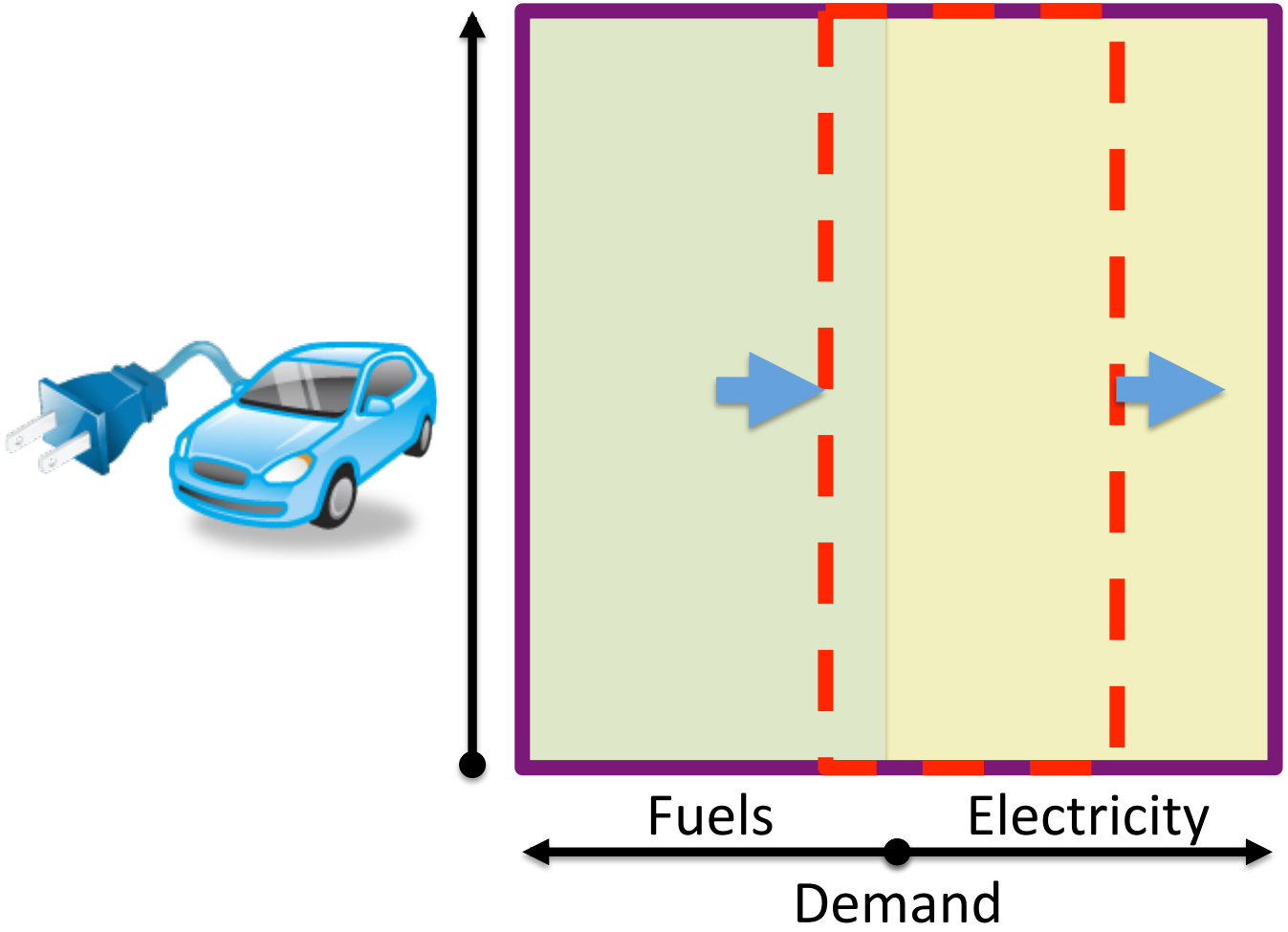
Electrification

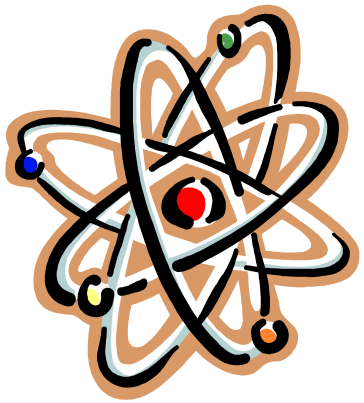


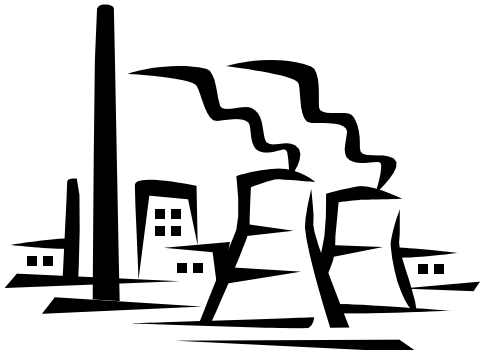
The realistic potential of electricity supply technologies in California

