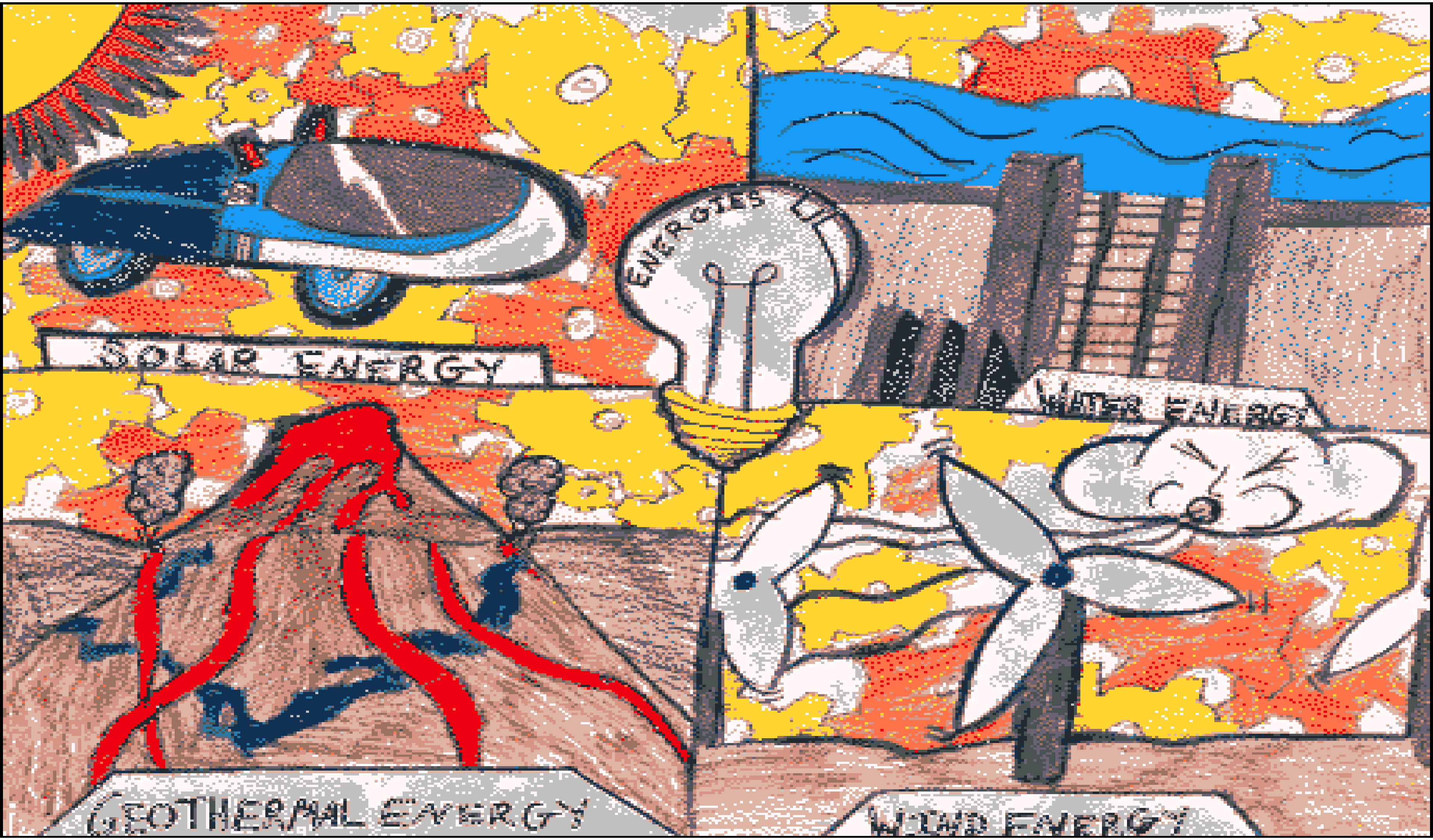
# California Energy System Portraits for 2050: Targeting 80% emission reductions




Based on a study of the California Council on Science and Technology,
Jane C. S. Long, co chair (Artist: **Jon Wingo**, Fourth grader at Preston School)

