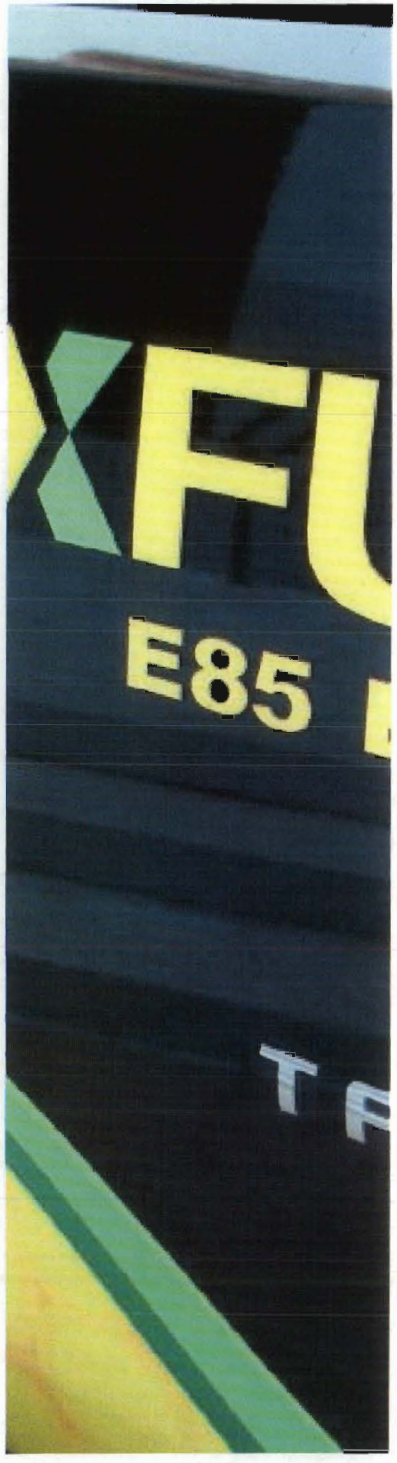


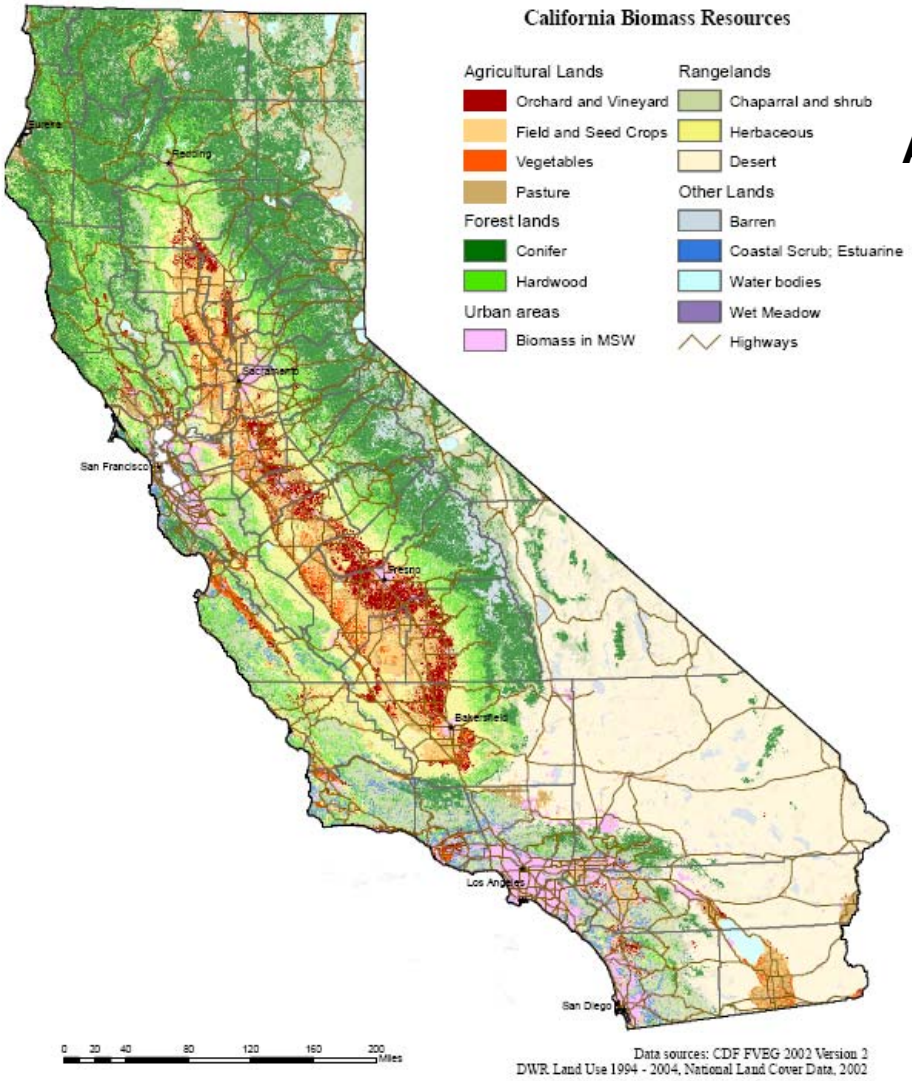
Ethanol and other Biofuels: Potential In-state Production