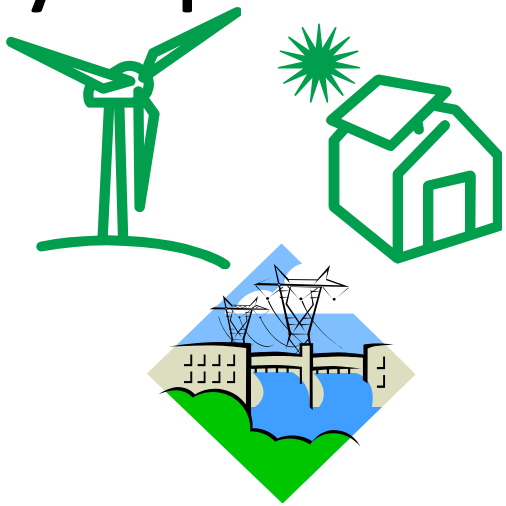
- Nuclear: GENIII technology
- Fossil fuel w/CCS: either coal or gas
- Renewables : 80% intermittent
- Load balancing: gas, storage, smart-grid

- 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

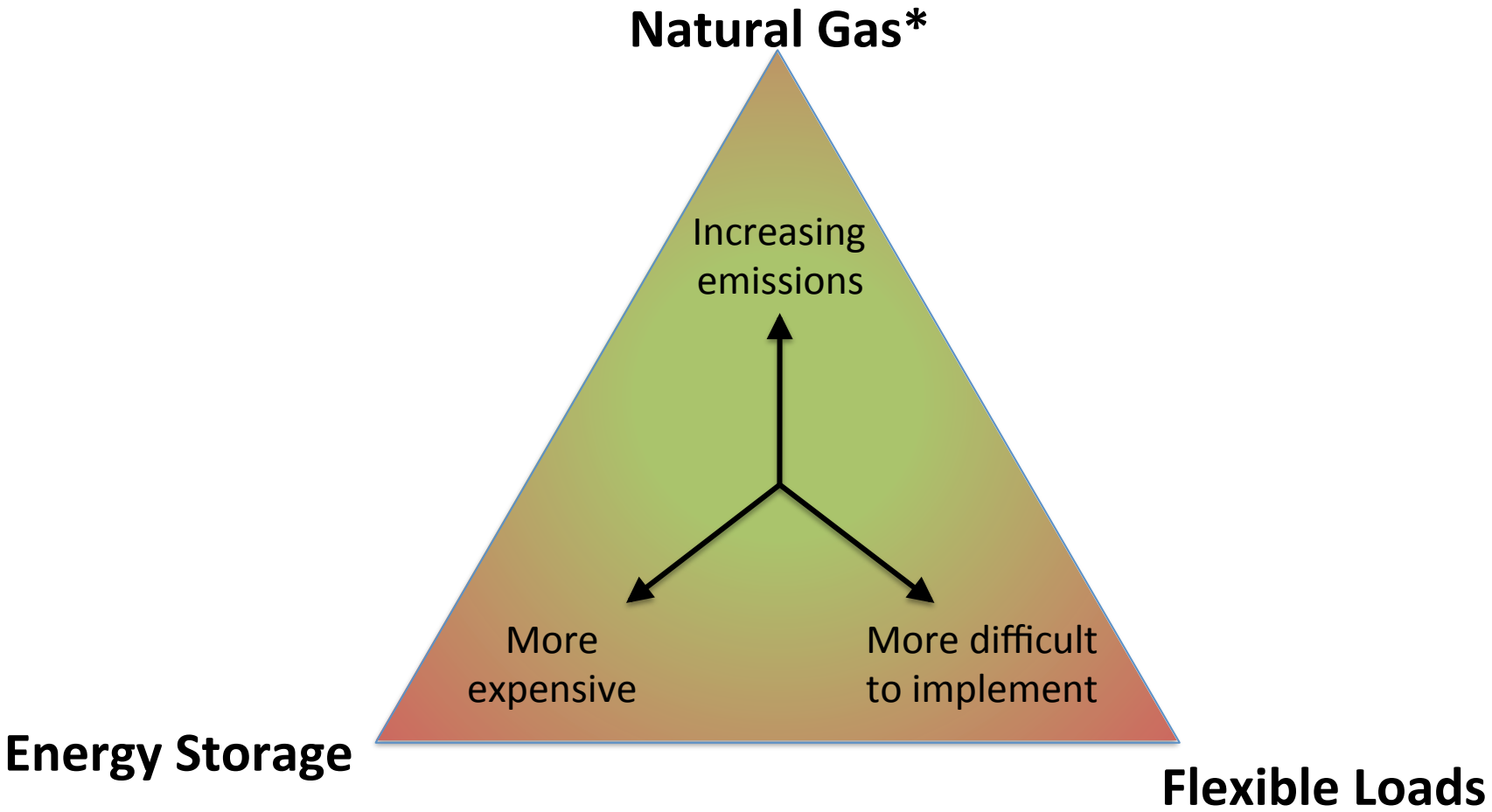
What is required for Renewables

- 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

