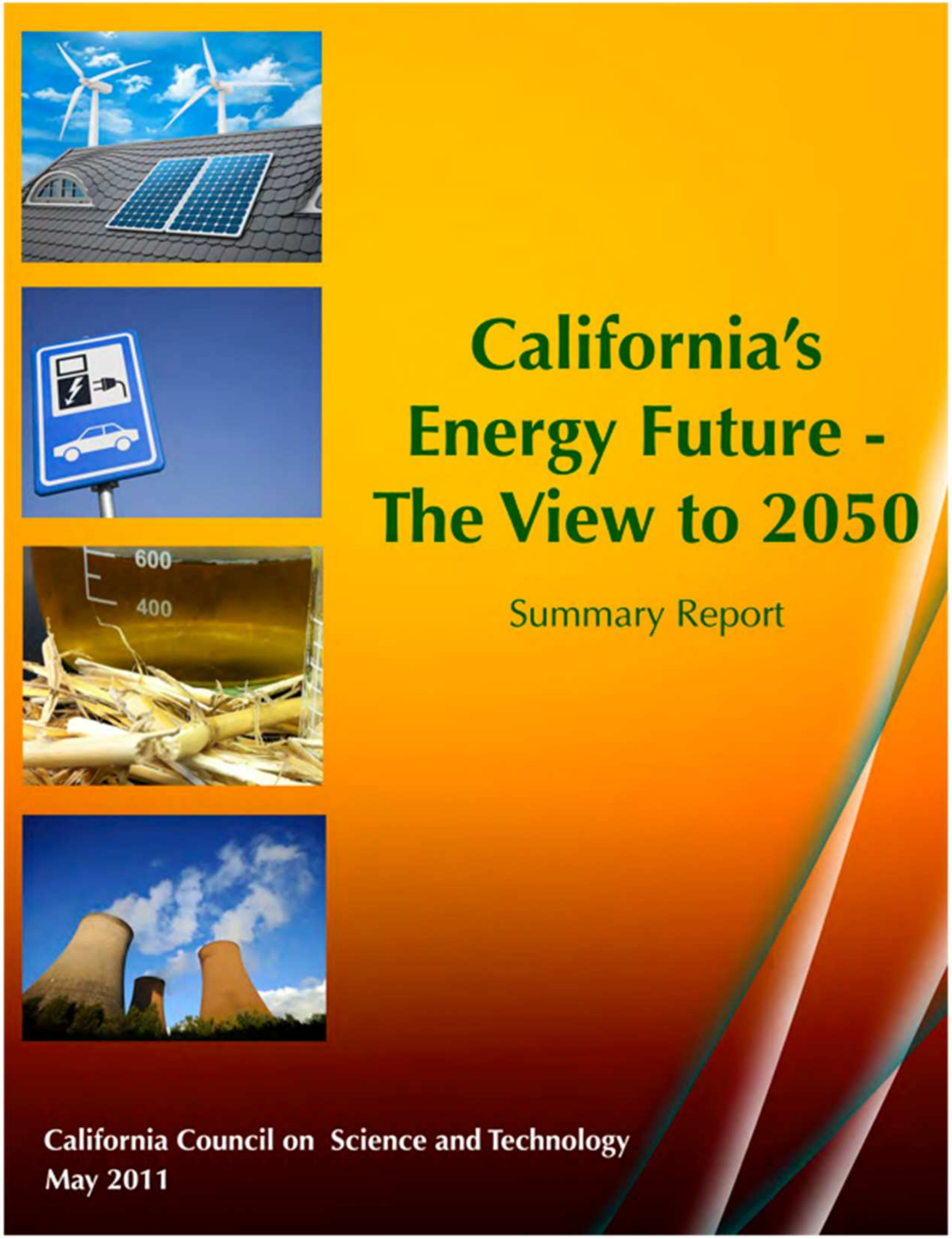


CHAIR'S LECTURE: CALIFORNIA ENERGY FUTURES STUDY RESULTS

July 15, 2011

Jane C. S. Long

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 CO_2e today to 80 mmT CO_2e 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

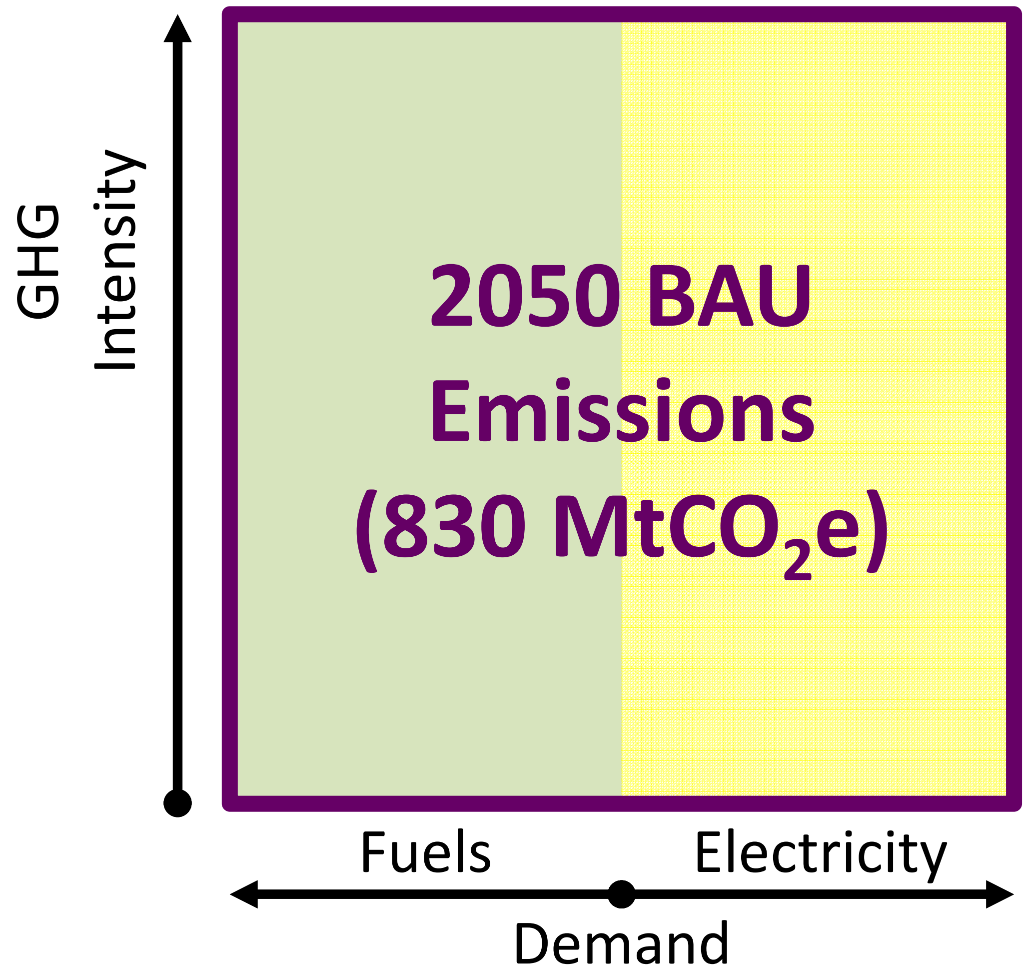
Logic–> eliminate fossil fuels*

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?	Nuclear, CCS, Renewables
How do we balance load?	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?

