Public Health Research Roadmap on Emerging Electricity Generating Systems

April 11, 2017
California Energy Commission
Sacramento, CA

Center for Climate Change & Health

Agenda

1. Project Overview

2. Health Impacts of Electricity Generation: Compared to What?

3. Health Impacts and Research Needs by Technology

4. Other Health Impacts and Research Questions

5. Next Steps

Public Workshops

We are seeking public feedback to address the following questions:

- Are there key emerging technologies that should be added to our assessment?
- Are you aware of important research on the health impacts of emerging electricity technologies that is not reflected in our presentation?
- Are there additional areas of concern about potential health impacts that have not been addressed?
- Do you agree with our criteria for prioritization?

1. PROJECT OVERVIEW

Project Background

- Thirteen month project
- Assess health impacts across the life cycle of technologies to look for gaps in current knowledge
  - Emphasize impacts in California
  - Include non-California impacts
- Incorporate health equity and occupational safety concerns
- Focus on technologies likely to scale in the next 10-15 years

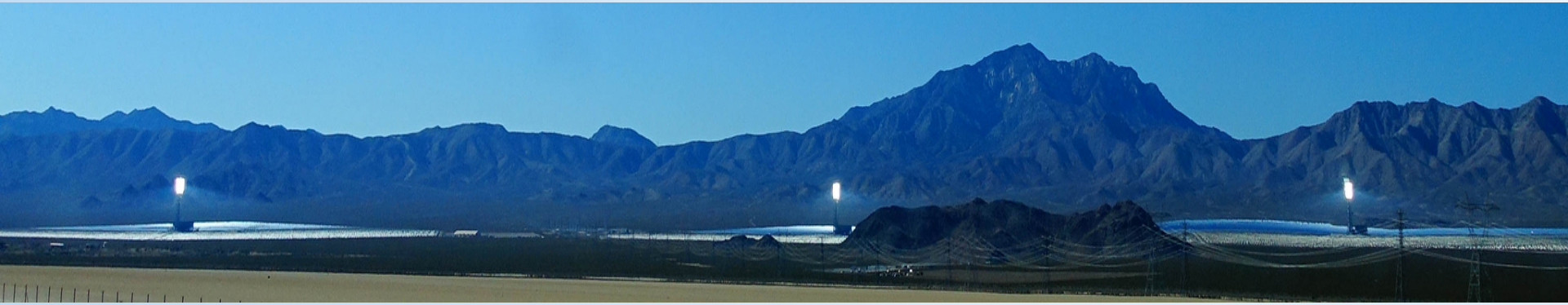
Project Goals

Produce a public health research road map for emerging electricity generating systems by identifying gaps in current knowledge on health impacts across technology life cycles

- Select key emerging energy technologies
- Identify known health impact pathways across life-cycles
- Create health impact matrix
- Determine information gaps and research questions on health impacts
- Decide criteria for prioritization of research needs

Project Methods

- Expert Interviews
- Literature Review
- Technical Advisory Committee
- Public and Stakeholder Input



Gregg Tavares, 2014

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Criteria for Prioritization

- Number of people exposed
  - CA specific
  - Global estimates
- Likelihood of Exposures
- Likelihood of Impact with Exposure
- Severity of Impact
- Available Control Technologies
- Equity Implications

2. HEALTH IMPACTS OF ELECTRICITY GENERATION: COMPARED TO WHAT?

Health Impacts of Electricity Generation: Compared to What?

- Electricity improves quality of life: lighting, heating/ cooling, cooking
- Fuel poverty
- Current fossil fuel based energy production a major source of air, water, and soil pollution and adverse health impacts
- All forms of energy production may have health/ environmental impacts, e.g.
  - Nuclear power radiation exposure/accidental release
  - Large-scale hydroelectric community displacement

Energy Production and Climate Change

- Energy production largest source of carbon pollution in US - 1/3 GHGE
  - Coal-fired power plants release 3.5 million tons CO2 per year
  - Natural gas production: significant methane emissions (SLCP), VOCs
- Electricity generated from renewables releases about 1/20th the GHGE of coal over the full life-cycle
- Climate change is the greatest health challenge of this century

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Health impacts Of Climate Change

- Potentially catastrophic for human survival
- Undermine the last half-century of gains in development and global health
- A medical emergency

From Nick Watts

http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(15)60854-6/fulltext

LANCET commission ON health & climate 15

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Health Impacts of Coal Production