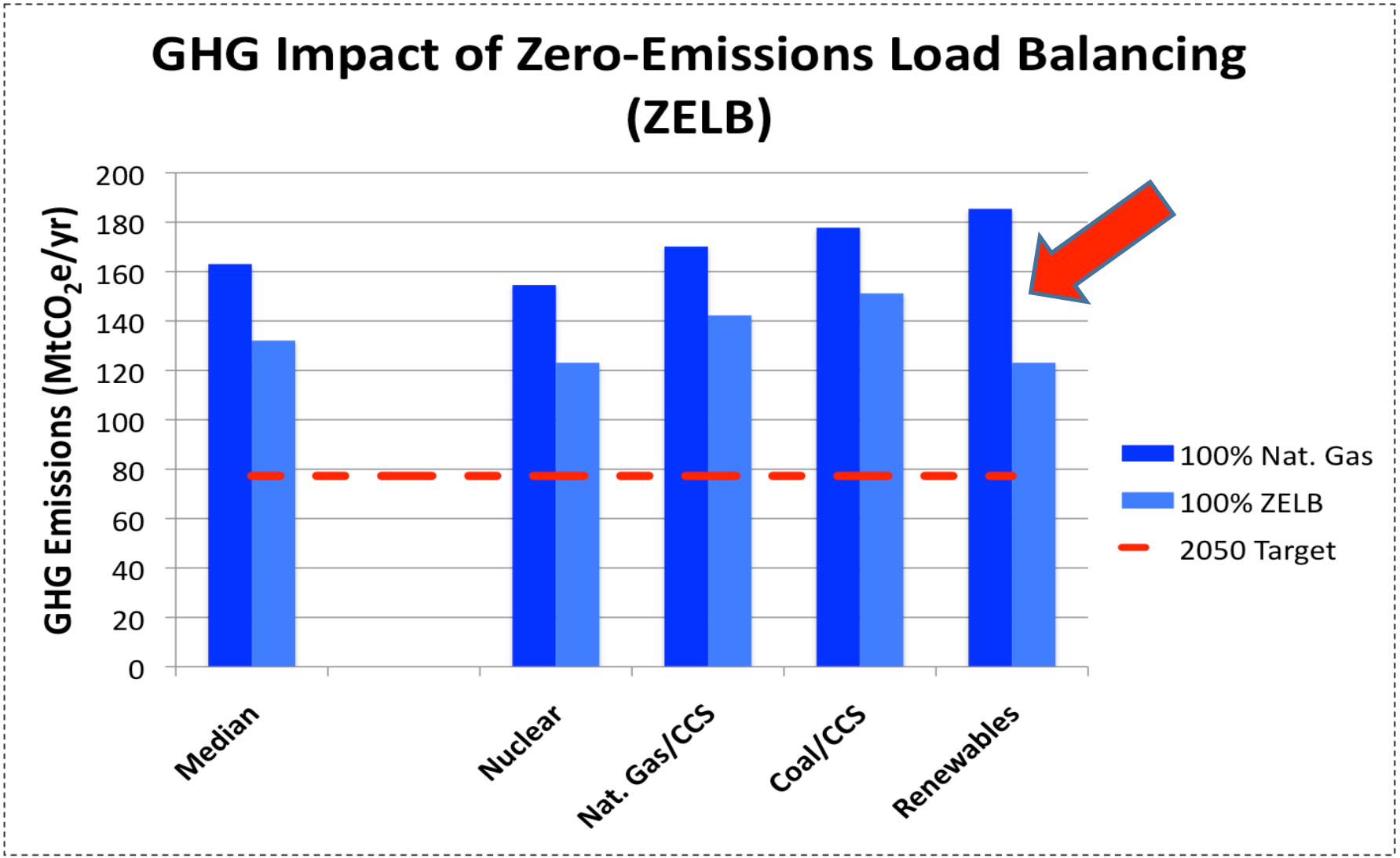
Bin	Wind	Concentra-ted Solar Power (CSP)	Solar Photovol-taic (PV)	Geothermal	Hydro and Ocean	Biomass
1	Onshore, shallow offshore turbines	Parabolic trough, central receiver	Silicon PV, Thin-film PV, Concen-trating PV	Conventional geothermal	Conven-tional hydro	Coal/bio-mass co-firing, direct fired biomass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