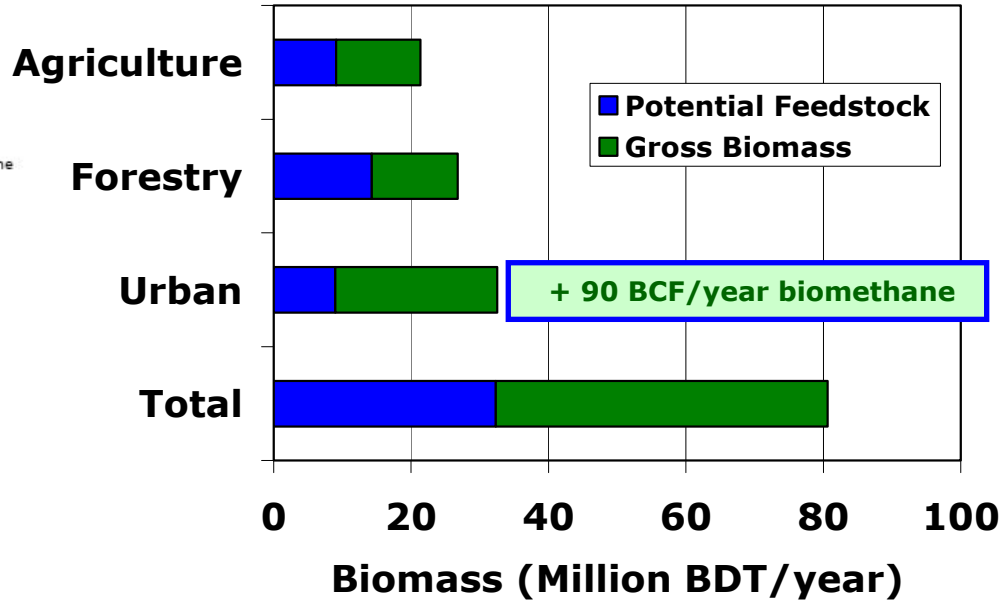
Alternative Transportation Fuels Plan, AB 1007
Joint California Energy Commission and California Air Resources Board Workshop

Sacramento, California
31 May 2007

Bryan M. Jenkins, Professor
University of California, Davis
Executive Director, California Biomass Collaborative

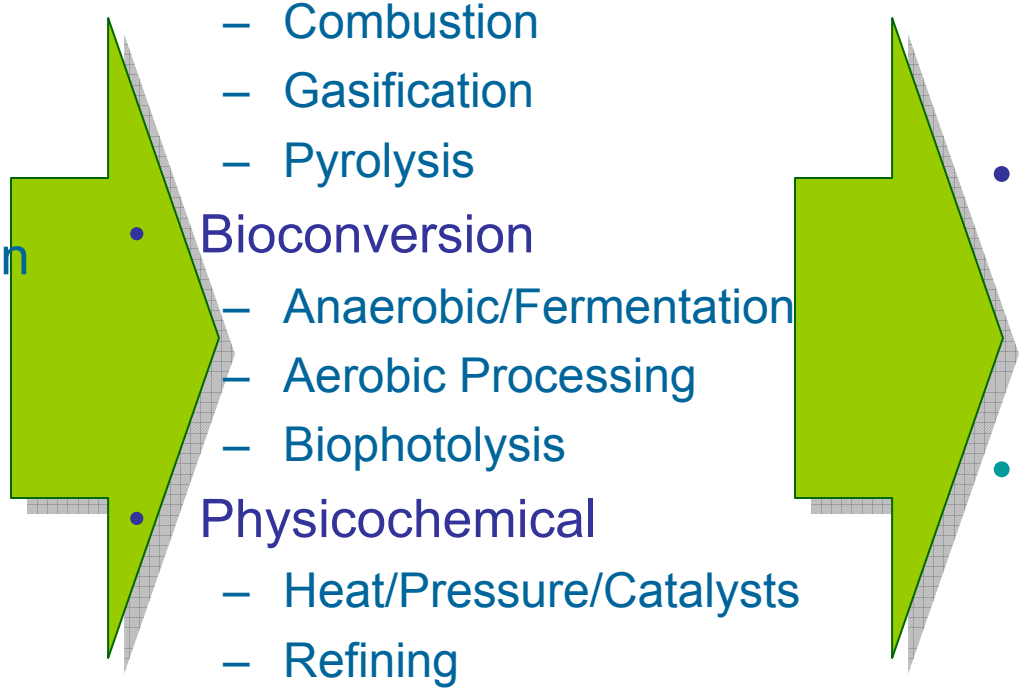
California Residue and In-forest Biomass Resources