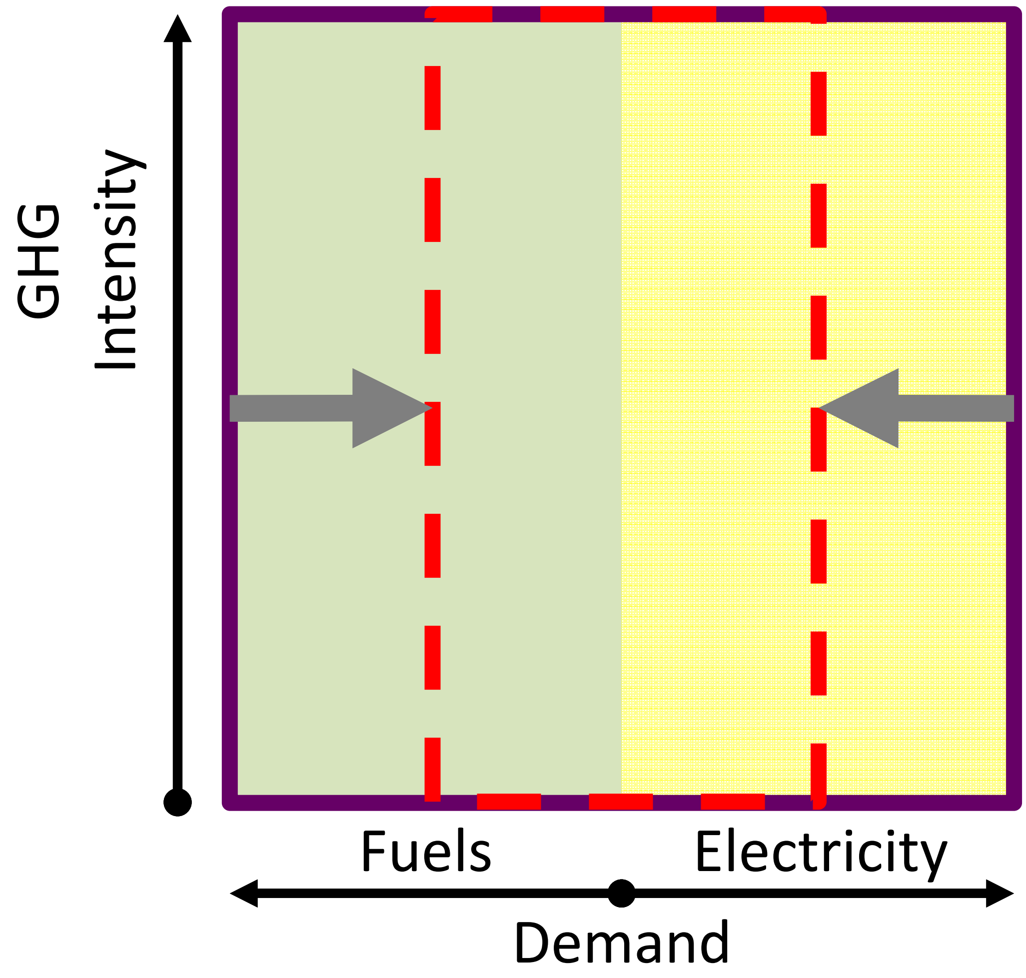
*unless emissions are sequestered

Four Actions to Reduce Emissions

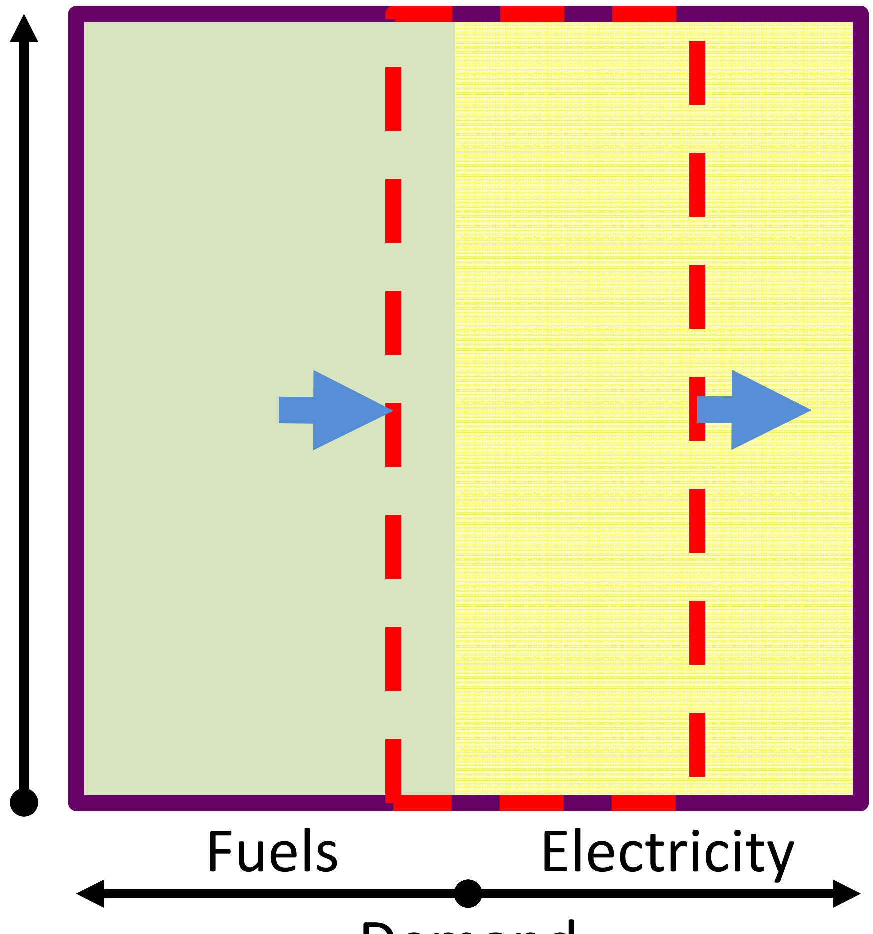
GHG Intensity-Demand Diagram



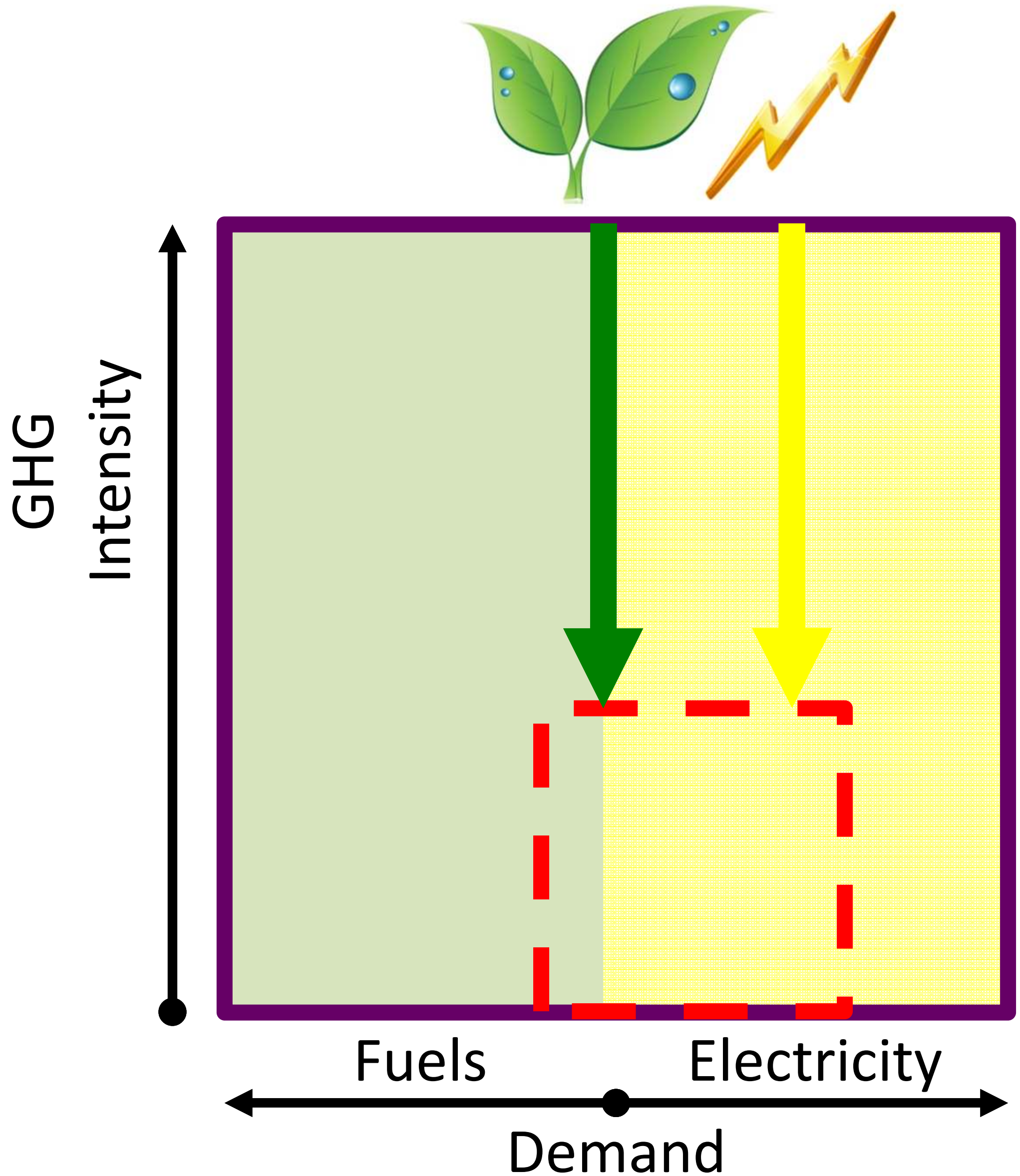
1. Efficiency



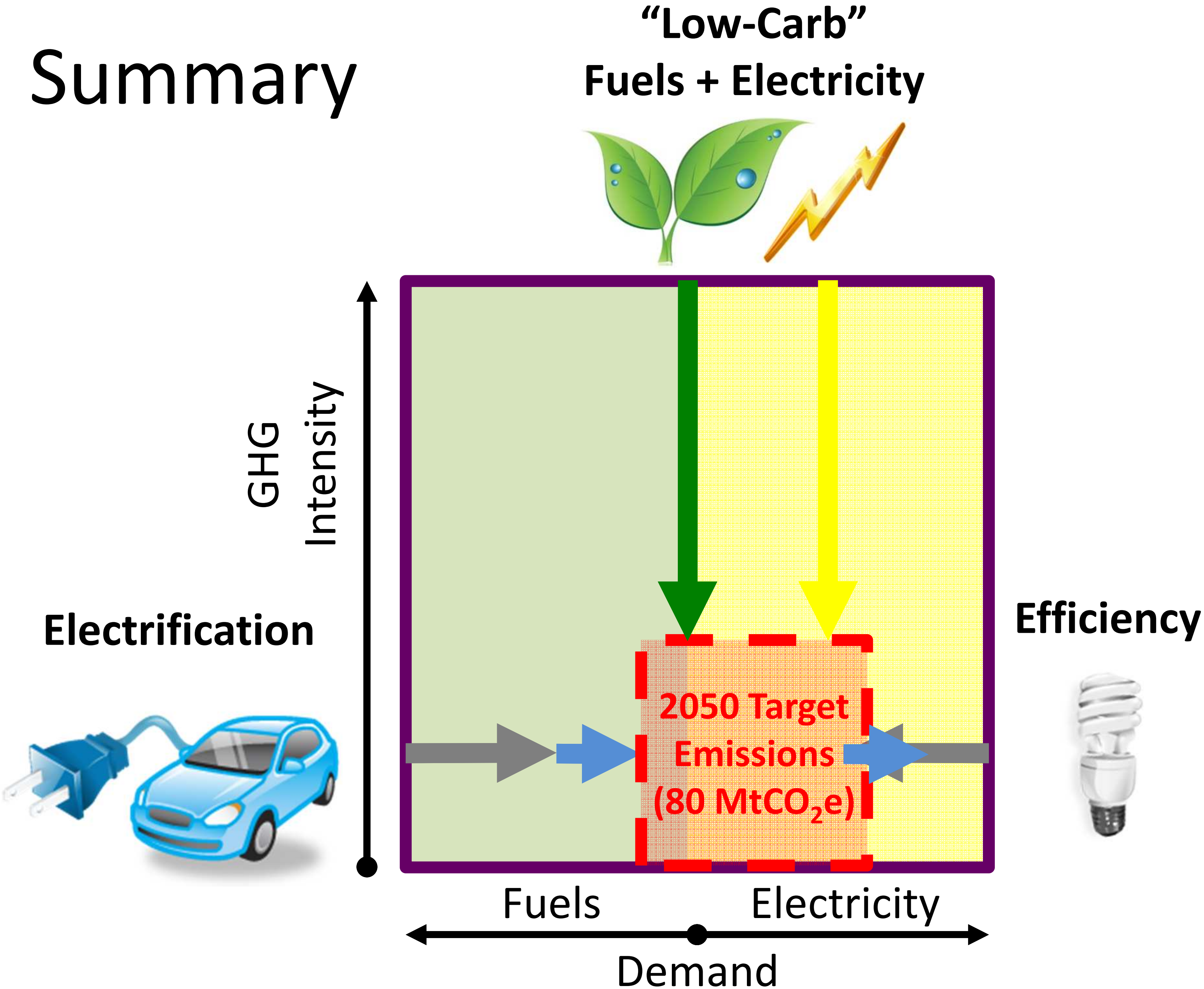
2. Electrification



3 + 4. “Low-Carb” Fuels + Electricity



Summary


"Low-Carb"
Fuels + Electricity
GHG Intensity
Electrification
Efficiency
2050 Target Emissions ($80\ MtCO_2e$)
Fuels
Electricity
Demand

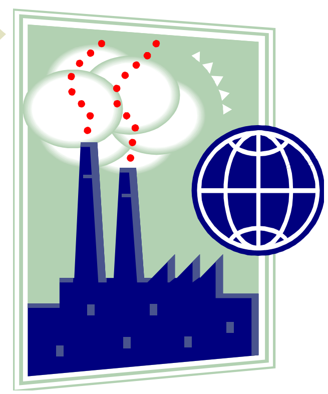
Technology bins

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

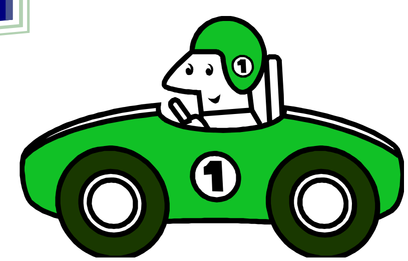
Three sectors of efficiency and electrification