- Coal combustion a major source of toxic air pollutants
  - Nitrogen oxides, sulfur oxides, particulate matter (PM)
    - Heart disease, asthma, chronic lung disease
  - Mercury (potent neurotoxin)
  - > 13,000 deaths and 20,000 heart attacks in U.S./year
- Communities of color disproportionately exposed and impacted
- Cumulative health costs of coal-based electricity in U.S/year
  - Between $62 billion and $523 billion annually
- Plus coal miner impacts, water pollution, other effects
- Clean Power Plan estimated net benefit due to health benefits;
  - $38 billion/year

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Co-Benefits of Renewable Energy

- Despite risks across the life cycle, the potential benefits include
  - Air emissions reductions
  - Health benefits
    - Reduced Emissions (PM)
    - Climate Change Mitigation
  - Fuel diversity
  - Electricity price stability
  - Energy security
  - Economic development & green jobs
  - Reduced water consumption

California Renewable Construction Jobs

- From 2003 – 2014,
  - 52,000 direct jobs from construction were created
  - 130,000 total job years

- Reaching the 50% renewable goal by 2030 would lead to
  - Up to 429,000 direct jobs from construction
  - Up to 1,067,000 total job years by 2030

California Goals

SB 32: GHG emissions target 40% below 1990 level by 2030

SB 350: 50% renewables by 2030 (from ~22% today)

Executive Order: 20,000 MW renewable generation by 2020

AB 197: Ensure disadvantaged communities benefit

Richard Ghawley, 2009

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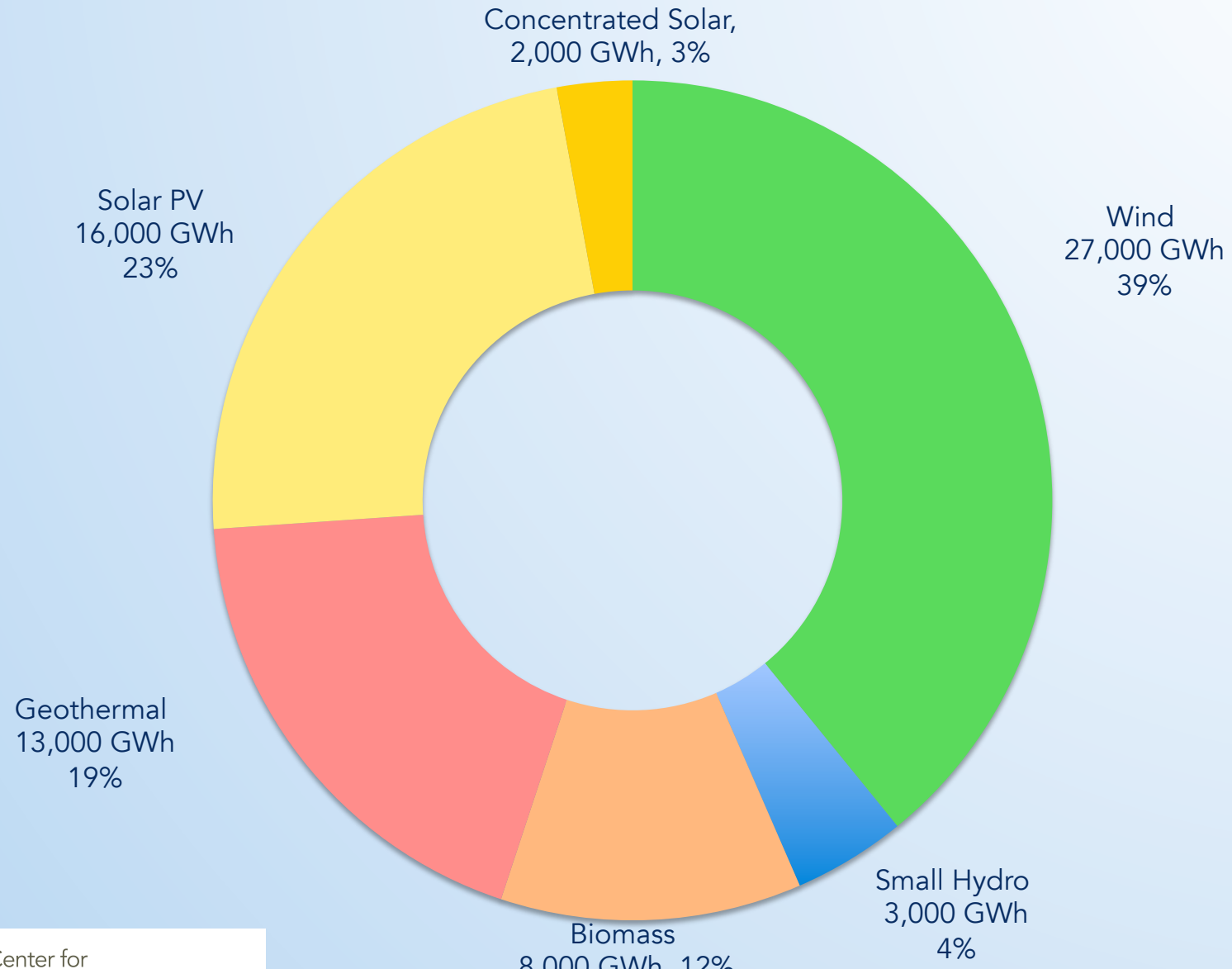
2016 Estimated Renewable Generation from Facilities Serving California