Principal Biomass Conversion Pathways

- Production
- Collection
- Processing
- Storage
- Transportation



- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
- Bioconversion
  - Anaerobic/Fermentation
  - Aerobic Processing
  - Biophotolysis
- Physicochemical
  - Heat/Pressure/Catalysts
  - Refining
  - Makes e.g. Esters (Biodiesel), Alkanes

- Energy
  - Heat
  - Electricity
- Fuels
  - Solids
  - Liquids
  - Gases
- Products
  - Chemicals
  - Materials

Biorefining Approaches

- Thermochemical

Thermolytic

Solids
Oils

Gasification, Pyrolysis

- Synthesis gas
  - ($CO + H_2$ + other)

Catalytic Synthesis

Syngas Fermentation

- Hydrocarbons, mixed alcohols, hydrogen, ammonia, SNG, ethanol, higher alcohols…

- Biochemical

Pretreatment, Hydrolysis
(cell wall deconstruction)

Hydrolytic
Cellulose
Hemicellulose

- Sugar monomers, acids

Fermentation

- Ethanol, higher alcohols, biomethane, hydrogen, acids…

Total Categorical Bioenergy Potentials in California

Category	Biomass (Million BDT/year)	Energy in Product (Trillion Btu/year)	Total Capacity
Electricity CHP Heat	32	118 (35 TWh) 230	4,650 MWe 9,050 MWt
Biochemical Biofuel	32	188	1.5 BGY gasoline equivalent
Thermochemical Biofuel	27*	250	1.7 BGY diesel equivalent
Biomethane	5 + Landfill gas and WWTP	106	90 BCF/y methane
Hydrogen (bio + thermal)	32	305	2.5 Million tons/y

* Tonnage for thermochemical biofuel assumed to be constrained by moisture content.

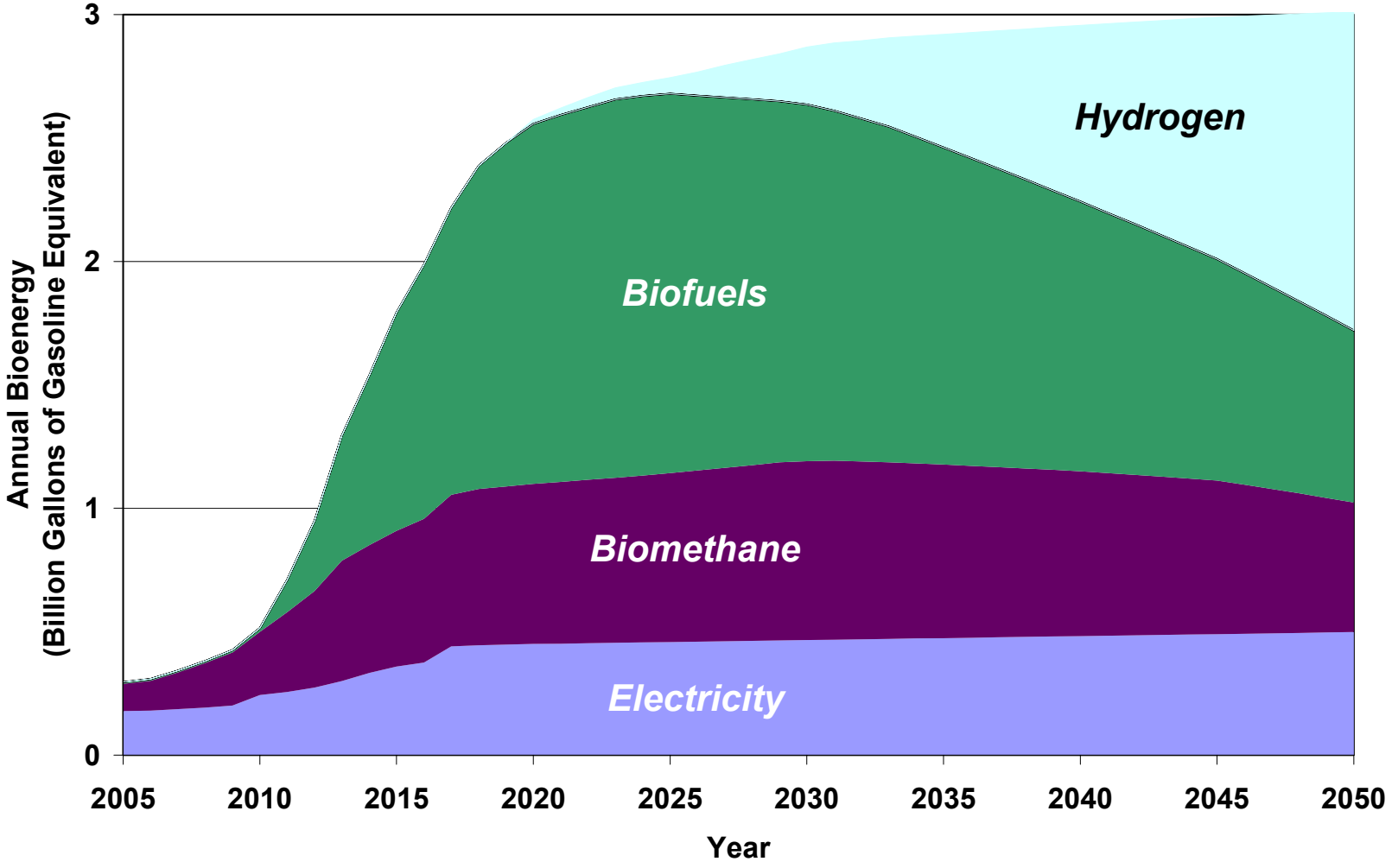
Current California consumption:

16 billion gallons gasoline + 4 billion gallons diesel = 2,500 Trillion Btu/year direct energy content

300 TWh/y electrical energy = 1,024 Trillion Btu/year direct energy

California biofuel scenario:

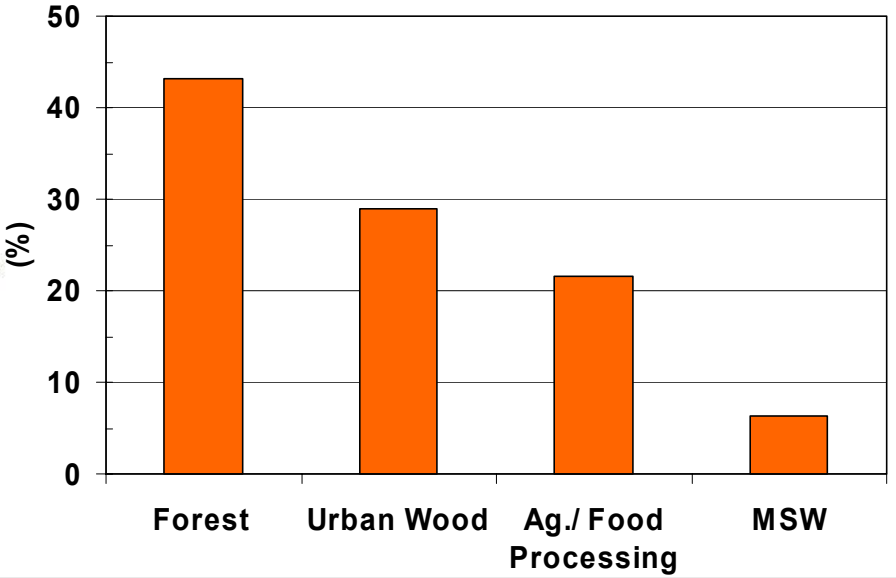
In-state residue + bioenergy crop additions



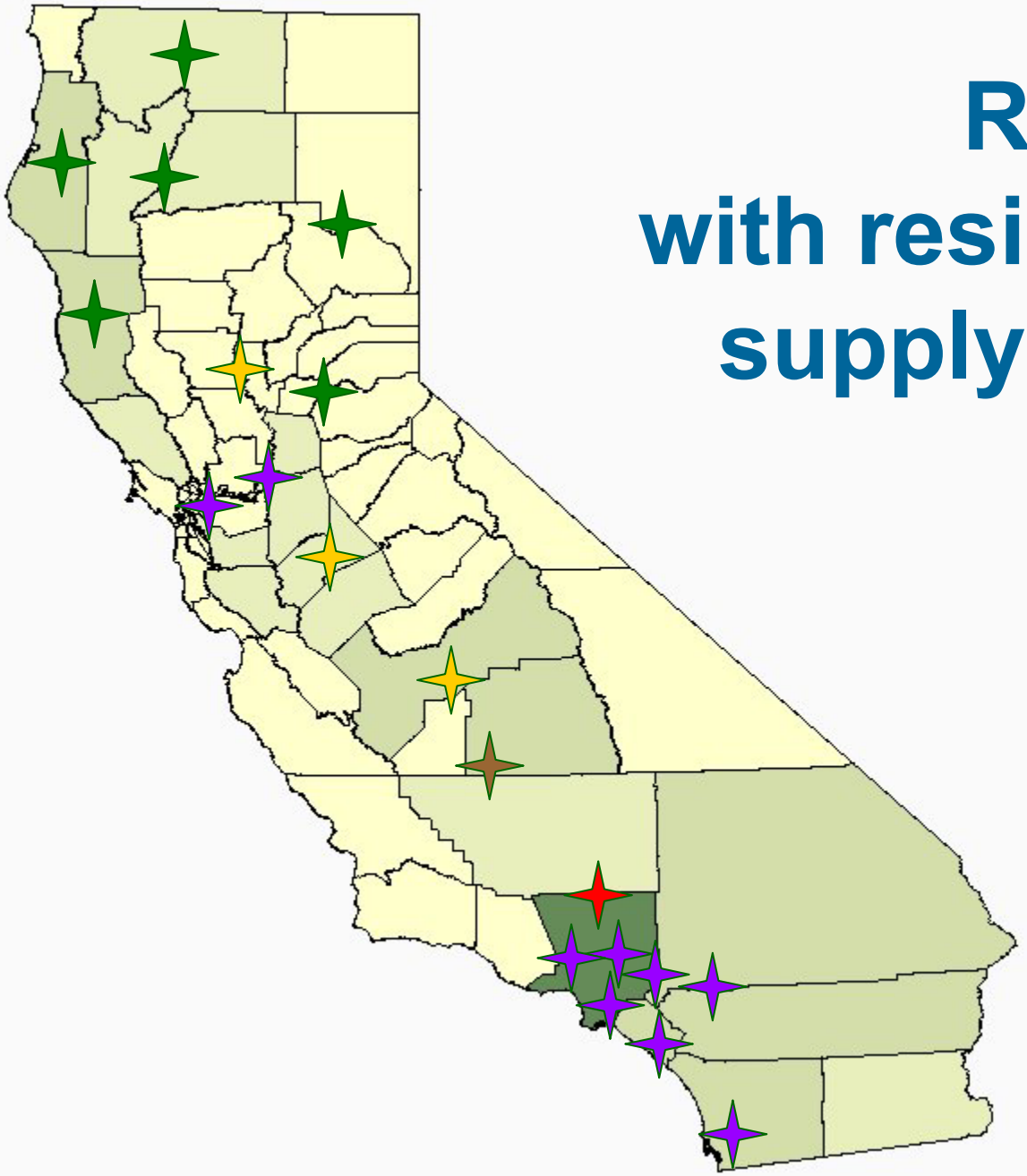
Current Biomass Power Capacity in California