# 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 475 GT $CO_2e$ today to 80 GT $CO_2e$ in 40 years

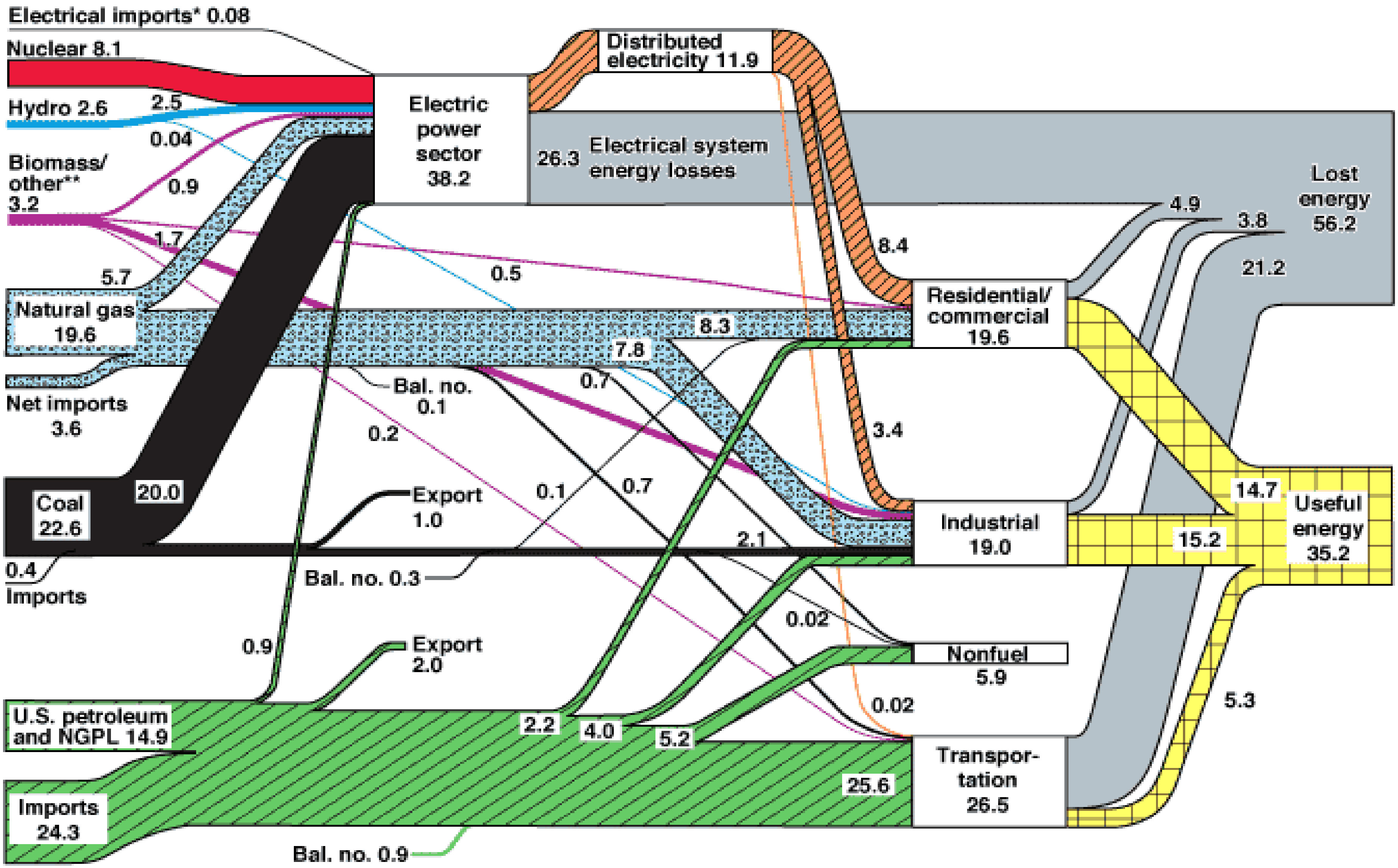
# What is the California 2050 standard? What does it mean?

- California ‘s population projected to grow from 38 million to 60 million by 2050.
- We can hope for moderate concurrent economic growth.
- →For BAU we would need roughly twice as much energy in 2050 as we use today.

# What does it mean

- 85% reduction in emissions per capita while doubling energy services.
- Can (essentially) not burn fossil fuel without sequestration.