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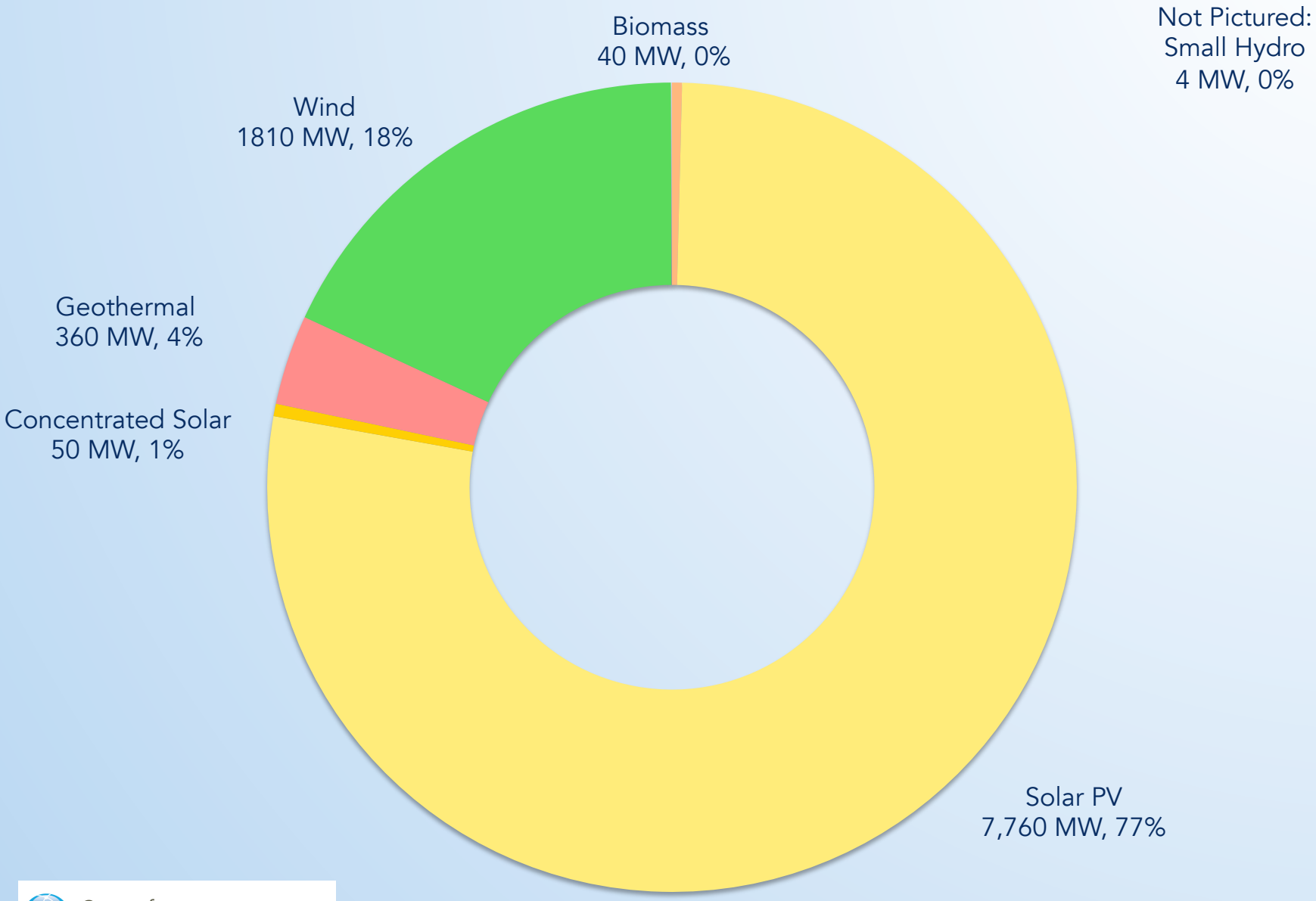
Renewable Projects in CA