Technology/ Fuel Source	Number of facilities	Gross Capacity (MW)
Solid Fuel Combustion (includes 3 MSW facilities)	30	640
Landfill gas-to-energy	60	275
Wastewater treatment *	20	64
Animal and food waste digester	22	5.7
Totals	132	985
* Suspect - Probably higher		

Solid Combustion Fuel Sources



Source: Williams, 2007



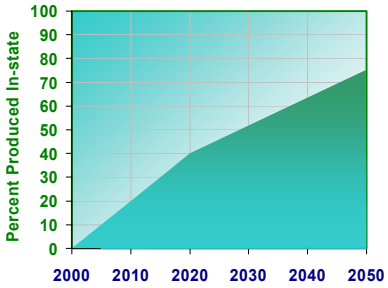
Regional sites with residue biomass supply for 100 MGY

(1.25 million odt/year)

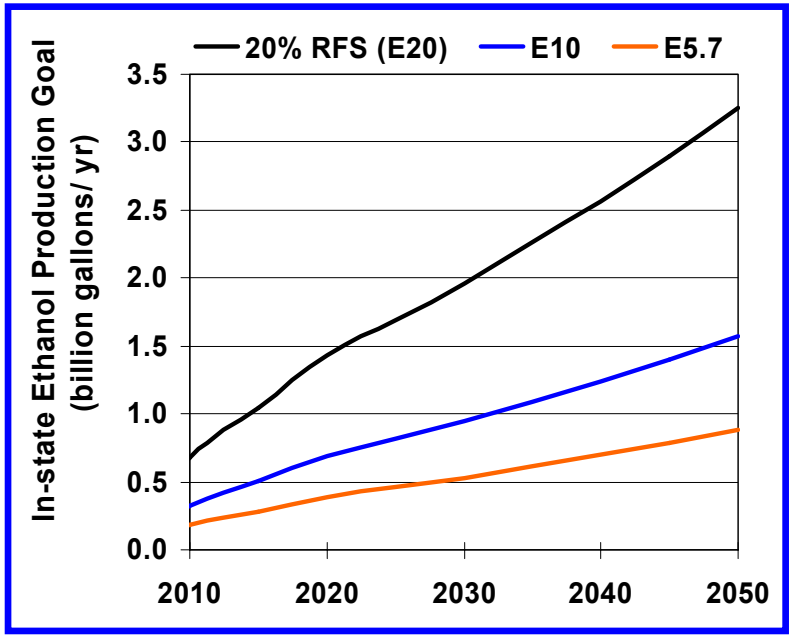
- Agriculture (non-manure)
- Manure
- Landfill
- Forestry
- Mixed