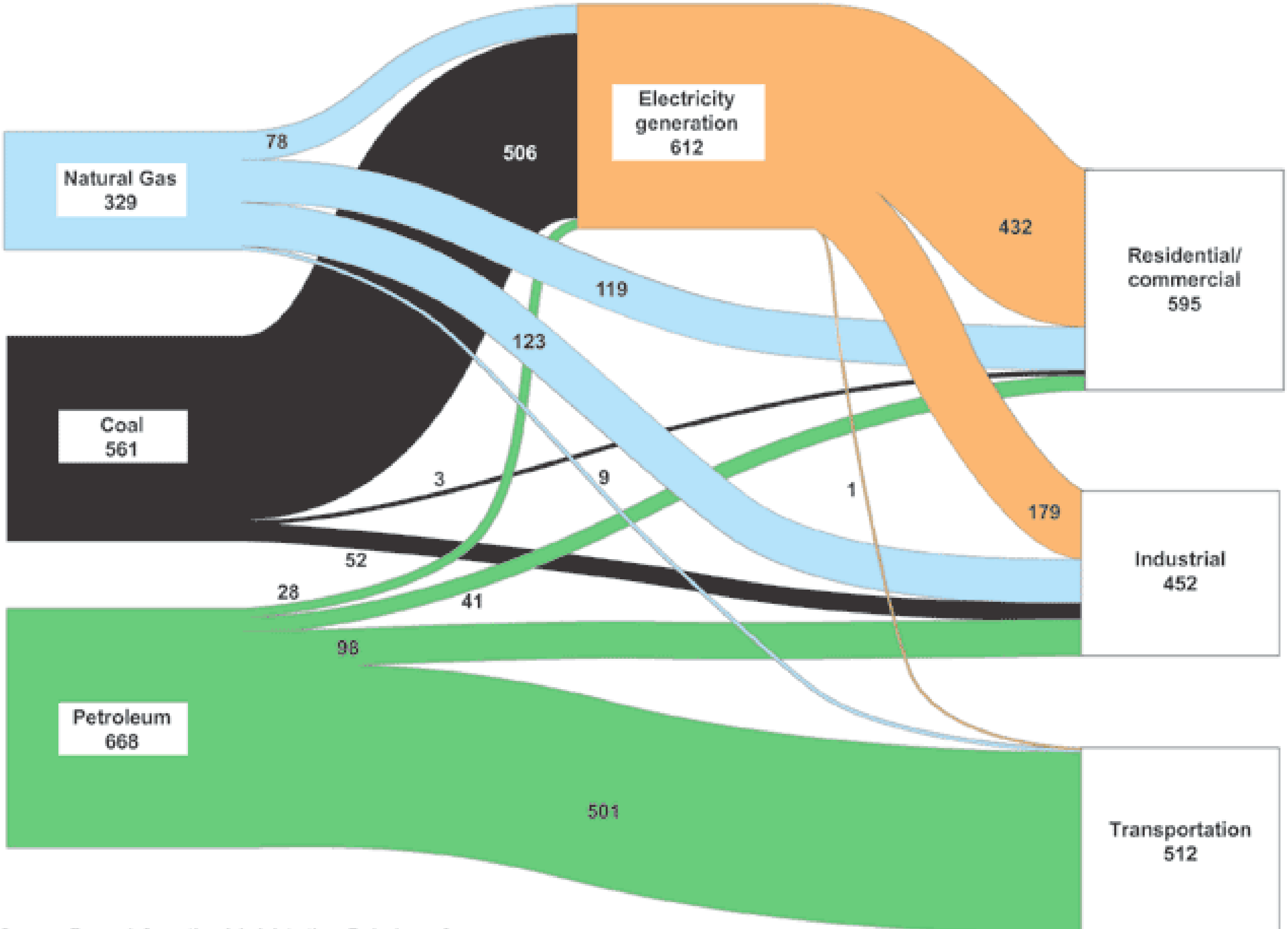
# U.S. Energy Flow Trends – 2002
# Net Primary Resource Consumption ~97 Quads




Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002*.
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore
National Laboratory
http://eed.llnl.gov/flow