– Buildings

– Industry

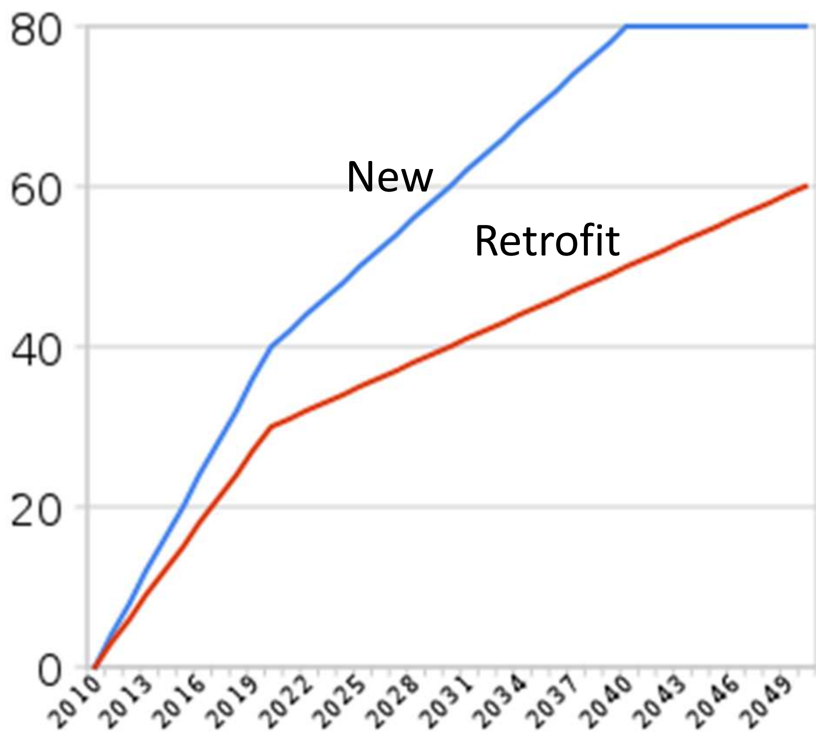


– Transportation

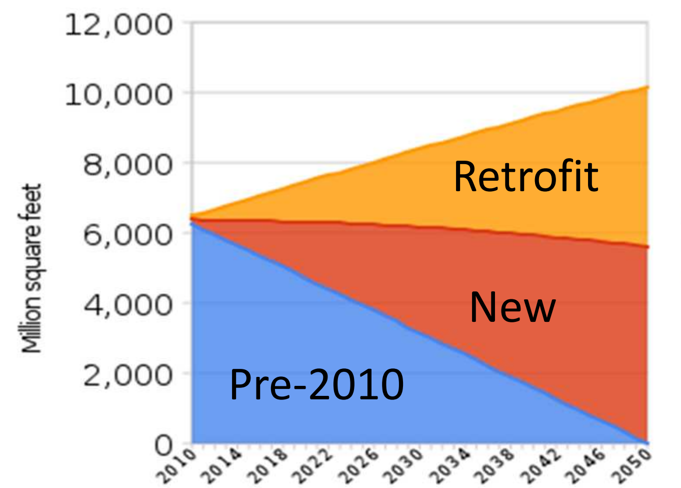


Building efficiency

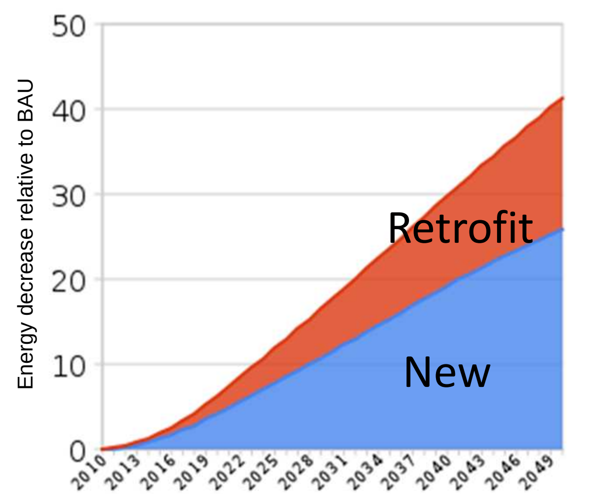
Efficiency decrease in energy from BAU



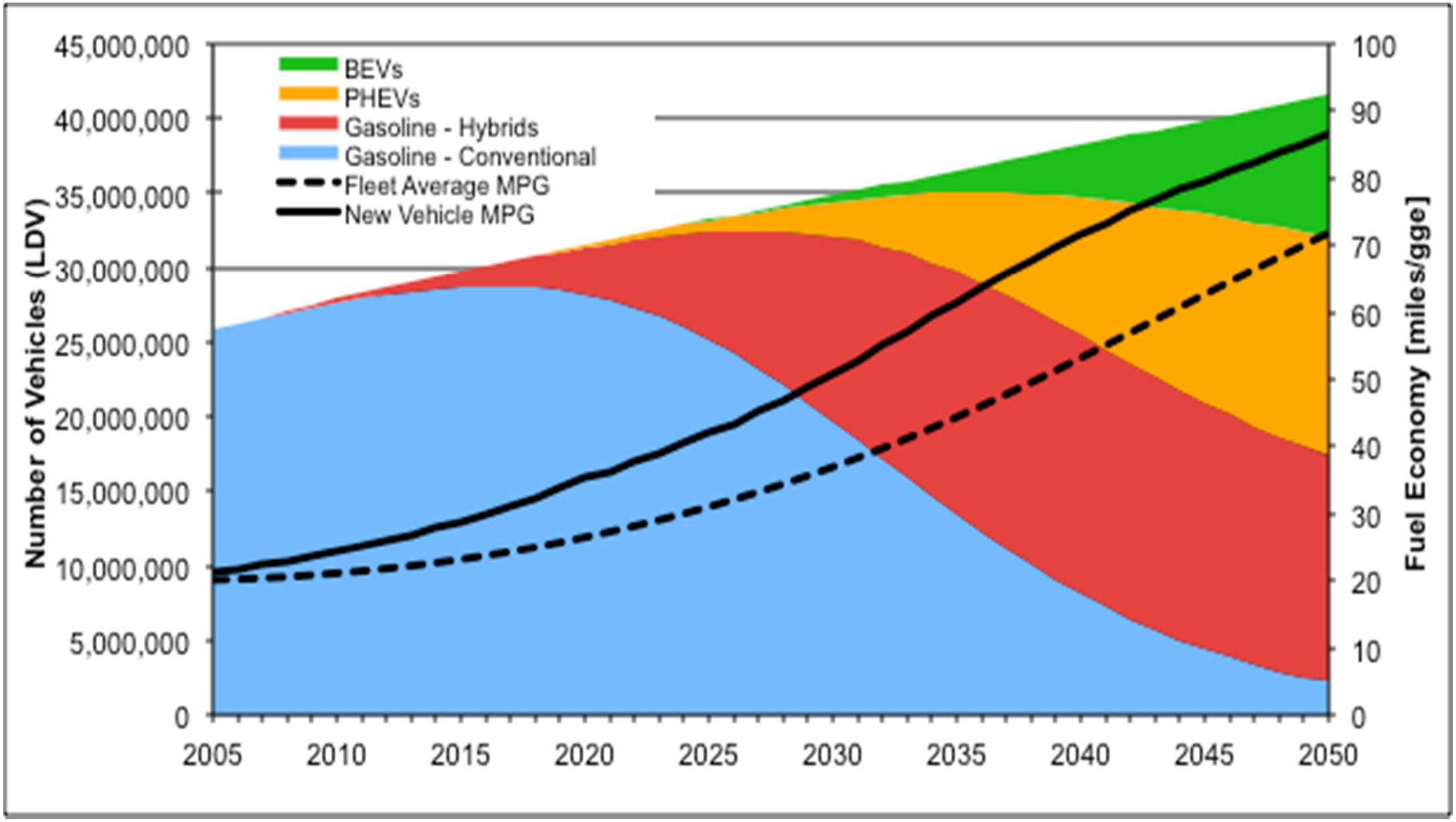
Building stock turnover



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

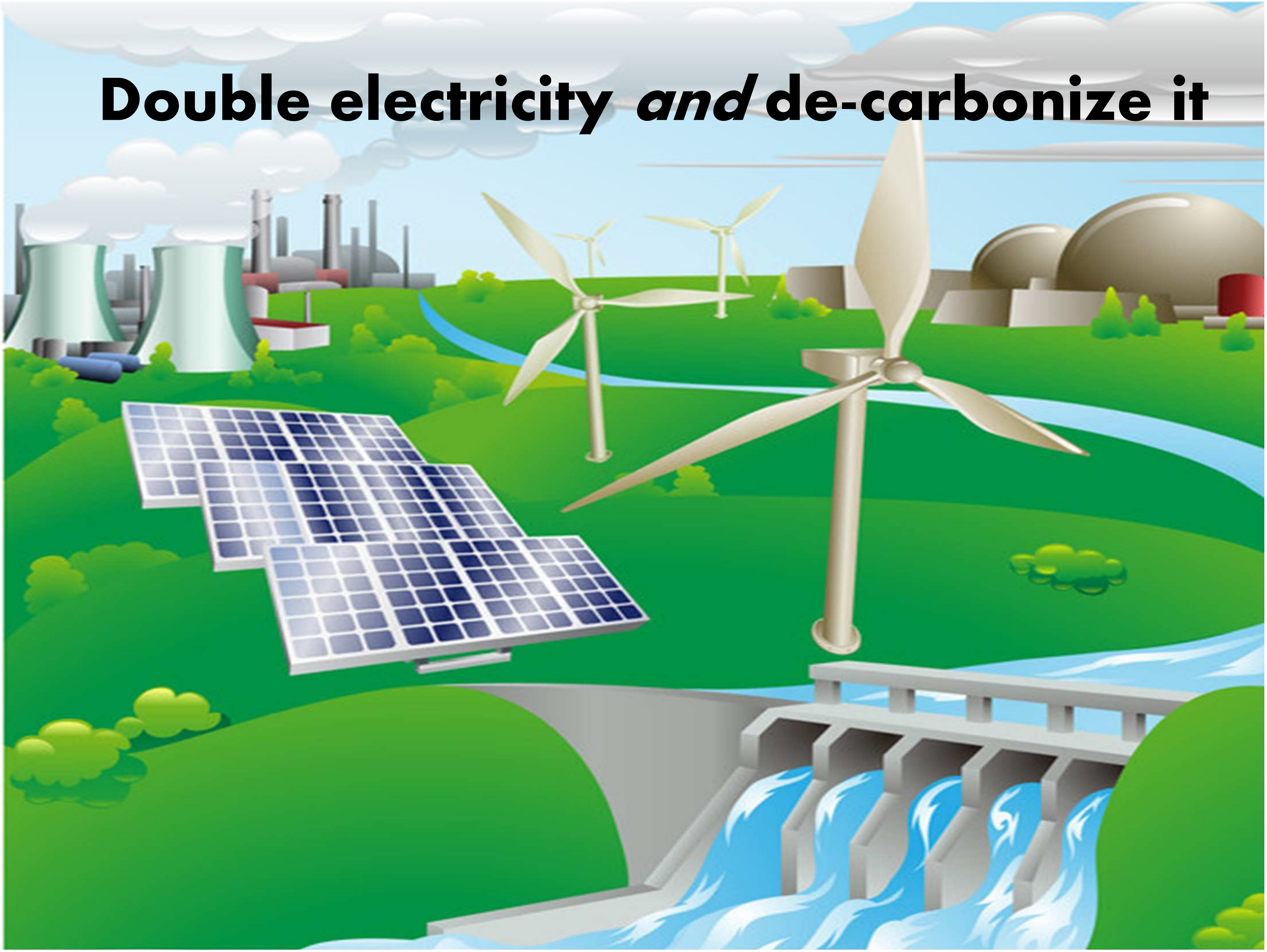
Technology maturity light duty transportation

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	

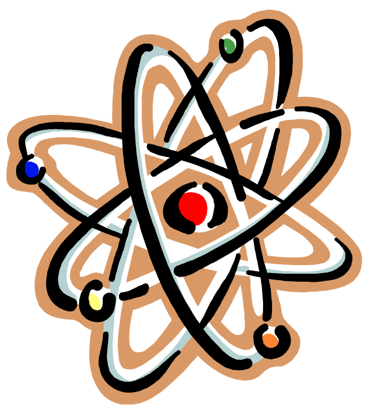
Projected Energy Demands

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

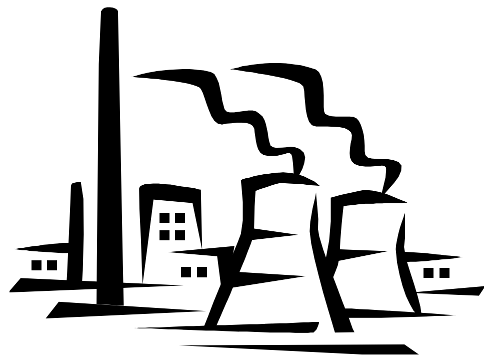
*Billion gallons gasoline equivalent


Double electricity *and* de-carbonize it

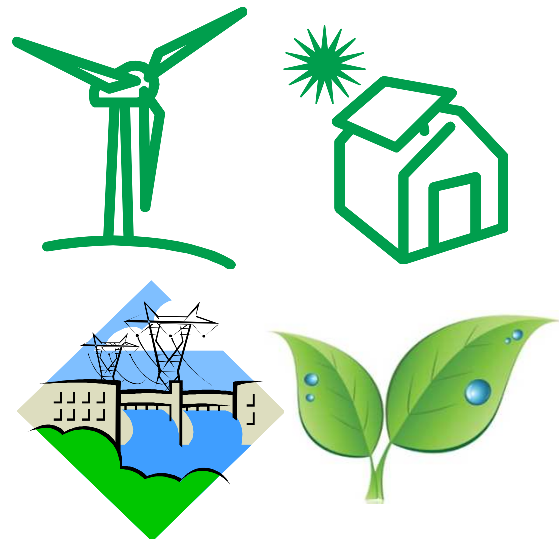
There are 3 Low-Carbon Electricity Options



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 CO_2e – for coal – about 1/3 the total budget
  - 13 mmt CO_2e --- 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

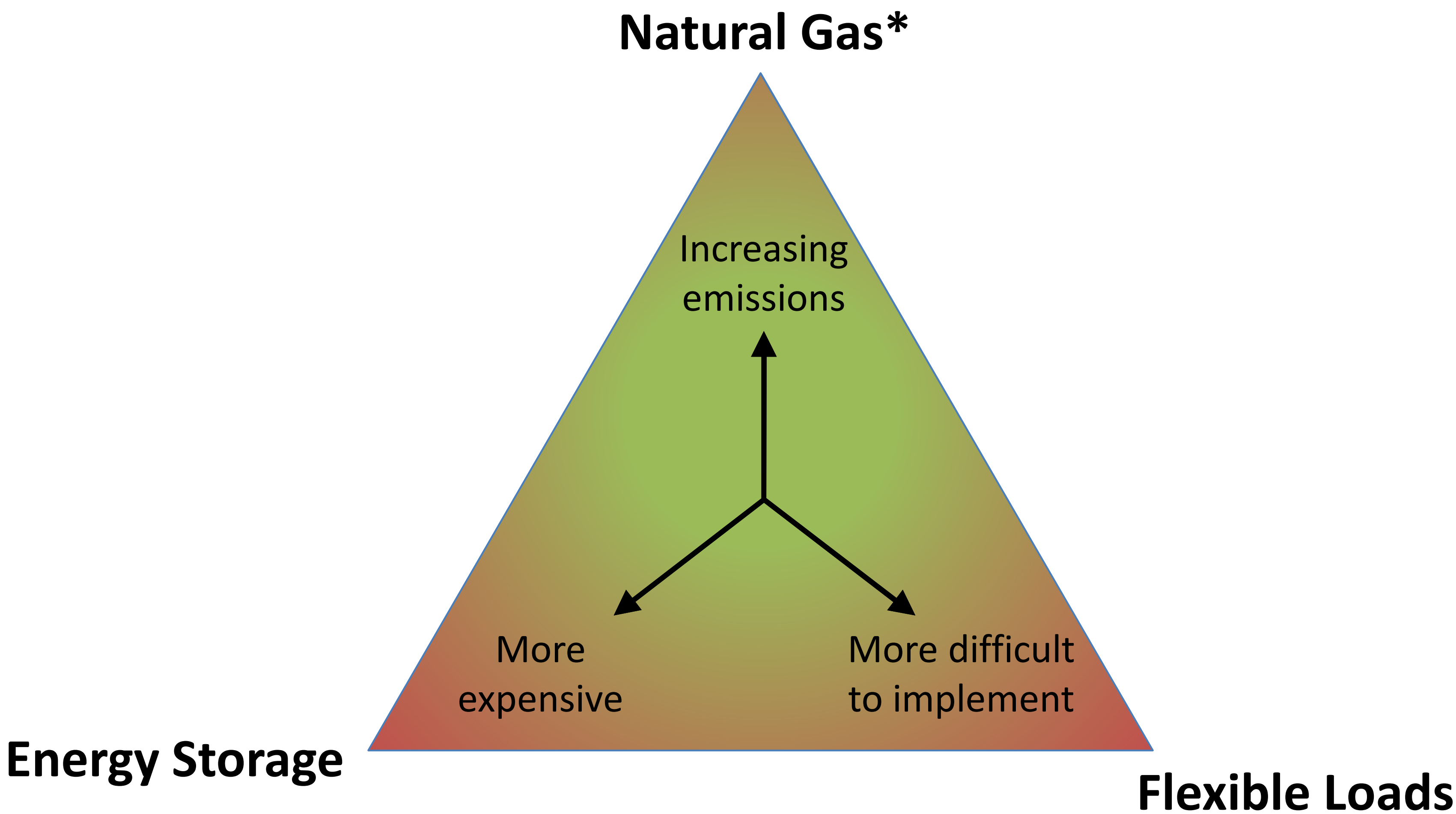
Renewable Electricity

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

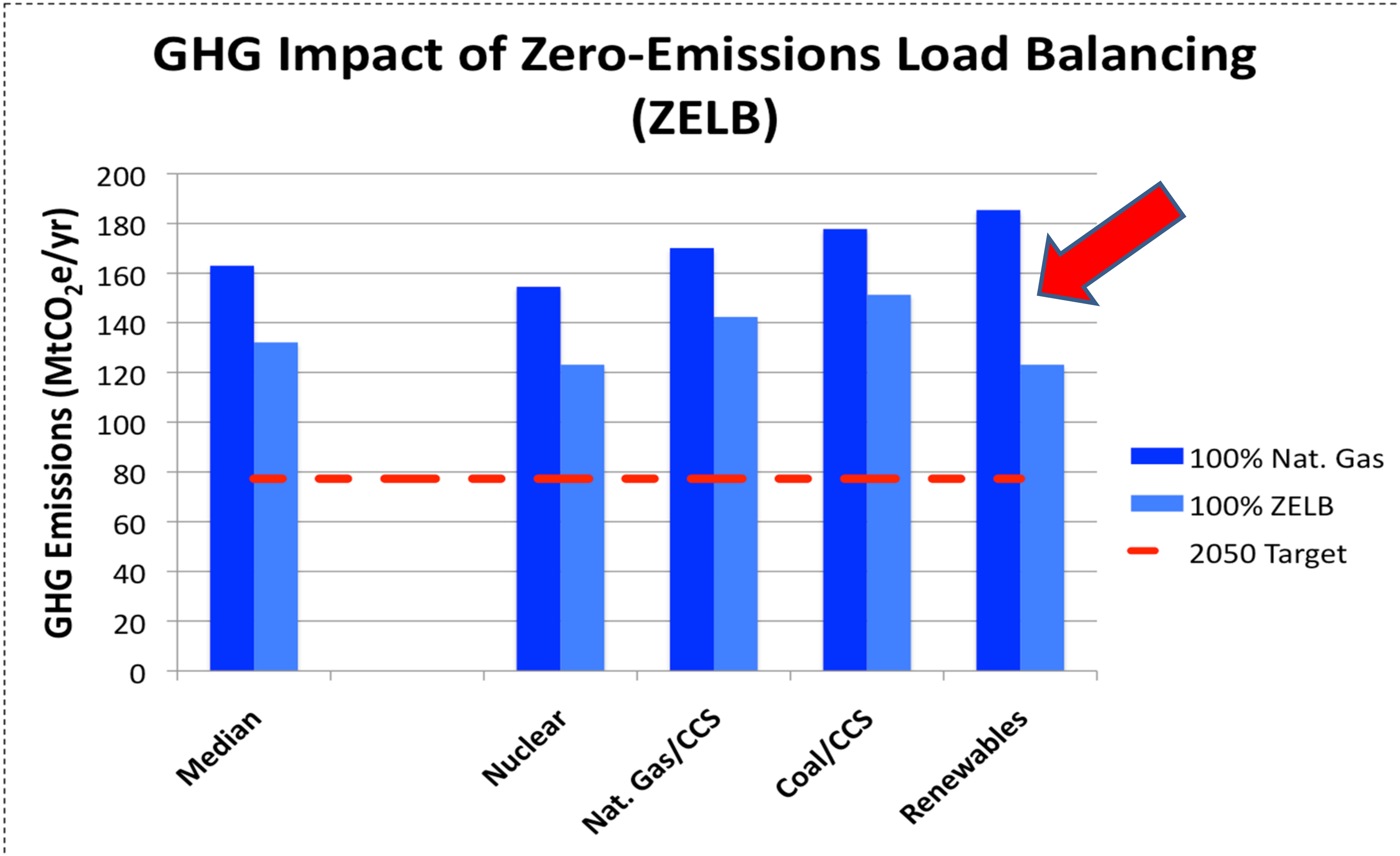
Strategy	Assumed plant size	Total plant capacity needed in 2050	Build rate 2011-2050 (Plants/year)
Nuclear	1.5 GW	44 GW	**0.7**
Fossil/CCS	1.5 GW	49 GW	**0.8**
Renewables Mix		**160 GW**	
Wind	500 MW	59 GW	**3**
Central Solar (CSP and PV)	500 MW	57 GW	**3**
Distrib'd. Solar PV	5 kW	19 GW	**100,000**
Biomass/CCS	500 MW	7 GW	**0.3**
CA Biofuels	50 Mgge/yr	5,500 Mgge/yr	**3**
H_2 (onsite NG)	0.5 Mgge/yr	800 Mgge/yr	**40**
H_2 (central plant)	440 Mgge/yr	7,200 Mgge/yr	**0.4**