In-state biofuel production goals for blend rate scenarios

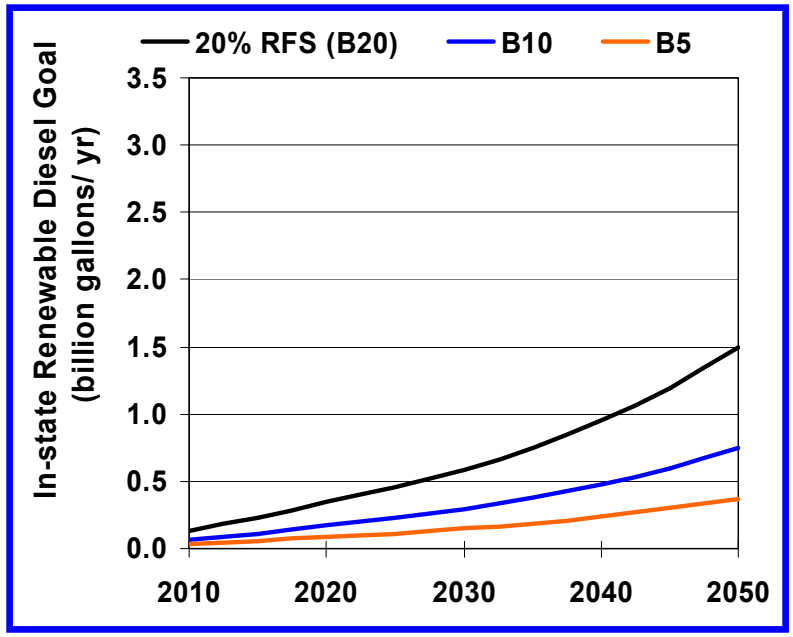
- Assuming projected transportation fuel growth rates and
- Executive Order S-06-06 goals for in-state biofuel production
  - 20% by 2010
  - 40% by 2020
  - 75% by 2050



Ethanol



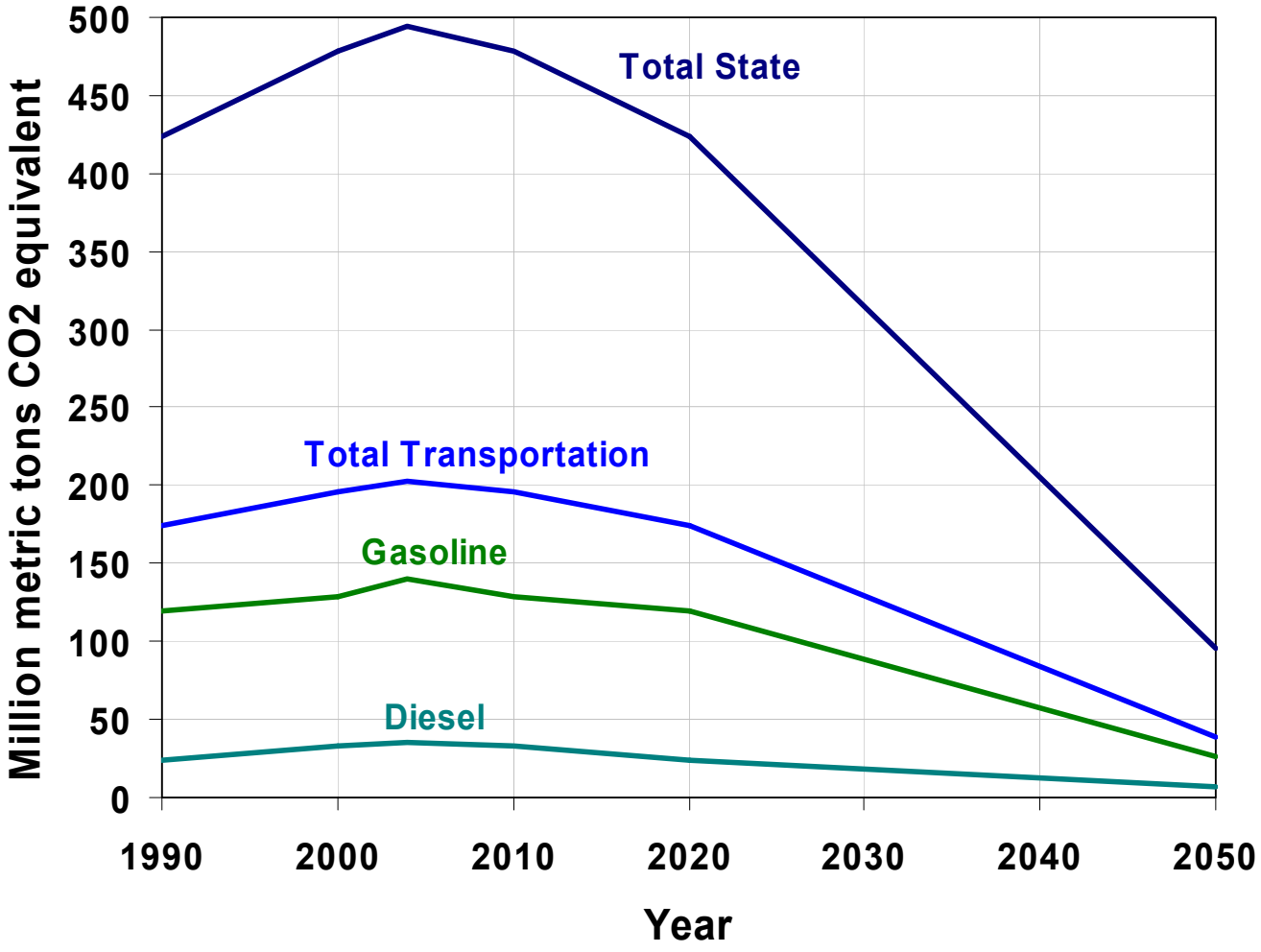
Renewable Diesel



Source: Williams, 2007

State GHG reduction target

(with uniform sectoral reductions)