# U.S. 2001 Carbon Emissions from Energy Consumption – 1547* MtC

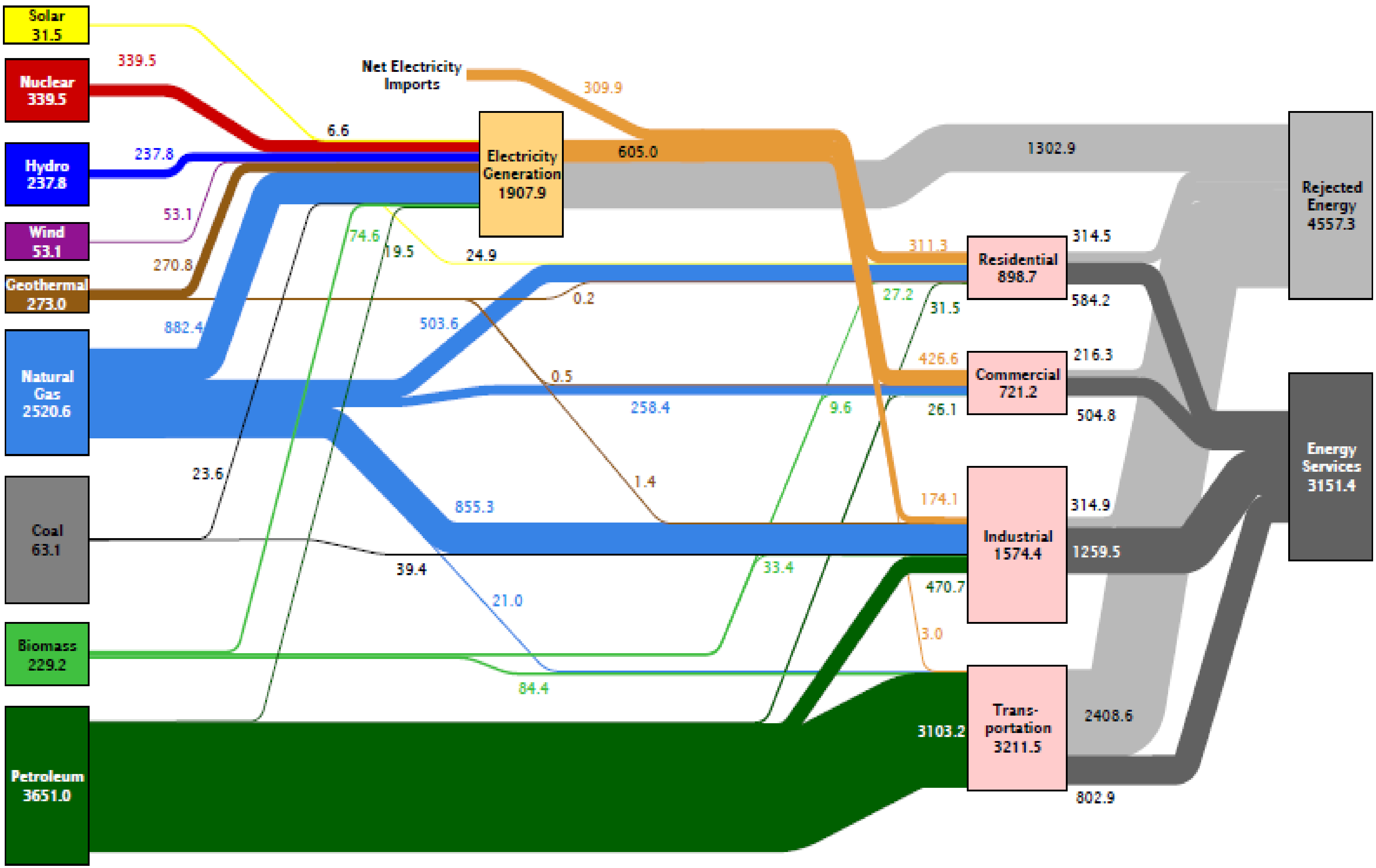



Source: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2001*
*Includes adjustments of 14.8 million metric tons of carbon (MtC) from U.S. territories, less 26.4 MtC from bunker fuels
Note: Numbers may not equal sum of components because of independent rounding