Received Environmental Permits - Not Operational



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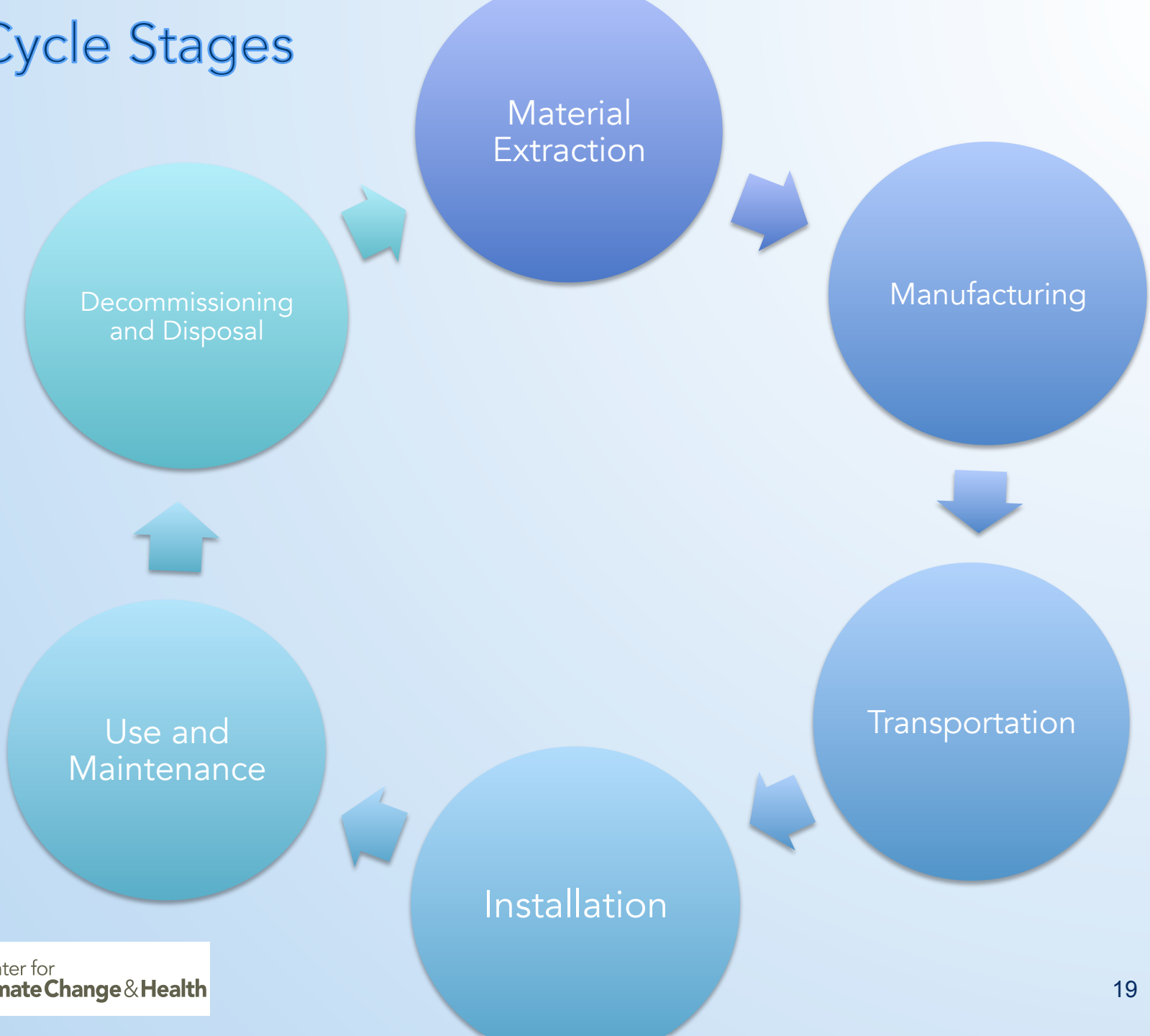
http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf

Life Cycle Stages



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3. HEALTH IMPACTS AND RESEARCH NEEDS BY TECHNOLOGY

Solar PV

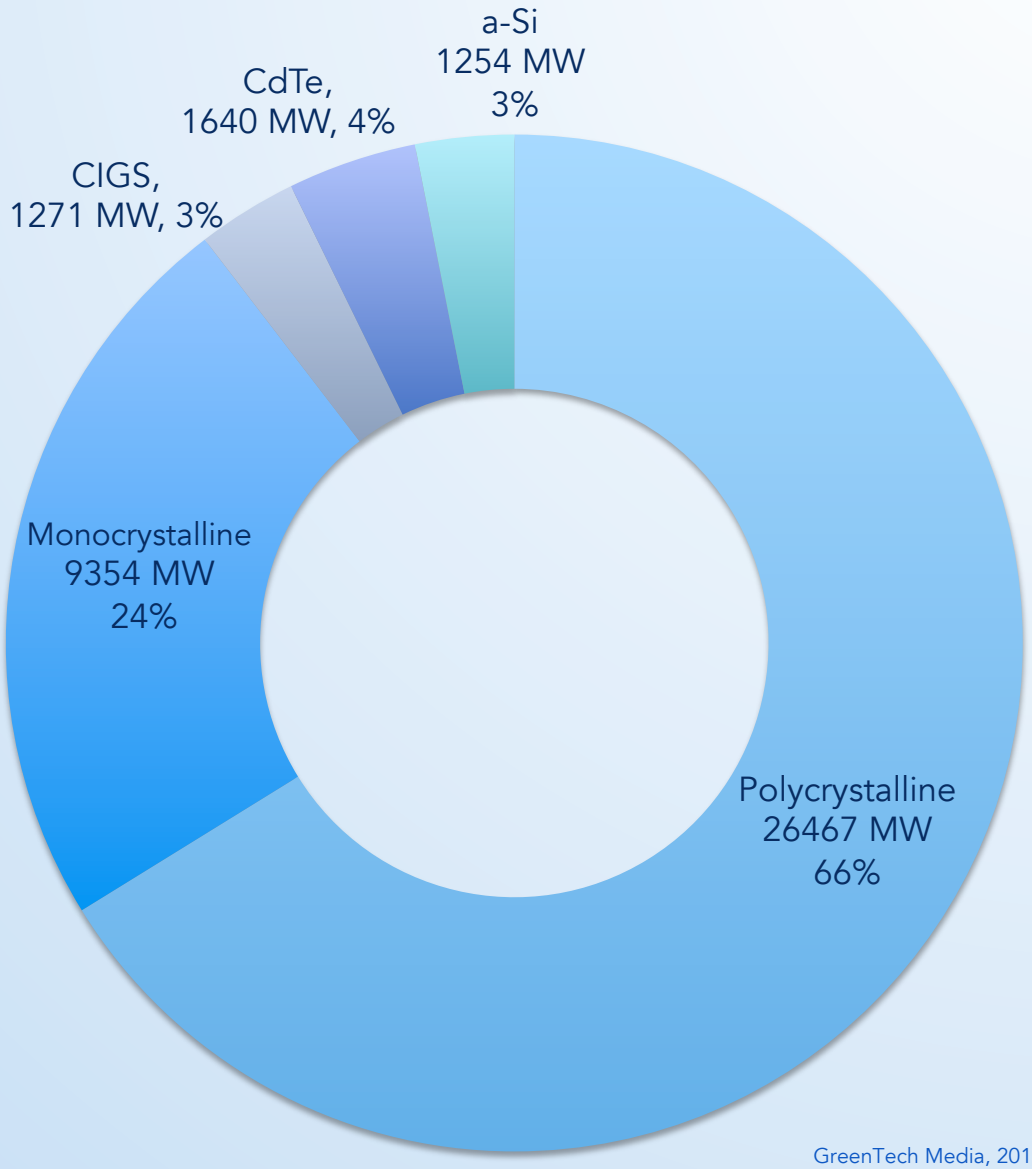
Silicon-based Panels

- Polycrystalline
- Monocrystalline (Cz)
- Amorphous silicon (a-Si)

Thin Films

- Cadmium Telluride (CdTe)
- Carbon Indium Gallium Selenium (CIGS)
- Gallium Arsenide