Blending levels and fractions to meet GHG reduction goals in transportation

(Million metric tons CO_2 equivalent per year)

Demand Case	Gasoline High	Gasoline Low with GHG	Diesel High	Diesel Low with GHG	Total High	Total Low with GHG
Year						
2010	2	2	5	5	7	7
2020	24	20	8	7	31	27
2050	75	47	90	83	165	130
Year	Blended Fraction (%)					
2010	90	90	90	90		
2020	35	35	90	90		
2050	80	80	90	90		
	Blending level (% by vol.)					
	Ethanol equivalent		Renewable Diesel			
2010	10	10	20	20		
2020	85	85	20	20		
2050	85	85	100	100		

E10

E85

R20

R100

UCDAVIS

CALIFORNIA biomass

Biofuel supply to meet GHG reductions

(Million gallons per year)

Demand Case	Gasoline High	Gasoline Low with GHG	Diesel High	Diesel Low with GHG	Total High	Total Low with GHG
Year	as Ethanol		as Renewable Diesel			
2003	1,360	1,360	481	481	1,841	1,841
2010	1,464	1,367	588	581	2,052	1,947
2020	5,378	4,549	785	761	6,163	5,310
2050	16,866	10,618	9,337	8,561	26,203	19,179
In-state production targets						
Year						
2010	293	273	118	116	410	389
2020	2,151	1,820	314	304	2,465	2,124
2050	12,649	7,964	7,003	6,421	19,652	14,384

California starch and sugar crop yields, acres harvested, and ethanol potentials

	Product Yield (tons/acre)	Ethanol Yield		Acres Harvested in 2005 (thousands)	Ethanol Potential (million gallons)	
		(gallon/ ton)	(gallon/ acre)		2005 Crop	Historical Max. Crop
Rice	4.0	90	355	526	187	211
Wheat	2.3	93.3	210	369	78	283
Corn	4.8	96.4	459	110	51	172
Sugar beets	35.0	24.8	870	44	38	305
Barley	1.4	58.3	84	60	5	161
Sorghum	2.4	96.4	230	10	2.3	97
Oats	1.3	58	75	20	1.5	17
Totals				**1,139***	**360**	**1,250**

*Approximately 9 million irrigated acres in production in California.

Bioenergy Crops

- **Cereals**
  - Grains for fermentation (known), cellulosic residuals and dedicated crops for fermentation (developmental), thermochemical processing, or other
  - Price impacts due to large fuel demand
  - Current California corn imports equivalent to 200 to 450 million gallons ethanol

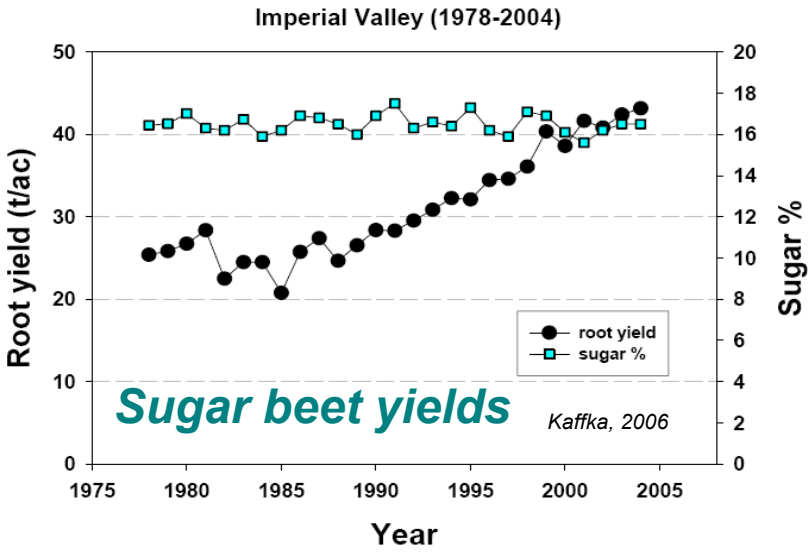
Bioenergy Crops

- **Oilseeds**
  - Safflower is primary oilseed crop in California currently
  - Canola
  - Jatropha
  - Jojoba
  - Flax
- Salt tolerance
- Phytoremediation

Crop	Biodiesel Yield (gals/acre)
Corn	14
Cotton	28
Soybean	38
Coffee	39
Safflower	66
Rice	70
Sunflower	82
Opium Poppy	99
Rapeseed	102
Olives	103
Avocado	226
Coconut	230
Oil Palm	508