Lawrence Livermore National Laboratory, July 2003
http://eed.llnl.gov/flow/

# Estimated California Energy Use In 2008
# ~8381.5 Trillion BTU

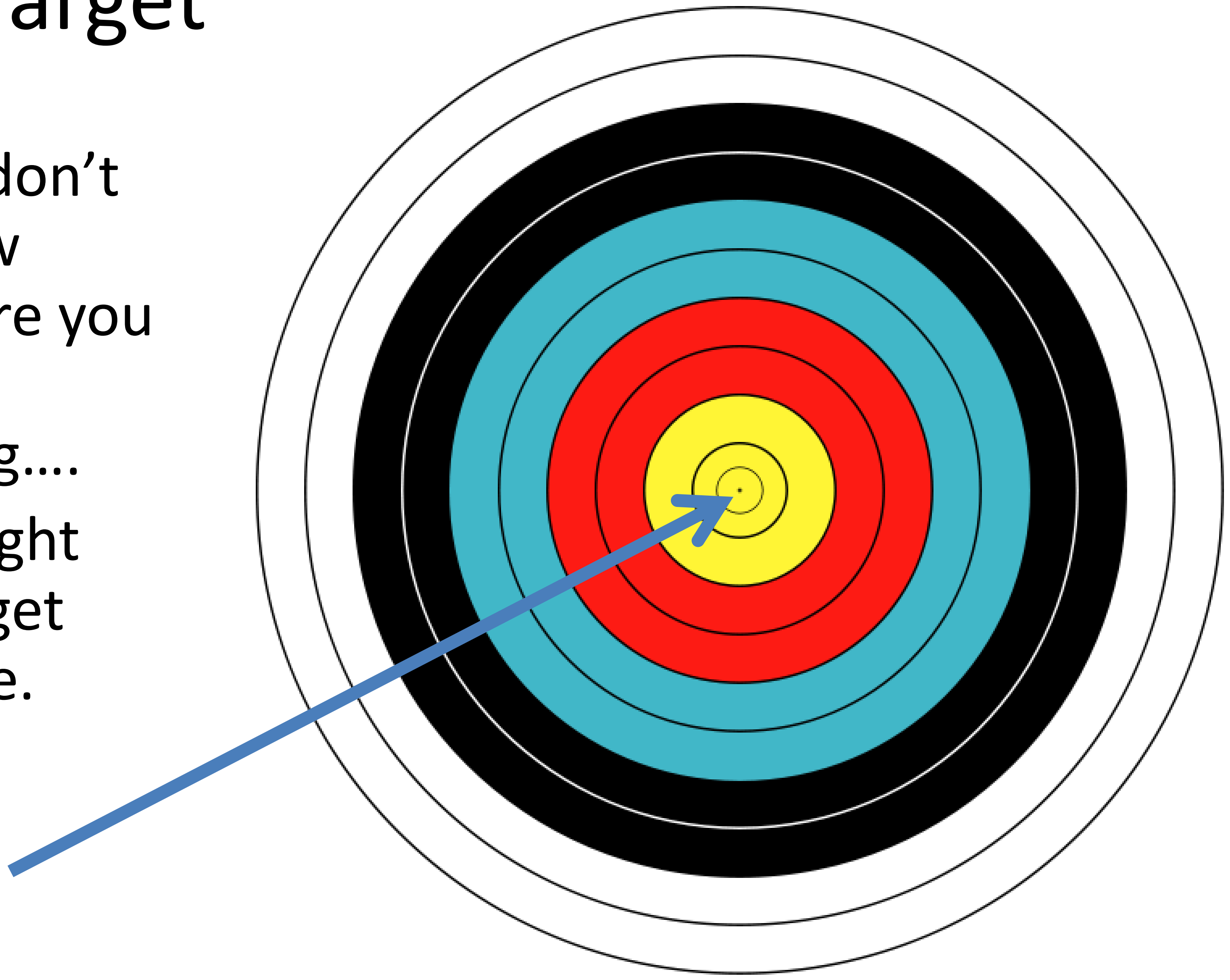
Lawrence Livermore National Laboratory




Source: LLNL 2010. Data is based on DOE/EIA-0214(2008), June 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. Interstate and international electricity trade are lumped into net imports or exports and are calculated using a system-wide generation efficiency. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

# Target

- If you don't know where you are going....
- You might not get there.



# 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
4. How do we load follow? → Storage, gas, or load following
5. How do we de-carbonize enough fuel (hydrocarbons or hydrogen) to meet the remaining demand? → Biofuel, fuel from electricity?

*unless the emissions are sequestered

# Approach:

## The sectors

- Efficiency + electrification
  - Buildings
  - Industry
  - Transportation (LDV, HDV, Air)
- Electricity
  - Nuclear
  - Fossil with CCs
  - Renewable
- Load Following
  - Gas
  - Batteries
  - Flexible loads
- Fuel
  - Biofuel
  - Fuel from electricity

## The analysis:

- How much can we do by 2050?
  - How much can we control demand?
  - Can supply meet demand?
- What are the emissions?
- What technology bins?
  - 1 deployed at scale now
  - 2 demonstrated, not at scale
  - 3 in development
  - 4 research concepts
- What impacts?
- What policies?

# Summary demand changes:

| Sector | Energy Carrier | Efficiency | Electri-fication | Net |
|---|---|---|---|---|
| **Residential** | Electricity | -40% | +77% | +6% |
| | Gaseous fuel | -40% | -70% | -82% |
| **Commercial** | Electricity | -40% | +27% | -24% |
| | Gaseous fuel | -40% | -70% | -82% |
| **Industry** | Electricity | -14%* | +59% | +37% |
| | Gaseous fuel | 0% | -36% | -36% |
| | Liquid fuel | -90%* | -18% | -92% |
| **Transport (see below)** | Electricity | n/a | n/a | n/a |
| | Liquid fuel | -49% | -37% | -68% |

# Example: Building efficiency Technology Bins

| Bin no. | Space conditioning and building envelope | Water heating | Appliances | Electronics | Other | Fraction |
|---|---|---|---|---|---|---|
| 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 | 40% |
| 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 | 40% |
| 3 | Non-invasive insulation retrofits | | | | | 20% |
| 4 | | | Magnetic refrigeration | | | Not considered |

# LDV Transportation Technology Bins

| Bin | Light-Duty Vehicles | Fraction of solution achievable |
|---|---|---|
| 1 | **Hybrid engines, lightweight materials, better aerodynamics, low-resistance tires** | **30%** |
| 2 | **Battery- electric and plug-in hybrids** | **50%** |
| 3 | **Advanced batteries** | **20%** |
| 4 | None | Not considered |

# 2050 Total Energy demand

| Energy Carrier | 2005 | 2050<br>With enhanced efficiency and electrification |
|---|---|---|
| **Electricity** | 271,300 GWh/yr | 584,600 GWh/yr |
| **Gaseous fuel** | 1,423 TBtu/yr | 1,099 TBtu/yr |
| **Liquid fuel** | 27,550 Mgge/yr | 15,150 Mgge/yr |