Global PV Module Production, 2013



GreenTech Media, 2013

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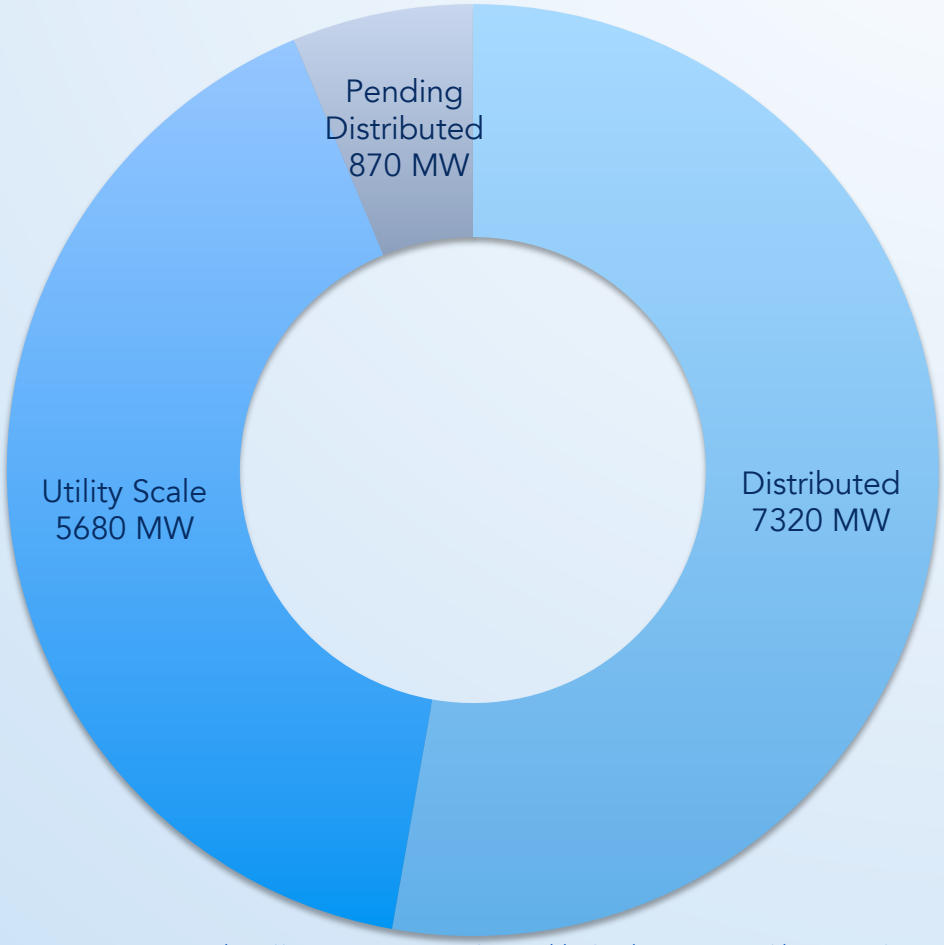
Distributed vs. Utility Scale Solar

Different impacts

- **Land use**
- **Cost**
- **Grid connectivity**
- **Transmission build out**
- **Equity and access**
- **Job impacts**

Distributed v. Utility Scale Solar in California, 2016



http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf

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Solar PV Manufacturing – Primary Exposures

Silicon-Based Panels

- Accidental releases
  - Silicon tetrachloride in waste water streams
  - Silane gas
  - Hydrofluoric acid
- Kerf dust exposure when cutting

Thin Films

- Accidental exposures
  - Indium tin oxide (ITO)
  - Cd during Zn processing (CdTe)
  - Hydrogen selenide and selenium (CIGS)
  - Hydrogen, arsine, phosphine gases (all)

Solar PV – Other Life Cycle Stages

- Material Extraction
  - Silica (Silicon-based)
  - Cadmium from Zinc Processing (CdTe)
  - Tellurium from Copper Processing (CdTe)
- Installation
  - Occupational hazards of roofing for distributed installation
- Maintenance and Use
  - Heat exposure and hazards related to facility maintenance
  - Water use in water scarce areas
  - Fire and hazardous exposures for first responders
- Decommissioning and Disposal
  - Potential cadmium and indium exposures (thin films)
  - Potential lead and heavy metal exposure (all)

Solar PV – Research Needs

- Updated assessments of long-term health impacts of toxic exposures during PV manufacturing
- Identification, development, and evaluation of more healthy, safe, and sustainable recycling and disposal methods – extended producer responsibility?
- Expand research into green chemistry and other safety-by-design approaches throughout PV manufacturing