Bioenergy Crops

- **Sugar crops**
  - Sugar beets
    - High yields
    - Salt tolerant
  - Sugar cane
    - Trials in Imperial Valley
    - Harvest season can be staged with beets
    - 18 – 30 dry tons/acre-year
  - Sweet Sorghum
    - Testing program by CDFA 1980s-1990s



Example: Sugar Cane

- Imperial Valley trials
  - Potential of 1200-1400 gallons ethanol per acre per year
  - Potential additional 400-700 gallons ethanol per year from bagasse via cellulosic fermentation or other conversion methods (reduced by use for power and heat generation)
  - 500,000 acres of cropland
  - 20% crop shift to sugar cane
    - 100,000 acres at 2,100 gallons/acre-year--
      210 Million gallons ethanol/year
- Some estimates suggest higher ethanol yields
    - 4,000-6,000 gallons/acre-year
    - Water and sustainability effects uncertain

Land area required for alternative biofuel scenarios

Starch and sugar crop land area requirements for in-state ethanol production goals (thousand acres)

Year	Corn			Corn + Stover			Sugar Beet		
	E5.7	E10	E20	E5.7	E10	E20	E5.7	E10	E20
2010	398	709	1,468	231	411	851	211	375	776
2020	845	1,504	3,116	489	871	1,805	447	795	1,647
2050	1,919	3,416	7,076	1,112	1,979	4,100	1,015	1,806	3,742

Oil seed crop requirements to meet in-state production goals for conventional biodiesel (thousand acres)

Year	B2	B5	B10	B20
2010	130	324	648	1,295
2020	343	857	1,713	3,427
2050	1,488	3,719	7,438	14,875

Source: LCFS report and Williams, 2007

Bioenergy Crops

- **Forages and grasses**
  - Alfalfa dominant, grass hays also widely produced
  - Switchgrass not yet tested for California
    - Research proposed, plant selection and genetic investigations beginning
  - Jose tall wheat grass, wild rye, bermuda grass, others under investigation in field trials
    - Salt tolerance
    - Waste water irrigation
  - Miscanthus, other high yielding grasses

Jose tall wheat grass

Cattle on bermuda grass

Bioenergy Crops

- **Tree crops**
  - Agroforestry crops investigated as part of integrated on-farm drainage management systems
    - Eucalyptus
    - Athel
    - Casuarina
  - Commercial plantation production of eucalyptus in northern California
  - Poplar testing on waste water
  - Many other species

Eucalyptus plantation, Corning, California

Poplar plantation, Jamestown, California

Bioenergy Crops

- **Algae**
  - Diatoms, green algae, blue-green algae, golden algae
  - Source of carbohydrates, protein, oils (principally triacyglycerols)
  - CO_2 recycling, potential for biohydrogen production
  - Productivity as high as 50 g m^{-2} day^{-1} (production may be seasonal)
  - Potential lipid yields 30X terrestrial oil crops
  - Research conducted under DOE Aquatic Species Program 1978-1996
  - Substantial technical hurdles remain, recommendations for additional research on basic biology
  - Integration with waste water and nutrient management

California cellulosic ethanol potential

Biomass Source		Potential Feedstock (million dry ton/yr)	Potential Ethanol (million gallons/y)	Potential Ethanol (million gge/y)
Field and Seed		2.3	160	105
Orchard/Vine		1.8	125	83
Landfilled Mixed paper		4.0	320	213
Landfilled wood & greenwaste with ADC		2.7	216	144
Forest thinnings		14.2	990	660
Totals- Current California		**24.9**	**1,814**	**1205**
1.5 Million Acres Dedicated Energy Crop				
Low Yield (5 dry tons/acre, 80 gallons/ton)		7.5	600	400
High Yield (9 dry tons/acre, 100 gallons/ton)		13.5	1,350	900
State potentials with 1.5 M acres energy crop	**Low Yield**	**32**	**2,414**	**1605**
			Range	
	High Yield	**38**	**3,164**	**2105**

Source: Williams, 2007

Resource sufficiency for 2020

- Biomass sources potentially sufficient to supply 2 - 3 BGY gasoline equivalent
  - meets in-state production targets for 2020
  - substantial additional amounts (3 – 4 BGY needed to satisfy GHG emission reduction targets if transportation to supply appropriate share of state reductions
    - crop shifting (e.g. 2 million acres might supply additional 2 BGY at average of 10 dry tons/acre-year, other resources potentially constraining)
    - biofuel imports
    - biomass imports
    - other alternative fuels, increased efficiency, biofuels not the only solution
  - technology deployment uncertain

Resource sufficiency for 2050

- Projected in-state biomass sources clearly insufficient to meet GHG emission reduction shares for transportation alone by 2050 without radical change to transportation system
- Projected in-state biomass supply to satisfy high growth fuel demand (20 BGY biofuels) exceeds 200 million tons per year
  - Supplemental biofuel imports but in-state production target not likely met
  - Biomass imports but global sustainability needs to be considered