# Nuclear power – no emissions

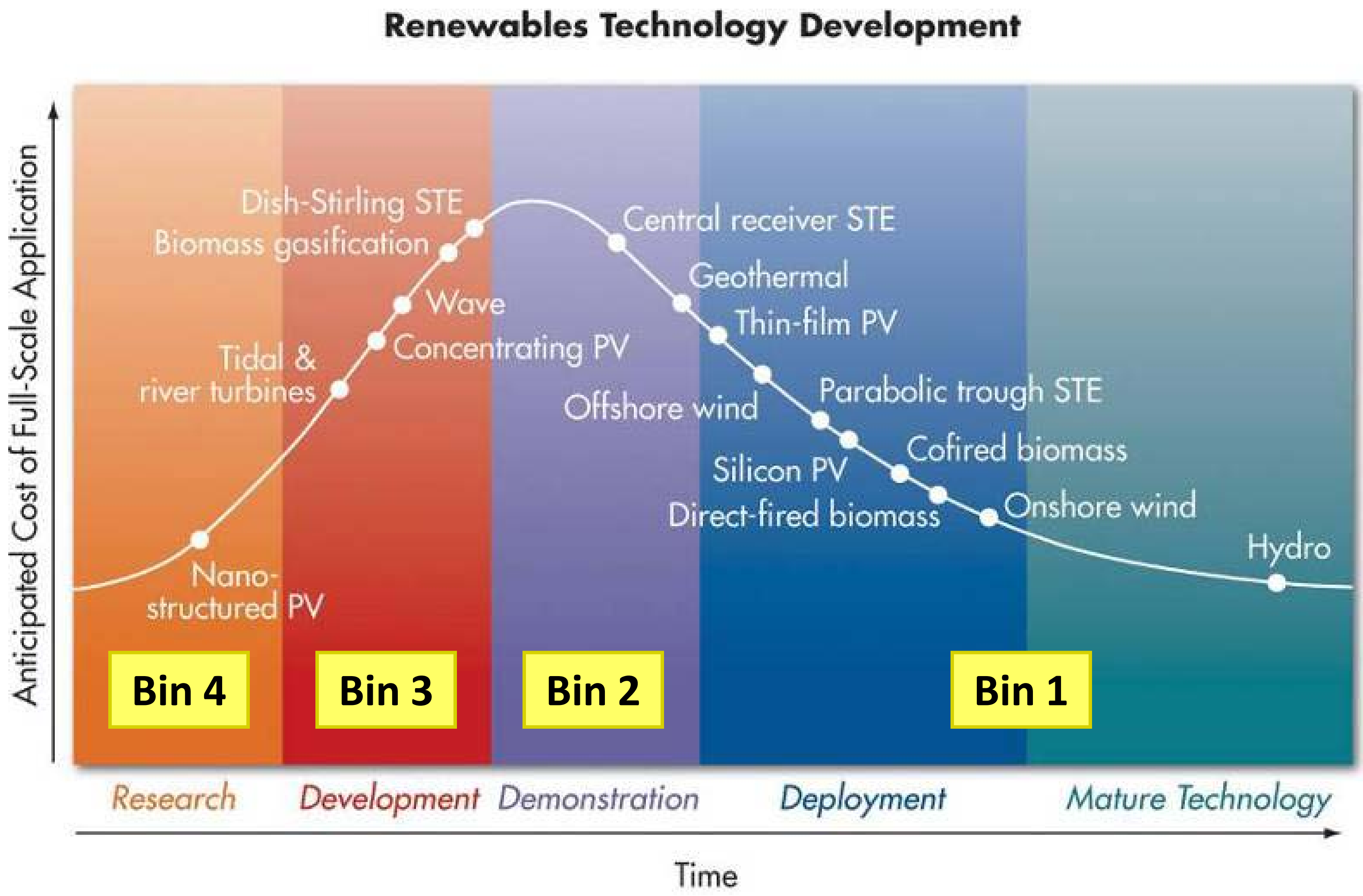
| | | |
|---|---|---|
| **Bin 1** | | |
| **Bin 2** | GEN III+ reactor technology<br>Permanent waste repository | 100% |
| **Bin 3** | Gen IV<br>Small reactors | |
| **Bin 4** | | |

# 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 (580 TWh) .**
- **Emissions:** At 90% capture rate, residual emissions =
  - 46 mmt $CO_2$e – for coal -- over half the total budget
  - 20 Mt $CO_2$e --- about 1/4$^{th}$ the total budget

- Without saline reservoirs, less than 15 – 30 years capacity exists in state
- Massive new infrastructure required with high transportation costs