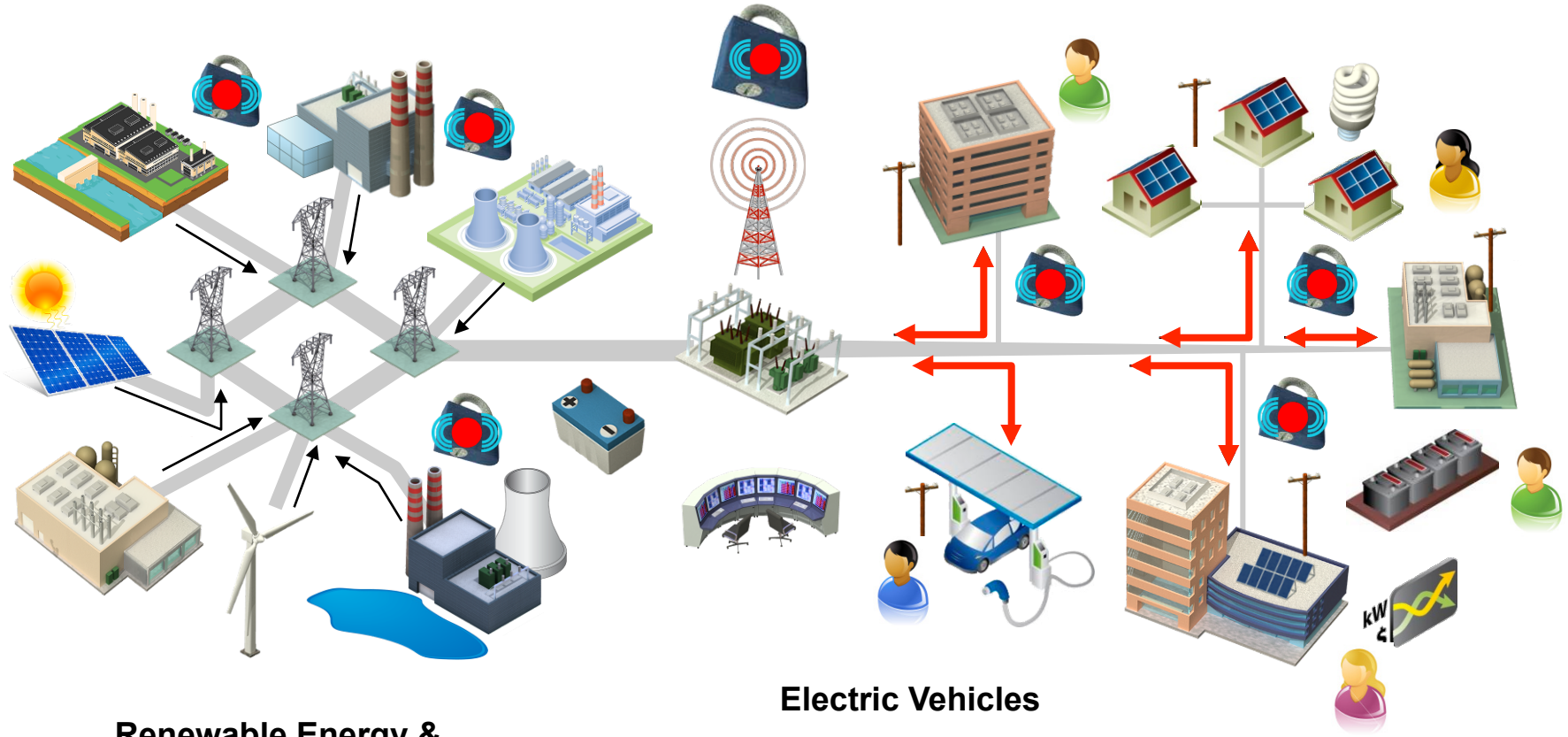
Load following technology bins

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

The Power System of Tomorrow



Renewable Energy & Integration

Near-Zero Emissions

Long-Term Operations

Water Management

Electric Vehicles

Demand Response & Efficiency

Distributed Energy Resources

Energy Storage

Sensors, Controls & Cyber Security

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