Load balancing can add emissions:



** May be possible with CCS in future*

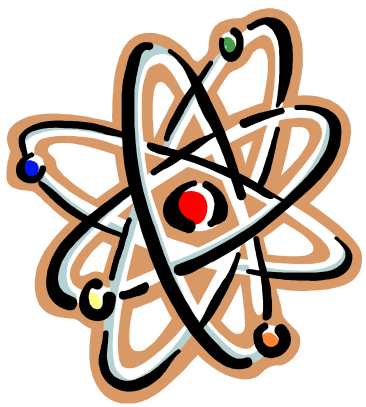
Zero-Emission Load Balancing (ZELB)



ZELB

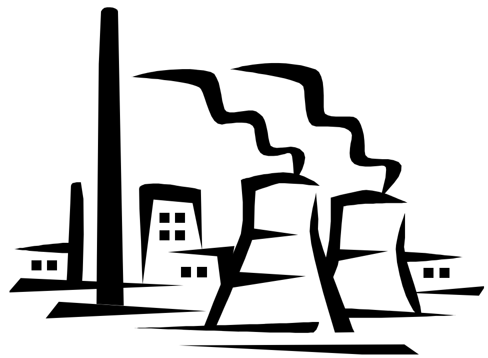
- More challenging for the maximum renewables case
  - GW-days of storage needed
  - Smart grid solution is a challenge
    - Smart meter fiasco
    - Completely change business model to demand follows load vs load follows demand
    - Need whole different system of system control – but will this ever 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



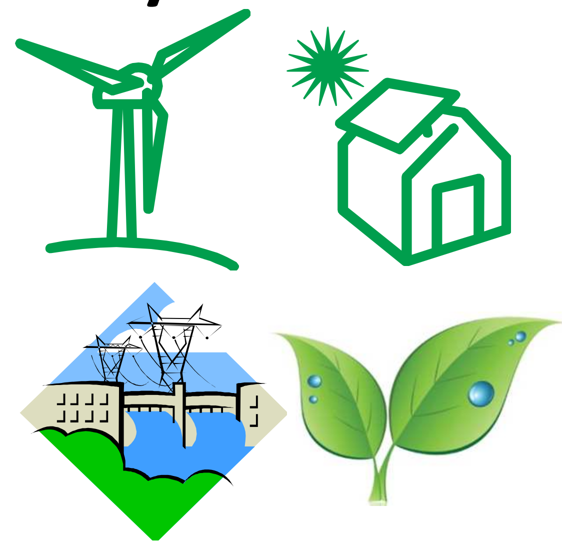
Nuclear

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



Fossil/CCS

Similar to nuclear, CO_2 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)		

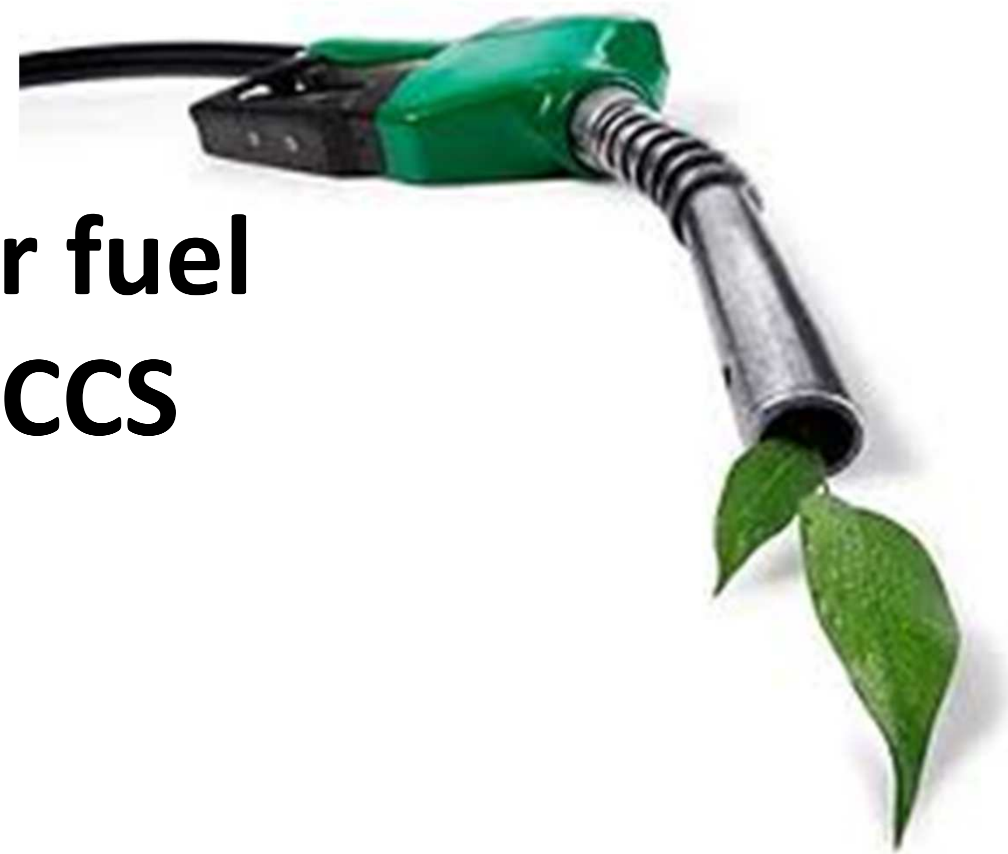
Load balancing technology bins

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

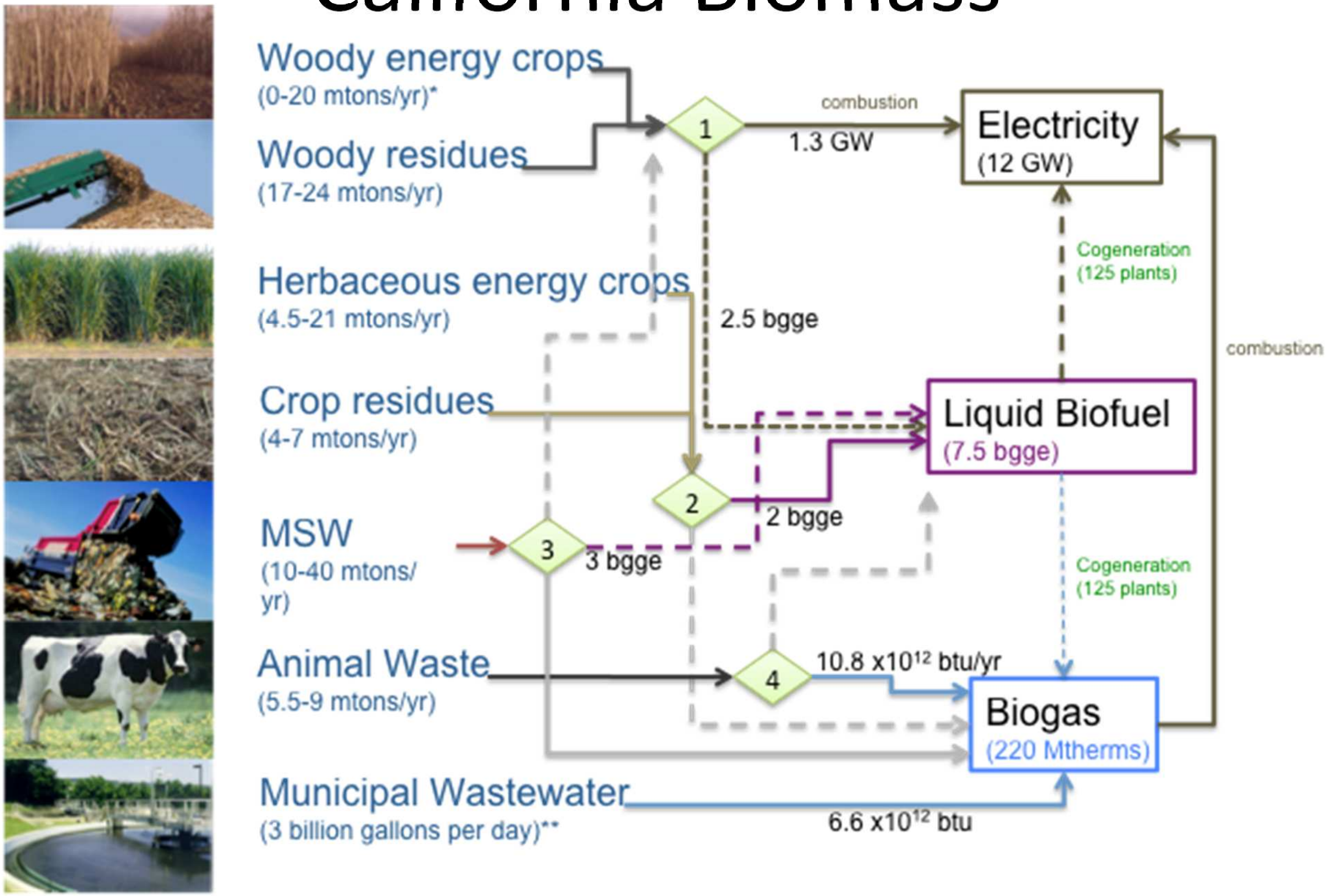


- Can't electrify
  - Heavy duty transport
  - Airplanes
- Plus fuel for
  - Load following
  - High quality heat
- Biofuels are the choice in the pipeline
  - How much biomass?
  - How green?

Meeting the demand for fuel

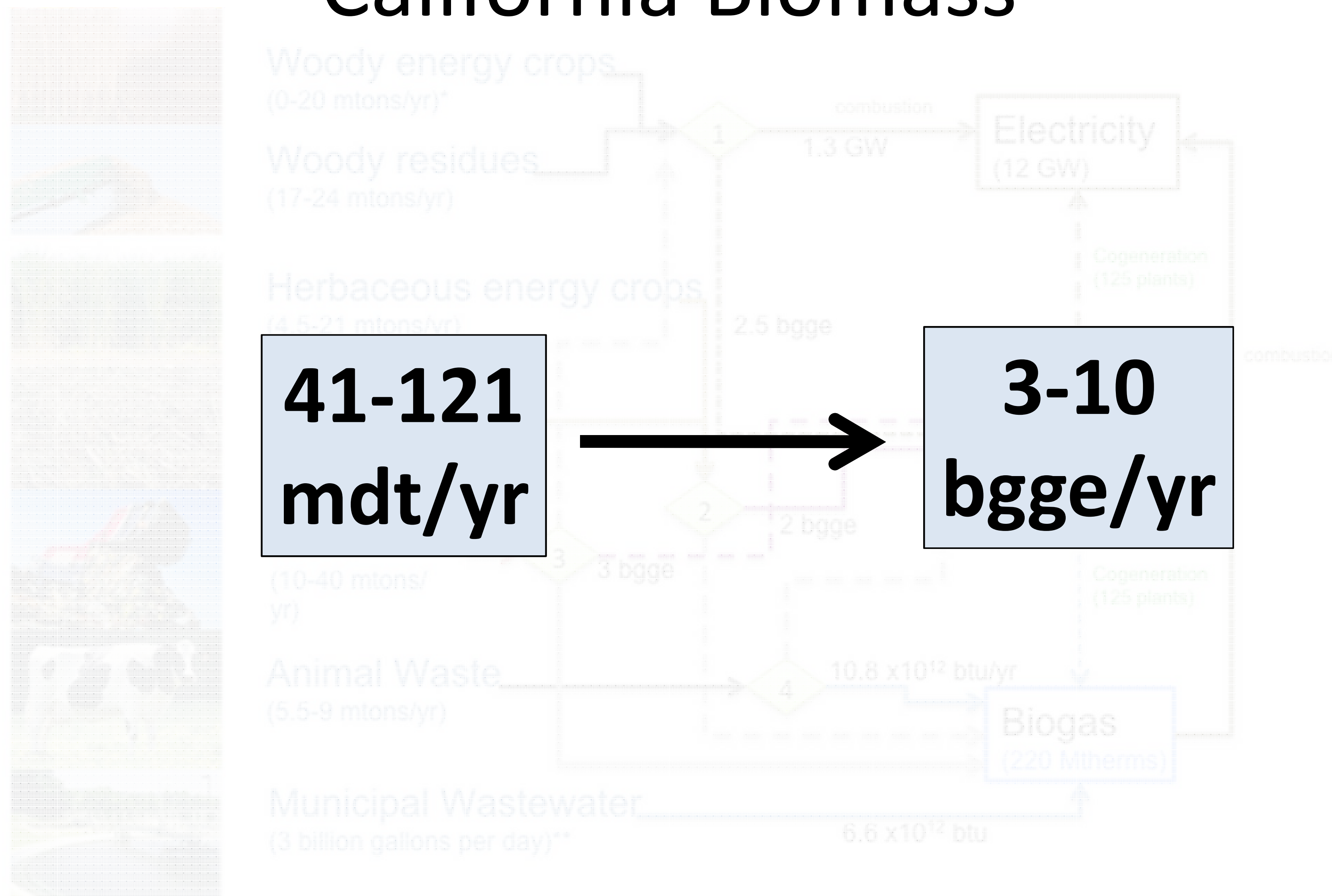
- **Total demand: 37 billion gge/yr**
- **About 10 billion gge/yr are for gas based electricity generation with CCS**
- **27 billion gge/yr can not have CCS**
  - **Heavy duty transport**
  - **Airplanes**
  - **Load following**
  - **High quality heat**