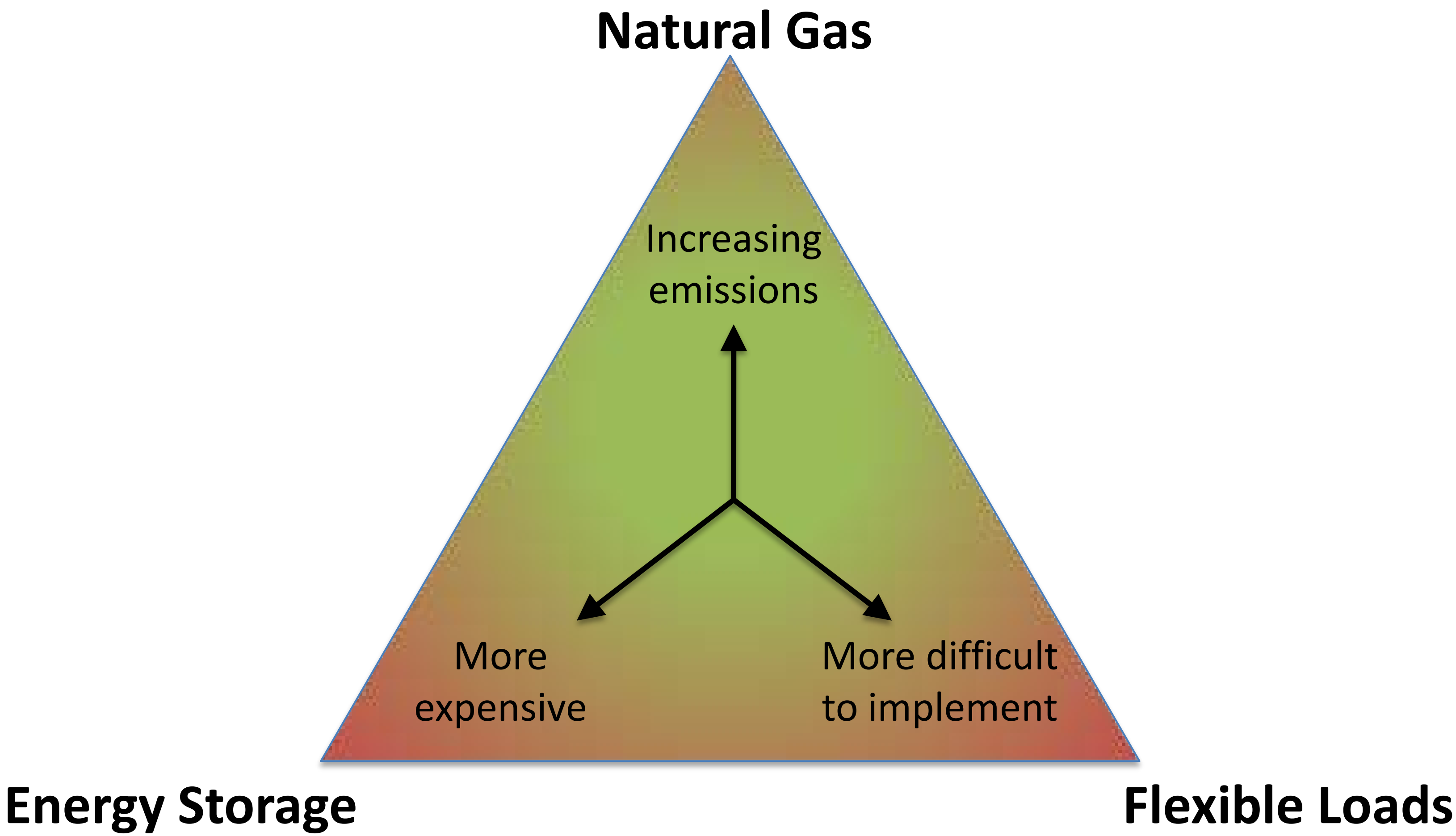
# Renewables – no emissions



# Biofuels are uncertain

- Total demand for fuel is 15 bgge.
- From state resources alone 3-12 bgge
- Emissions
  - E85 scenario (cellulosic ethanol + biodiesel) only reduces GHG emissions 16-53% from the BAU baseline..
  - Advanced biofuels (drop-in fuels) are **50%-100%** reduction of GHG.
- Build rate: **500 plants in 40 years**
- Investment: ~ **$1 trillion**
- Resources will depend on the feedstocks adopted
  - **Water,**
  - **land,**
  - **fertilizer requirements**

# The load following triangle



# Technology bins– TBD

| | | |
|---|---|---|
| **Bin 1** | **Flywheels**<br>**Pumped storage** | **20%** |
| Bin 2 | Compressed Air  Energy Storage<br>Batteries | 20% |
| Bin 3 | Advanced Batteries<br>System integration technology<br>Concentrated solar power (CSP) with thermal storage<br>buildings integrate storage technology | 50% |
| Bin 4 | Use of Electric Cars for storage<br>Fuel production | |