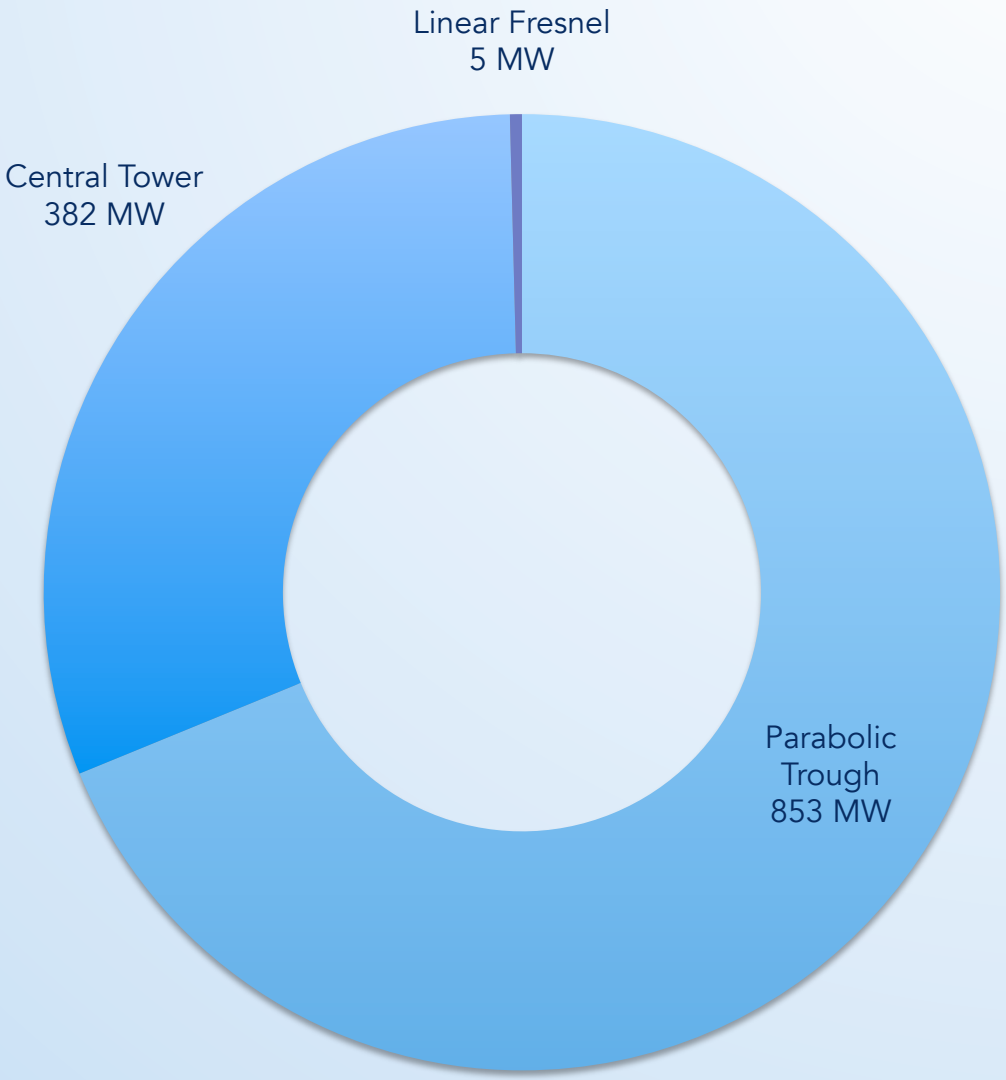
Concentrated Solar

Operating Facilities
- Parabolic Trough
- Central Tower
- Linear Fresnel

Outside of CA
- Parabolic Dish

Materials
- Mirrors
- Lenses
- Water
- Heat transfer fluid
- Storage Material (Molten Salt)

Operating Concentrated Solar Facilities in California



http://www.energy.ca.gov/sitingcases/solar/

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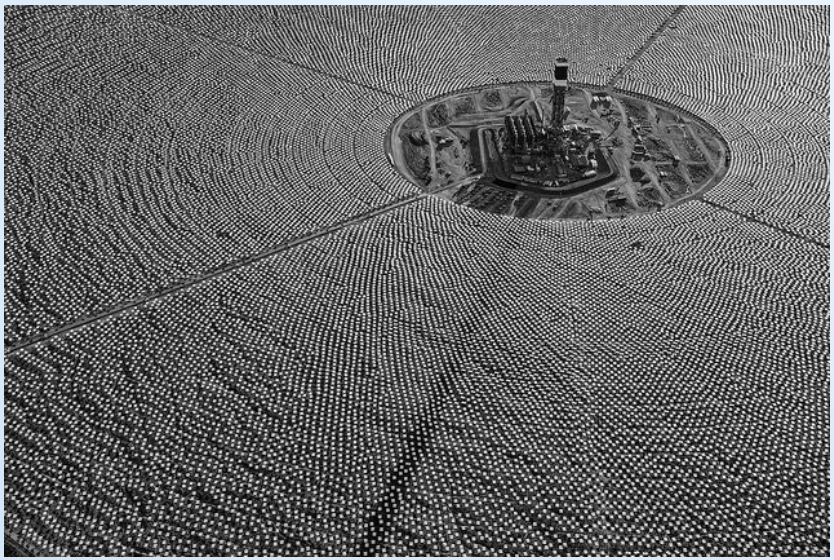
Concentrated Solar

- Manufacture
  - Nitric acid exposures for molten salt production
- Installation
  - Extreme heat
  - Reflected light
- Use and Maintenance
  - Accidental release of synthetic oils and molten salts
  - Reflected light hazards with tracking system failures
  - Fire risk during facility accidents or leaks
  - Heat exposure and hazards of maintenance work
  - Water use in water scarce areas

Concentrated Solar – Research Needs

- Assess potential health impacts of exposure during facility maintenance and end-of-life disposal of heat transfer fluids, including synthetic oils and molten salt