California Biomass



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

California Biomass



41-121 mdt/yr → **3-10 bgge/yr**

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

**not currently used for energy production

Median Case

3 GW
(2.0 bgge/yr)

+

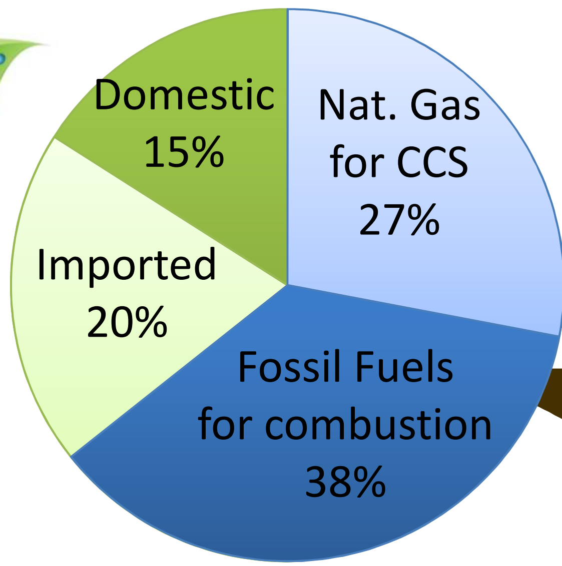
41-121 mdt/yr → **5.5 bgge/yr**

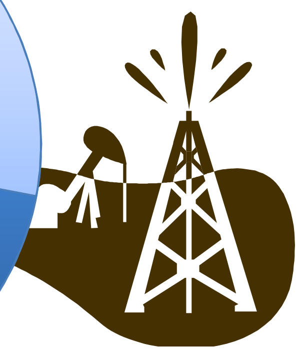
+

Imported **7.5 bgge/yr**

Median Case

Total demand:
37 billion gge/yr





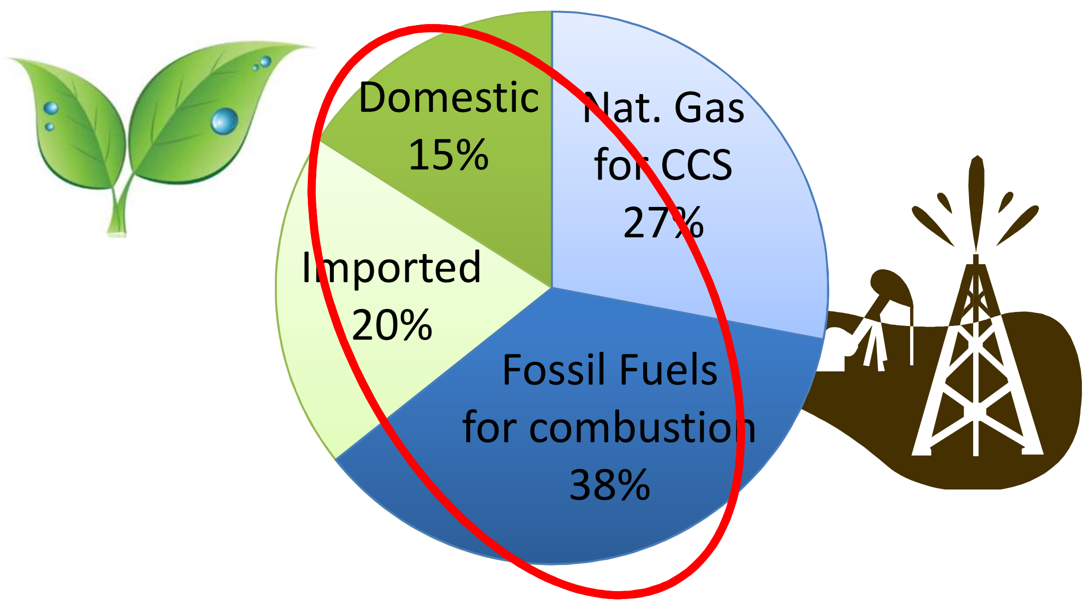
13 bgge/yr

+

7.5 bgge/yr

Median Case

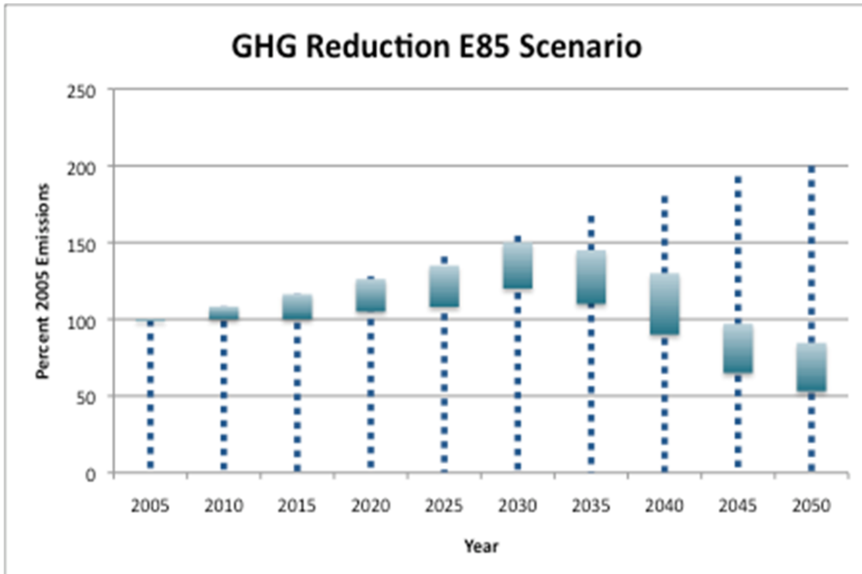
Total demand:
37 billion gge/yr

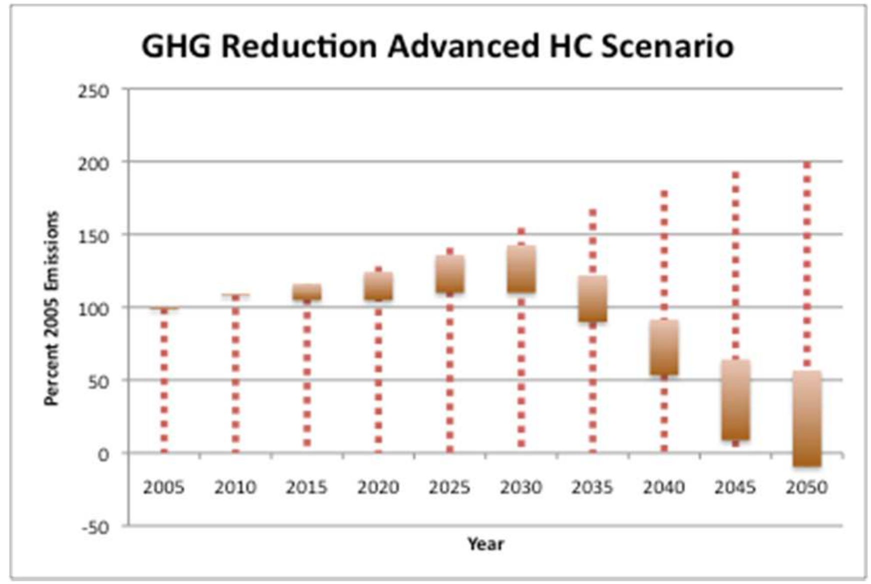


We might expect biomass to provide about ½ the fuel demand (27 bgge/yr) where CCS is not possible

including 2 bgge/yr for load balancing)

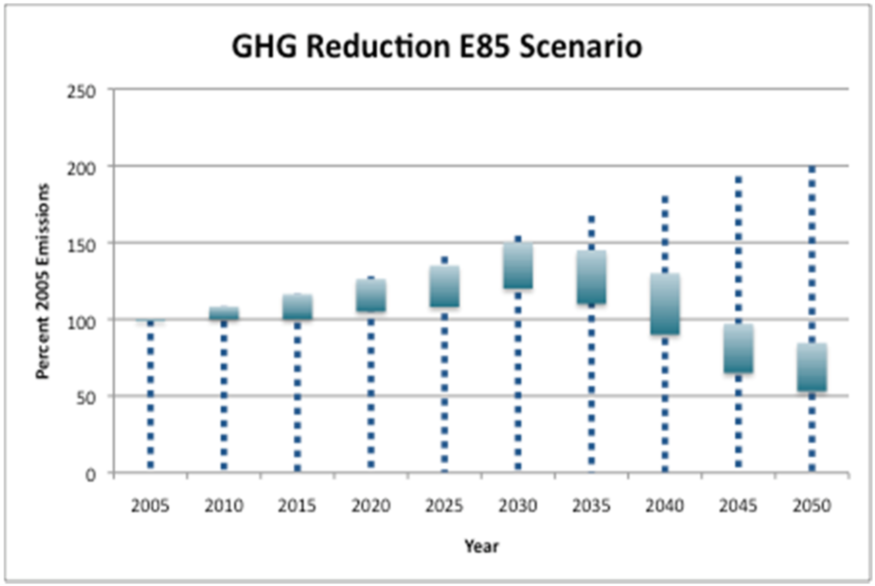
Biomass GHG reductions

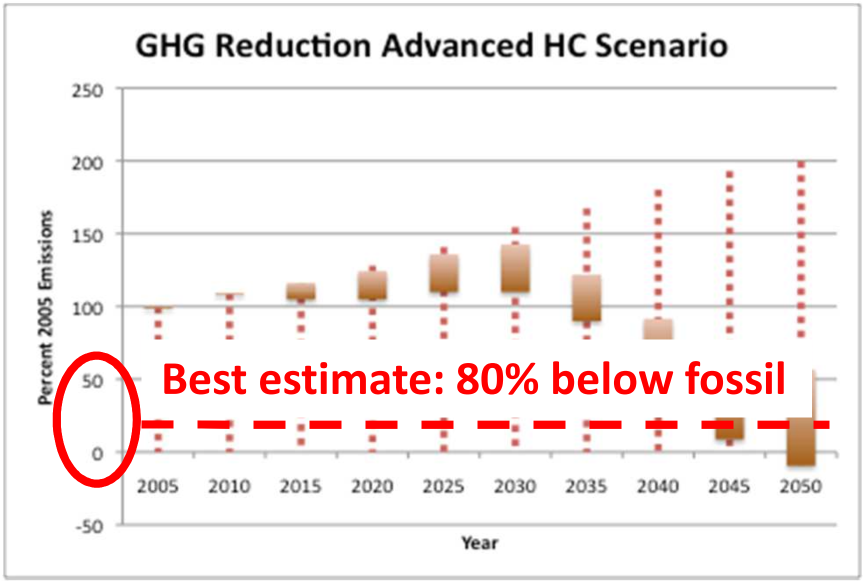




- Cellulosic E85 Falls Short (E100 could go farther)
  - Remaining petroleum footprint is high
  - Limitations on waste oil push biodiesel footprint higher (oil crops needed)
- Advanced Hydrocarbons have a chance to meet the goal
  - Direct replacement for diesel, gasoline and jet fuel with large GHG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