# Low or High emission cases

- For the low GHG emission case:
  - There are plenty of sustainable biofuels which have zero emissions
  - Load following is accomplished without emissions
- For the high GHG emission case
  - There are not enough biofuels and these still have 50% of the emissions of fossil fuel
  - Load following must rely on natural gas

# RESULTS DRAFT

| Portrait no.: | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low GHG Vs High GHG cases | **Nuclear electricity with biofuels** | | **Coal/CCS electricity with biofuels** | | **Natural gas/CCS electricity with biofuels** | | **Renewable electricity with biofuels** | | **Renewable and biomass/ CCS electricity with fossil fuels** | | **Nuclear electricity with biofuels (behavior change)** | | **Nuclear electricity and hydrogen with biofuels** | | **Coal/CCS electricity and hydrogen with biofuels** | |
| **Electricity:** | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** | **Low** | **High** |
| *Fossil/CCS* | | | 67% | 57% | 67% | 57% | | | | | | | | | 67% | 57% |
| *Natural gas (without CCS)* | | 10% | | 10% | | 10% | | 20% | | 15% | | 10% | | 10% | | 10% |
| *Biomass** | 5% | | 5% | | 5% | | 5% | | 38% | 11% | 5% | | 5% | | 5% | |
| *Renewables* | 28% | 33% | 28% | 33% | 28% | 33% | 95% | 80% | 62% | 74% | | 33% | 28% | 33% | 28% | 33% |
| *Nuclear* | 67% | 57% | | | | | | | | | 95% | 57% | 67% | 57% | | |
| **Biomass demand mdt/y** | 318 | 42 | 318 | 42 | 318 | 42 | 318 | 42 | 147 | 42 | 316 | 42 | 329 | 42 | 318 | 42 |
| | | | | | | | | | | | | | | | | |
| **Emissions mmT/y** | **0** | **230** | **31** | **256** | **14** | **241** | **0** | **250** | **75** | **207** | **0** | **198** | **12** | **194** | **55** | **220** |

# Or these results? DRAFT

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| **Electricity:** | | | | | | | | |
| *Fossil/CCS* | 0% | 62% | 62% | 0% | 0% | 10% | 0% | 0% |
| *Natural gas (without CCS)* | 5% | 5% | 5% | 10% | 7.5% | 7.5% | 5% | 5% |
| *Biomass** | 5% | 5% | 5% | 5% | 64.5% | 54.5% | 5% | 5% |
| *Renewables* | 28% | 28% | 28% | 85% | 28% | 28% | 28% | 28% |
| *Nuclear* | 62% | 0% | 0% | 0% | 0% | 0% | 62% | 62% |
| **Biomass fuel†** | 100% | 100% | 100% | 100% | 0% | 0% | 100% | 100% |
| **Biomass demand mdt/y** | | | | | | | | |
| *Domestic US* | 126 | 126 | 126 | 126 | 126 | 126 | 126 | 126 |
| *International* | 192 | 192 | 192 | 192 | 123 | 84 | 190 | 218 |
| **Emissions $MMtCO_2/y$** | **51** | **79** | **64** | **61** | **28** | **70** | **44** | **51** |



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| **Emissions $MMtCO_2/y$** | **51** | **79** | **64** | **61** | **145** | **44** | **51** | **83** |



*burned in thermal plants

†non-electricity uses

# Or these

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# Conclusions….
# These are mine….

*1.* *Must* do aggressive efficiency and probably behavior change to make it.
2. We have to electrify which means we have to double electricity generation at the same time we de-carbonize it.
3. Nuclear power is very attractive with little technology risk
4. Biofuel is a nexus of uncertainty and importance, especially if CCS is not implemented.
5. Should focus biofuels on heavy duty transport, not LDV
6. Chasms in storage and load following – should be considered an "energy sector"
7. Technology gaps in every sector
8. Policy pulls needed everywhere

# Some optimism

- I think the results will show that we can get close in a variety of ways…
- And with technology we largely know about
- But!  We can not get all the way there without technology development.
- Technology development will depend on policy

# But….

- There are dead ends…. Things which we are doing today to reduce emissions which do not play in a 2050 nearly zero-emission energy system. *eg*
  - Biofuels in cars – save biofuelf for HDT
  - E85
  - CCS with thermal coal plants won't get us to the energy system we need.  (but may be a pragmatic necessity)

# As to to the lamppost…

- We actually have about 4 sets of keys and at least one of them actually are under the lamppost
- The next set of keys aren't far from the lamppost either – finding them requires enough investment and good policy to make them economically attractive and reduce technical risk.
- We have some real technical work to move critical technologies to utility
  - Zero emission biofuels
  - Load following
- If it turns out we can't have enough zero emission biofuels or economical zero emission load following then