Biomass GHG reductions





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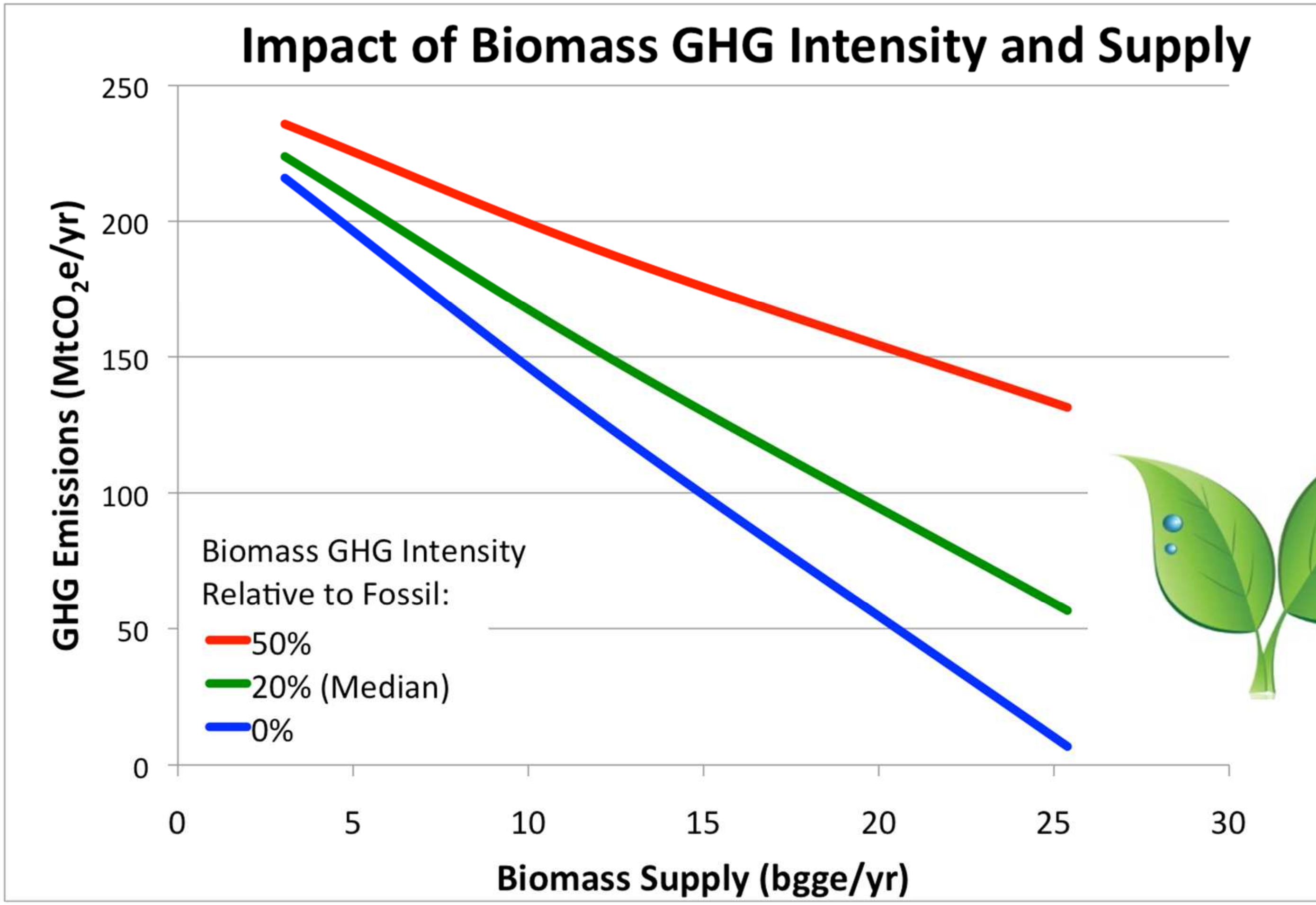
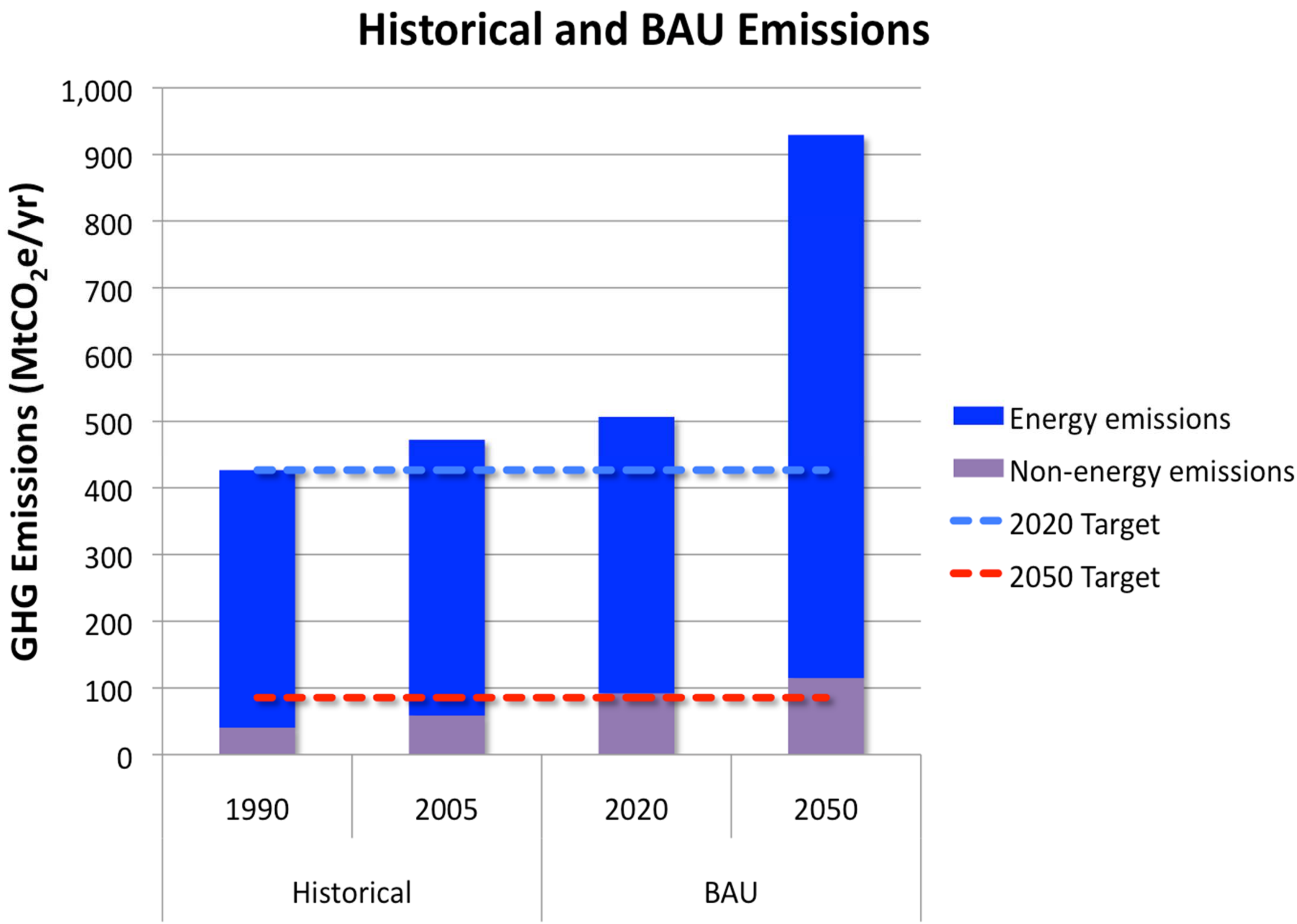
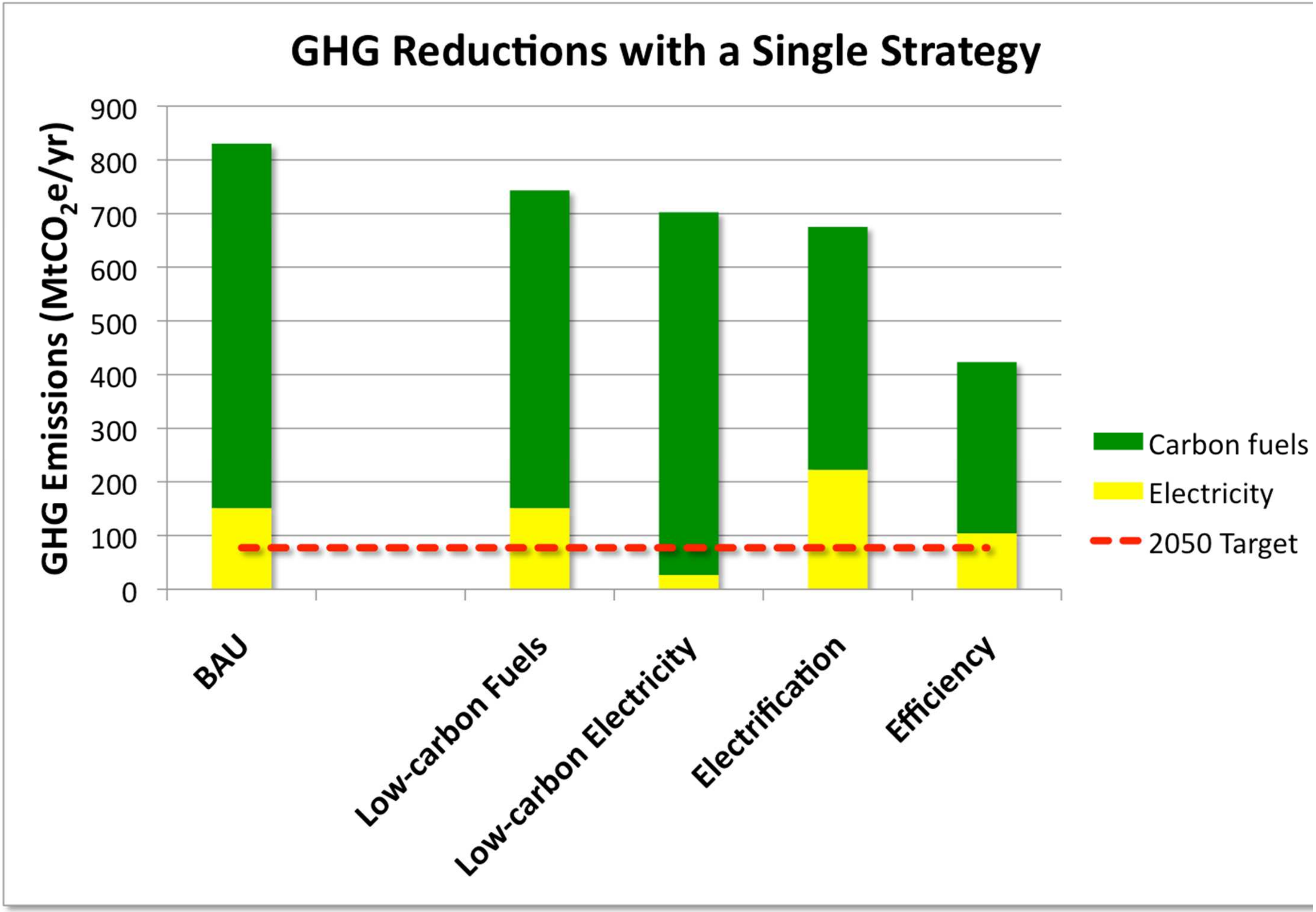
  - Direct replacement for diesel, gasoline and jet fuel with large GHG reductions

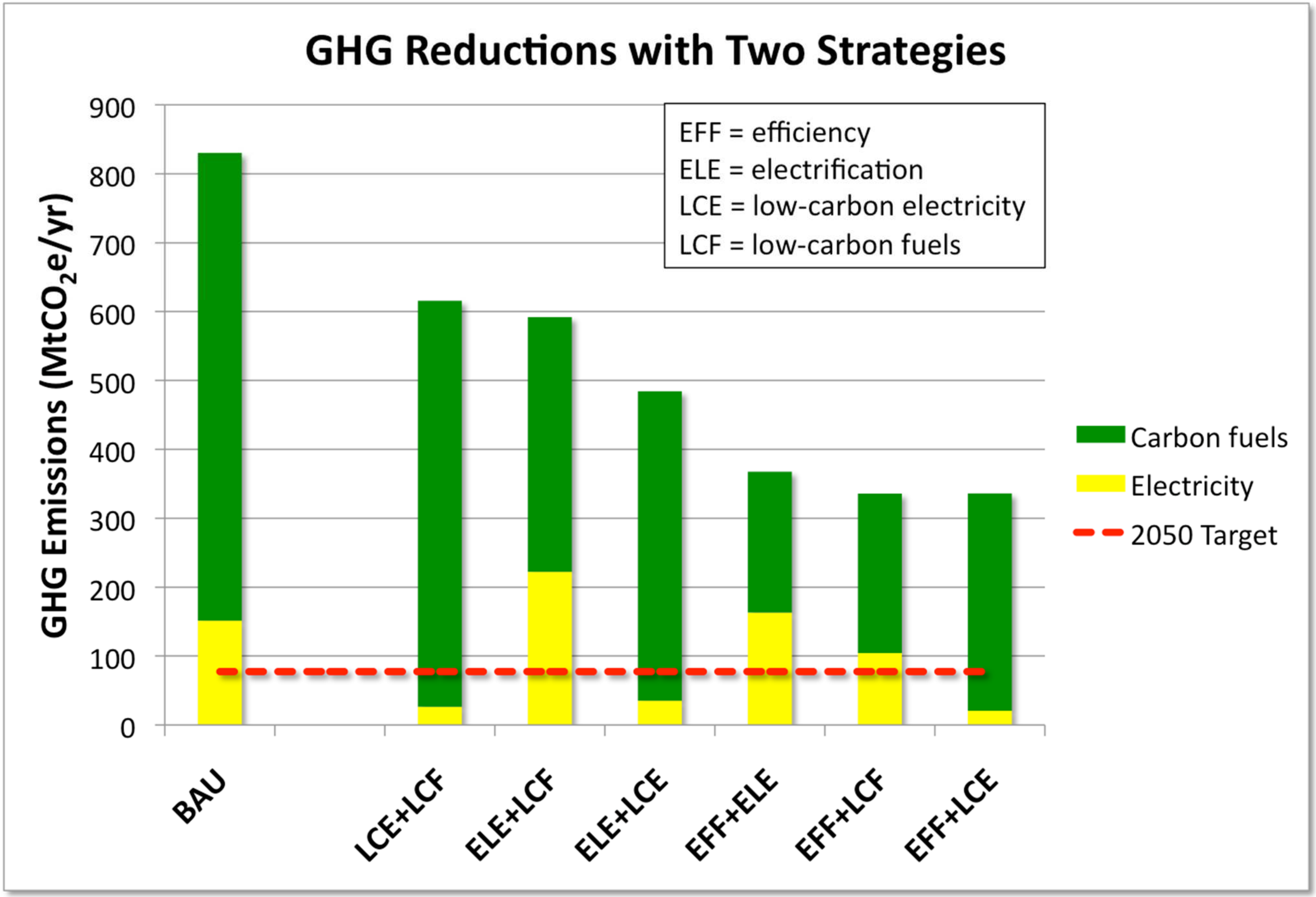
Biomass GHG Intensity and Supply



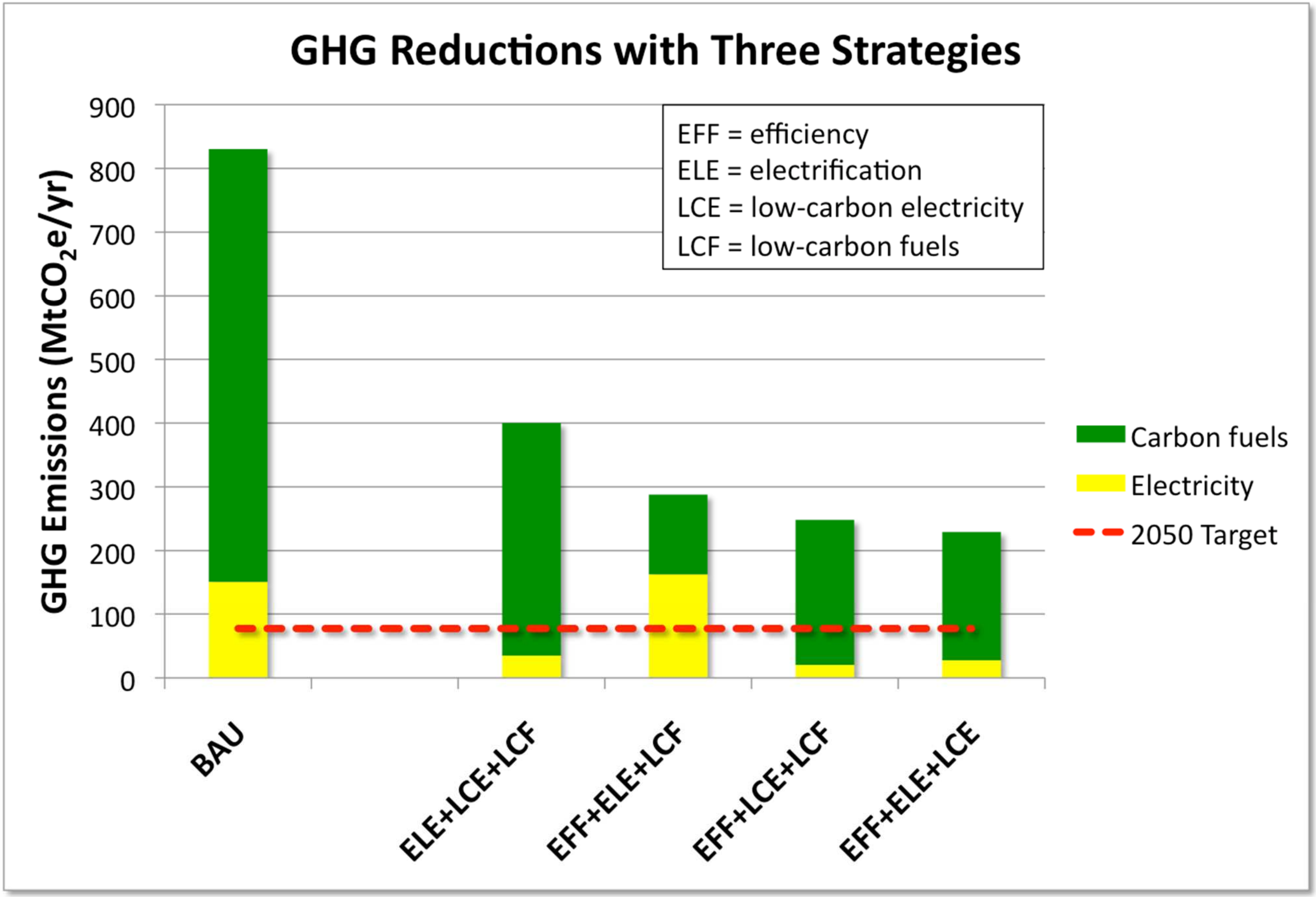

Historical and BAU Emissions
GHG Emissions (MtCO2e/yr)
1,000
900
800
700
600
500
400
300
200
100
0
1990
2005
2020
2050
Historical
BAU
Energy emissions
Non-energy emissions
2020 Target
2050 Target



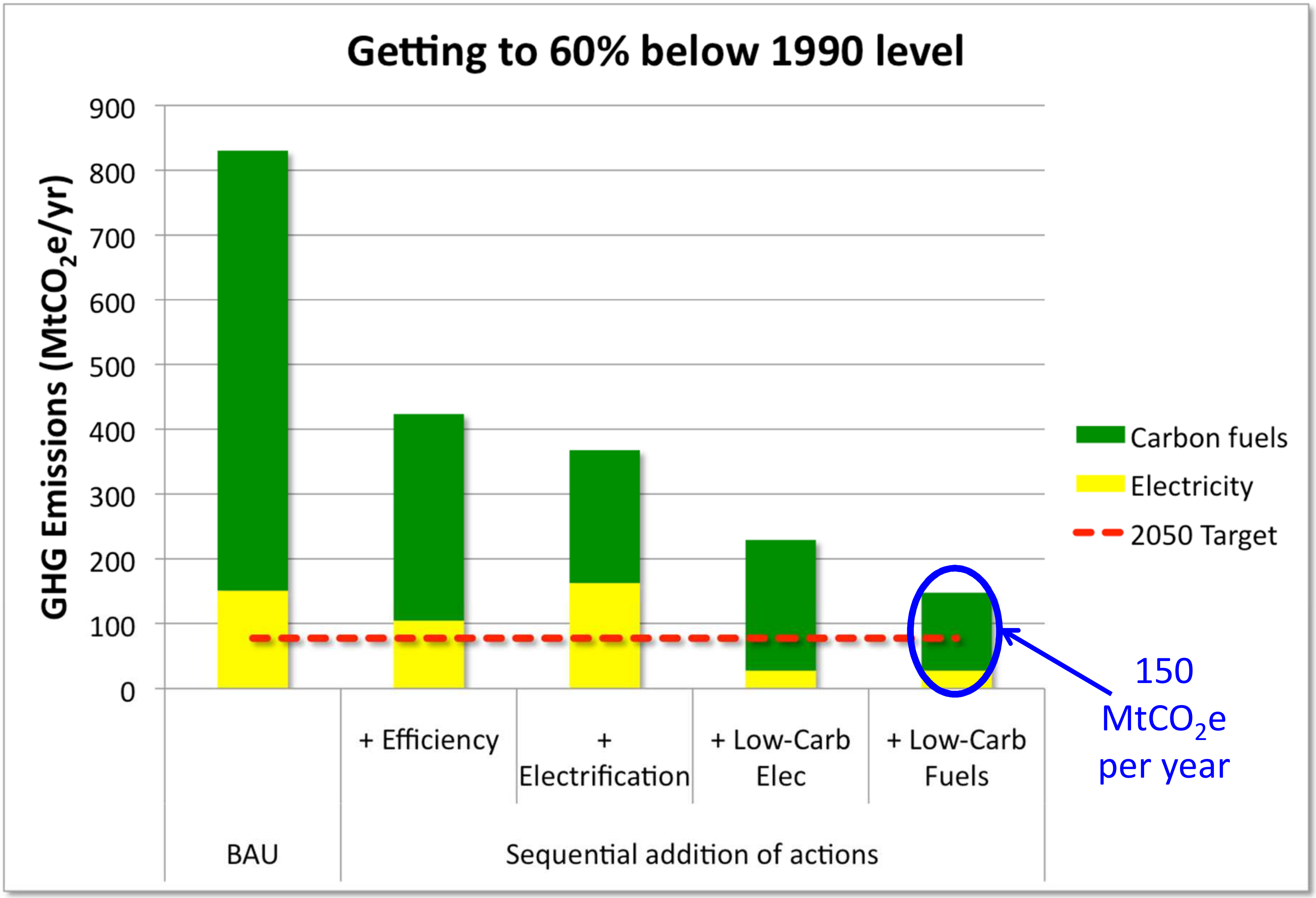
GHG Reductions with a Single Strategy
GHG Emissions (MtCO2e/yr)
900
800
700
600
500
400
300
200
100
0
BAU
Low-carbon Fuels
Low-carbon Electricity
Electrification
Efficiency
Carbon fuels
Electricity
2050 Target



GHG Reductions with Two Strategies
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
BAU
LCE+LCF
ELE+LCF
ELE+LCE
EFF+ELE
EFF+LCF
EFF+LCE


GHG Reductions with Three Strategies
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
BAU
ELE+LCE+LCF
EFF+ELE+LCF
EFF+LCE+LCF
EFF+ELE+LCE

Getting to 60%: All 4 Actions



Components of a 60% solution

Efficiency

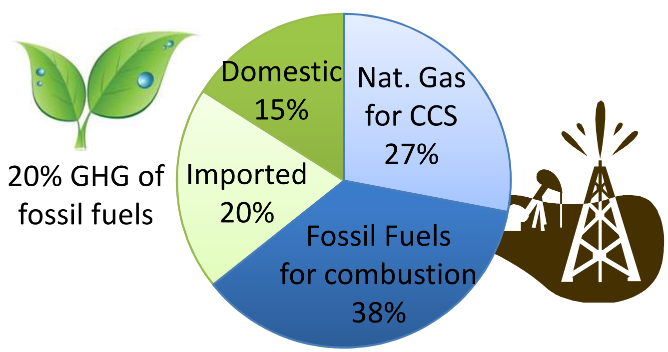
Percent energy decrease from BAU			
Buildings	40%	Cars	60%
Industry	0-15%*	Trucks	30%
*BAU 30-40% fr. 2005		Airplanes	50%
Electricity	**31%**	Bus, Rail	0%
Fuels	**52%**	Marine	40%

Electrification

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%

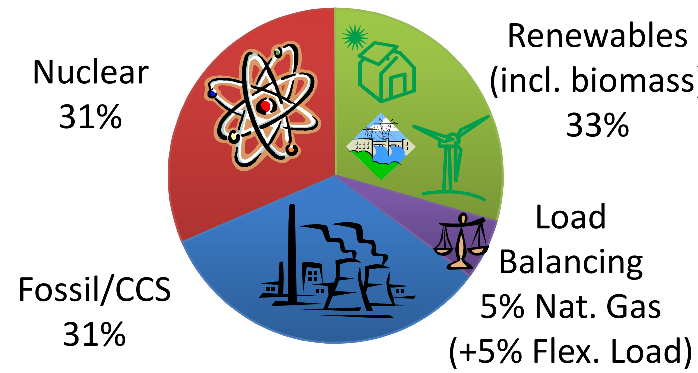
Low-Carb Fuels

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)

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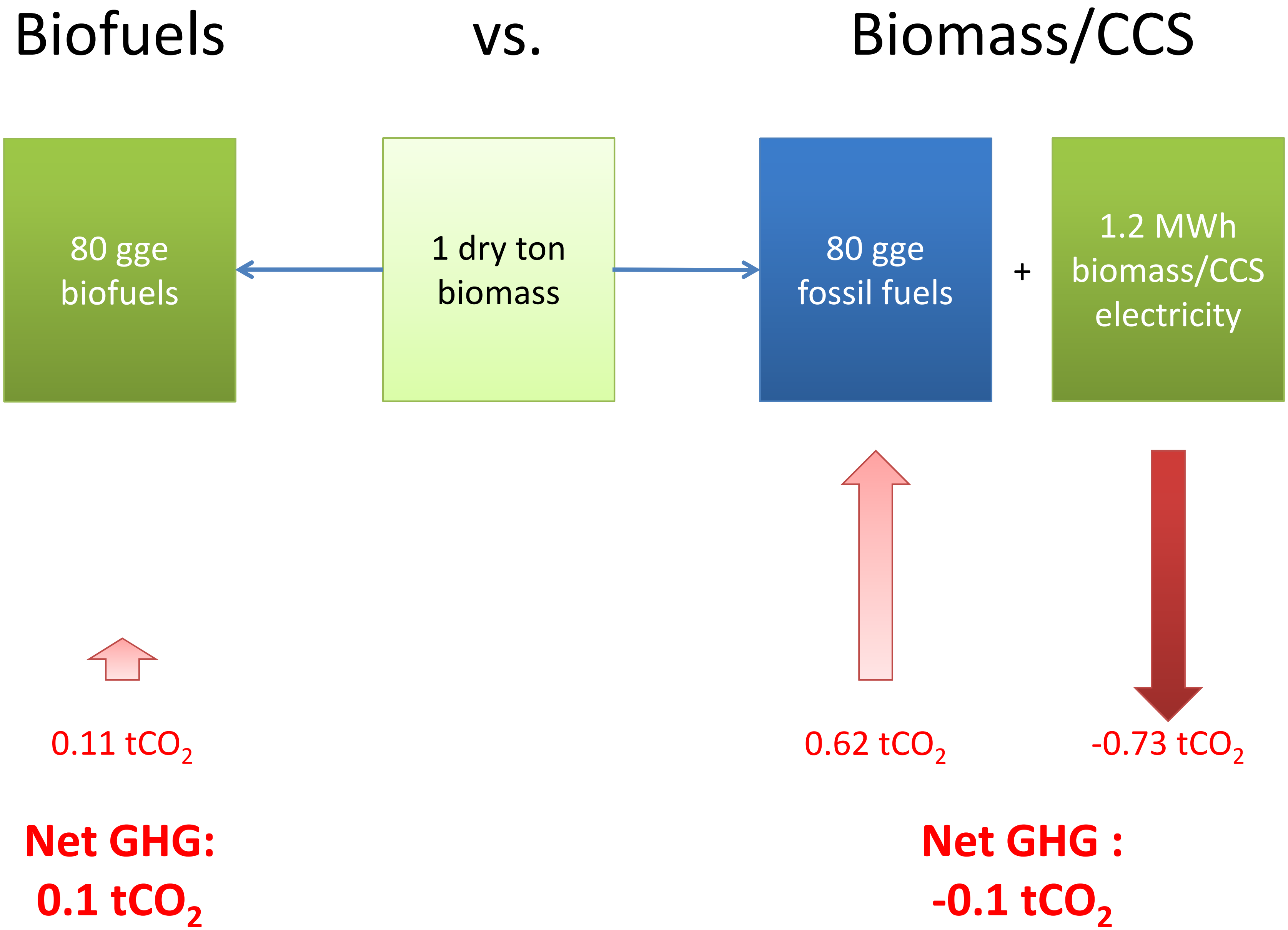
8. Double biomass supply
9. Biomass/Coal/CCS (make fuels + electricity)

---

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


Biofuels
vs.
Biomass/CCS
80 gge biofuels
1 dry ton biomass
80 gge fossil fuels
+
1.2 MWh biomass/CCS electricity
0.11 tCO_2
0.62 tCO_2
-0.73 tCO_2
Net GHG: 0.1 tCO_2
Net GHG : -0.1 tCO_2

Projected Energy Demands

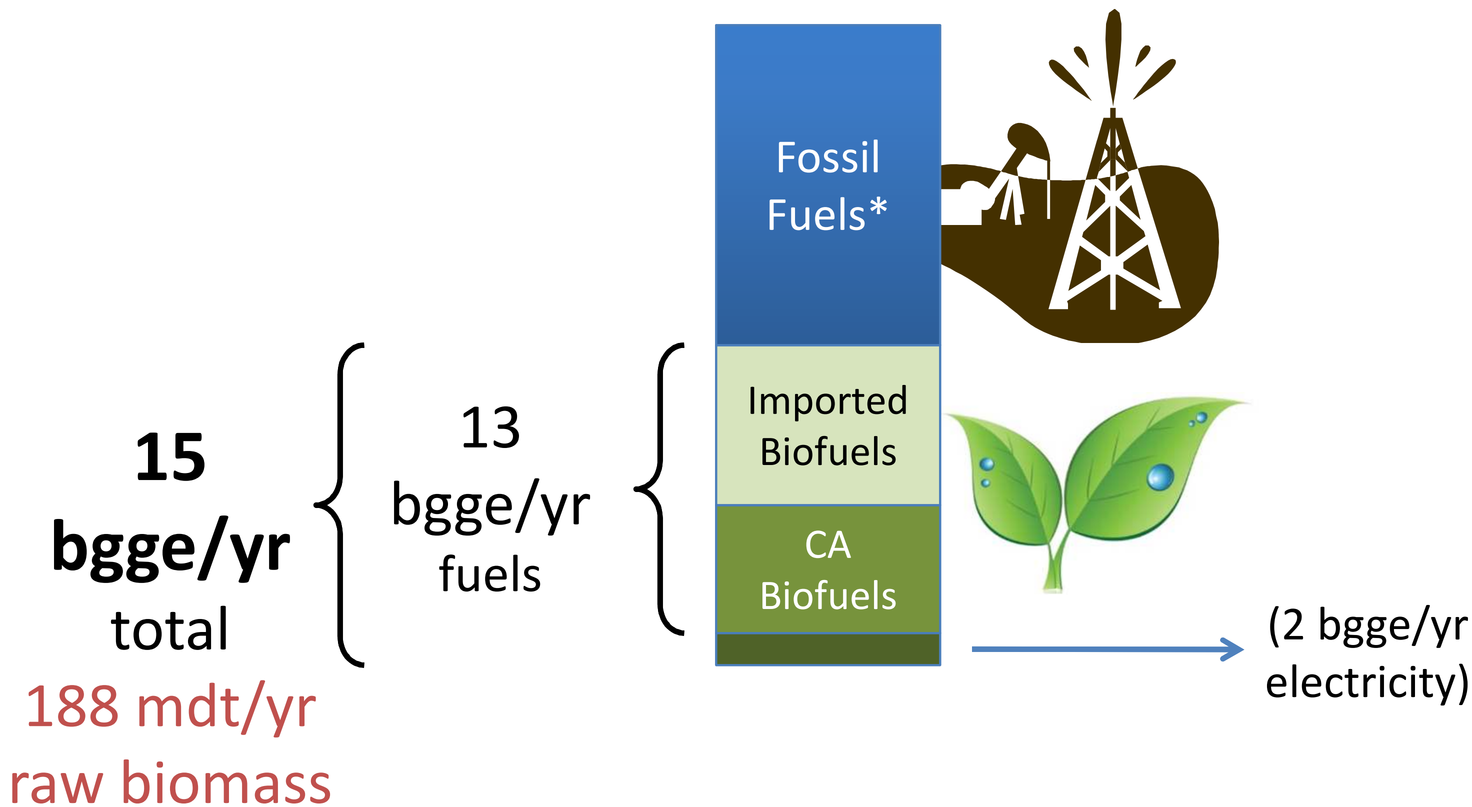
Energy Carrier	Units	2005	2050 BAU	2050 E1	2050 H1 E1 plus H2
Electricity	TWh/yr	270	470	510	470
Fuels HC/H2	bgge*/yr	36/0	68/0	25/0	18/8

*Billion gallons gasoline equivalent

H_2 Hydrogen case H_2

H_2 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%

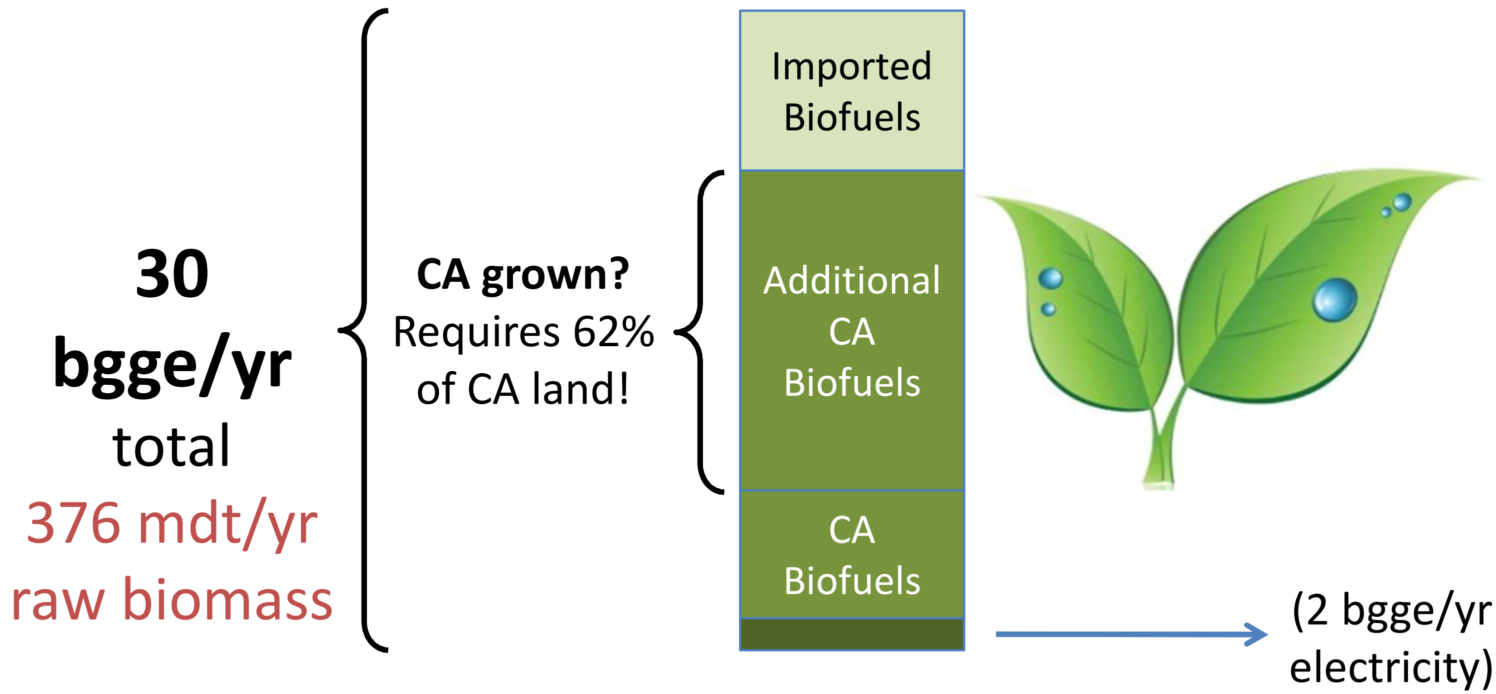
Doubling Biomass Supply



Median case

*Not including natural gas for CCS

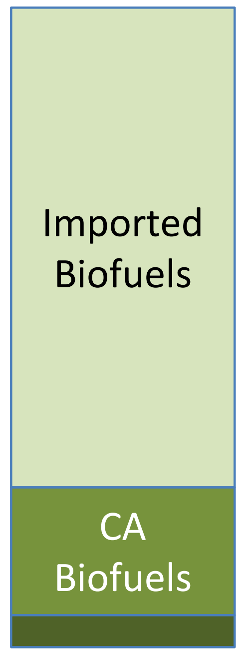
Doubling Biomass Supply



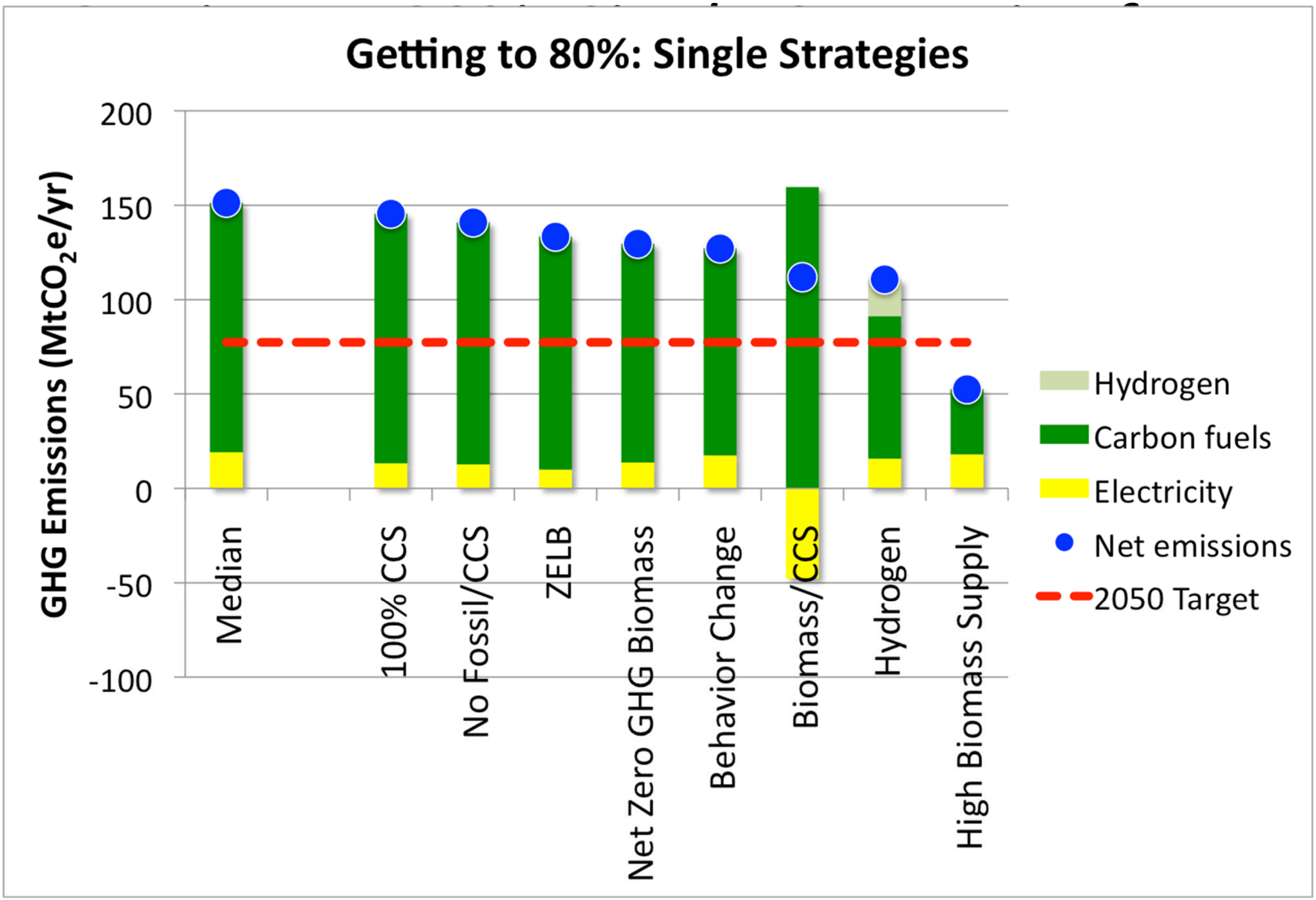
Doubling Biomass Supply

30 bgge/yr
total
376 mdt/yr
raw biomass

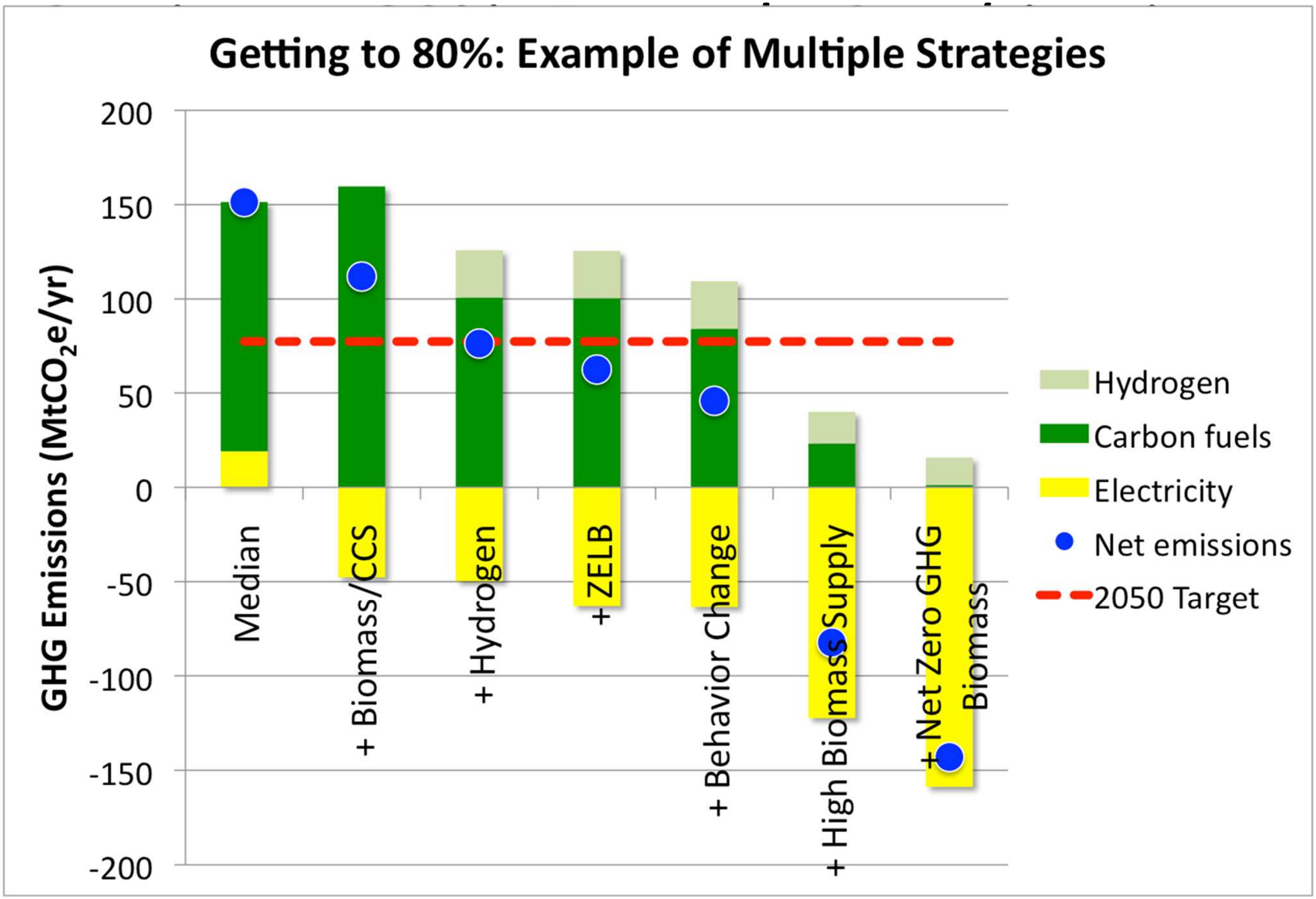
Imported?
Requires 3x
base imports
(22.5 bgge/yr)



(2 bgge/yr
electricity)

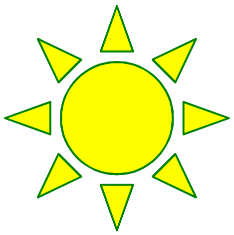


Getting to 80%: Single Strategies
GHG Emissions (MtCO2e/yr)
200
150
100
50
0
-50
-100
Median
100% CCS
No Fossil/CCS
ZELB
Net Zero GHG Biomass
Behavior Change
Biomass/CCS
Hydrogen
High Biomass Supply
Hydrogen
Carbon fuels
Electricity
Net emissions
2050 Target



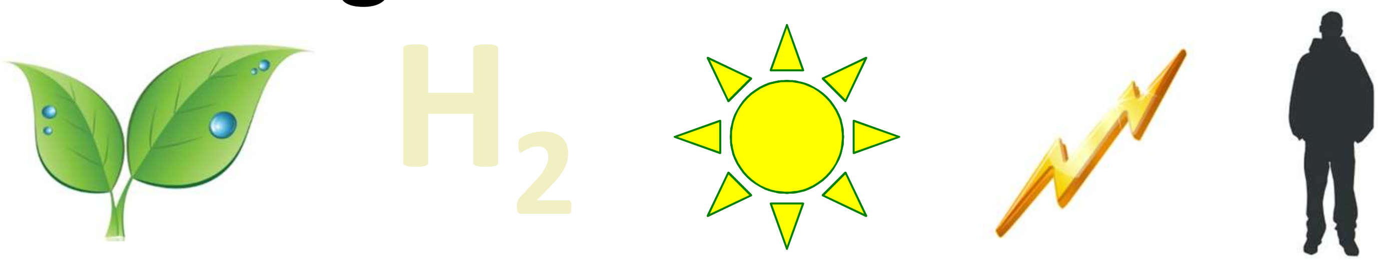
Getting to 80%: Example of Multiple Strategies
GHG Emissions (MtCO2e/yr)
200
150
100
50
0
-50
-100
-150
-200
Median
+ Biomass/CCS
+ Hydrogen
+ ZELB
+ Behavior Change
+ High Biomass Supply
+ Net Zero GHG Biomass
Hydrogen
Carbon fuels
Electricity
Net emissions
2050 Target

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

- **<u>Yes, we can:</u>** 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.