Kuraymat, 2011



Stillings, 2012

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Wind

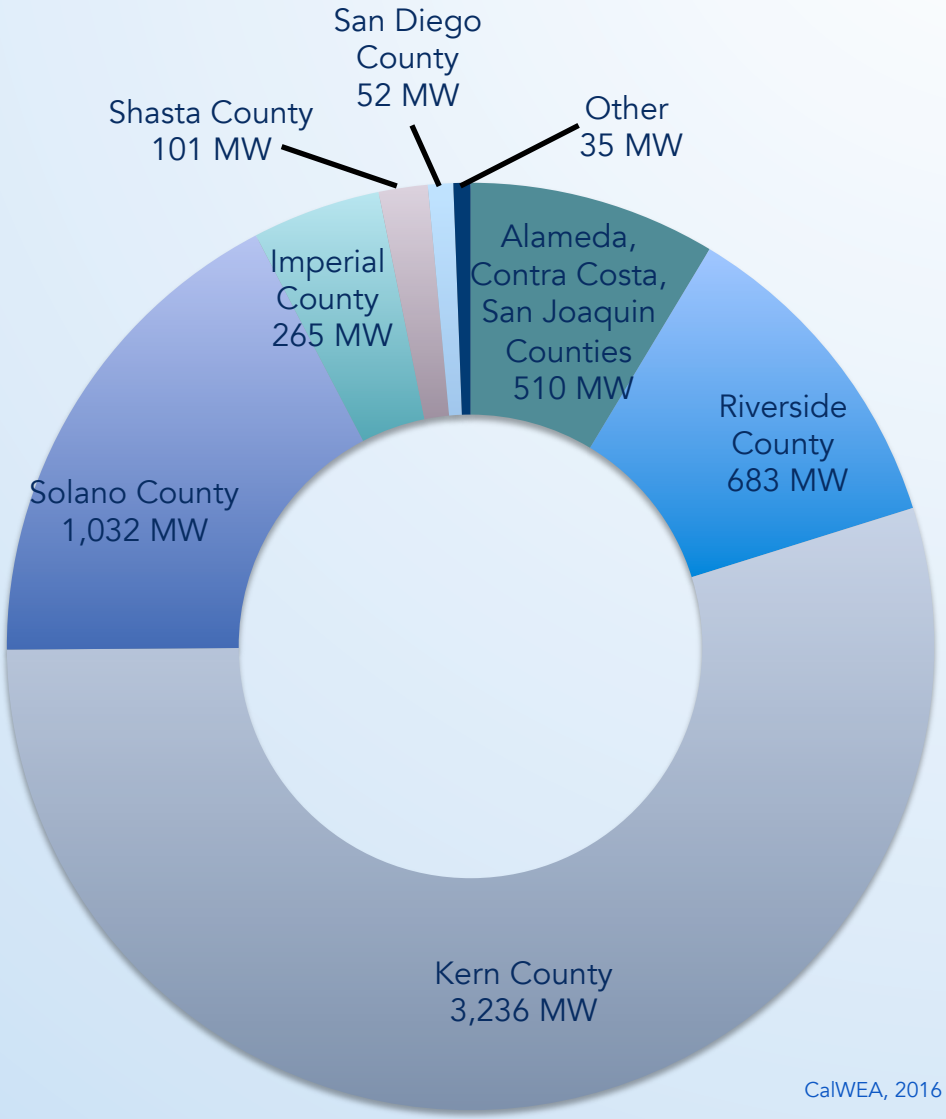
Onshore Technologies

- Developing larger
- Greater efficiencies

Offshore

- Floating turbines being researched for CA coast

Operating Major Wind Facilities in California, 2017



CalWEA, 2016

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Wind

Dombrowski, 2008

- Material Extraction
  - Neodynium and dysprosium mining
- Manufacture
  - Hazardous Exposures
    - Epoxy resins
    - Styrene vapor
    - Fiberglass, hardeners, and aerosols
- Installation
  - Working at heights and in confined spaces

Wind

- Maintenance and Use
  - Risk of fire due to turbine malfunction or lightning
  - Electrical or mechanical hazards of maintenance work
    - At heights
    - Over water
  - Hazards related to working in confined spaces
- Decommissioning and Disposal
  - Pollutant ash from incineration of fiber enforced plastics in blades
  - Chemicals and dust exposure during separation, crushing, and incineration

Wind – "Wind Turbine Syndrome"

- Studies have found that living within close proximity to a wind turbine can lead to exposures to:
  - Infrasound and noise disturbance
  - Shadow flicker
  - Vibration disturbance
  - Aesthetic effects
- Most epidemiological studies have found no direct link between noise and health outcomes other than potential effects on sleep quality and annoyance

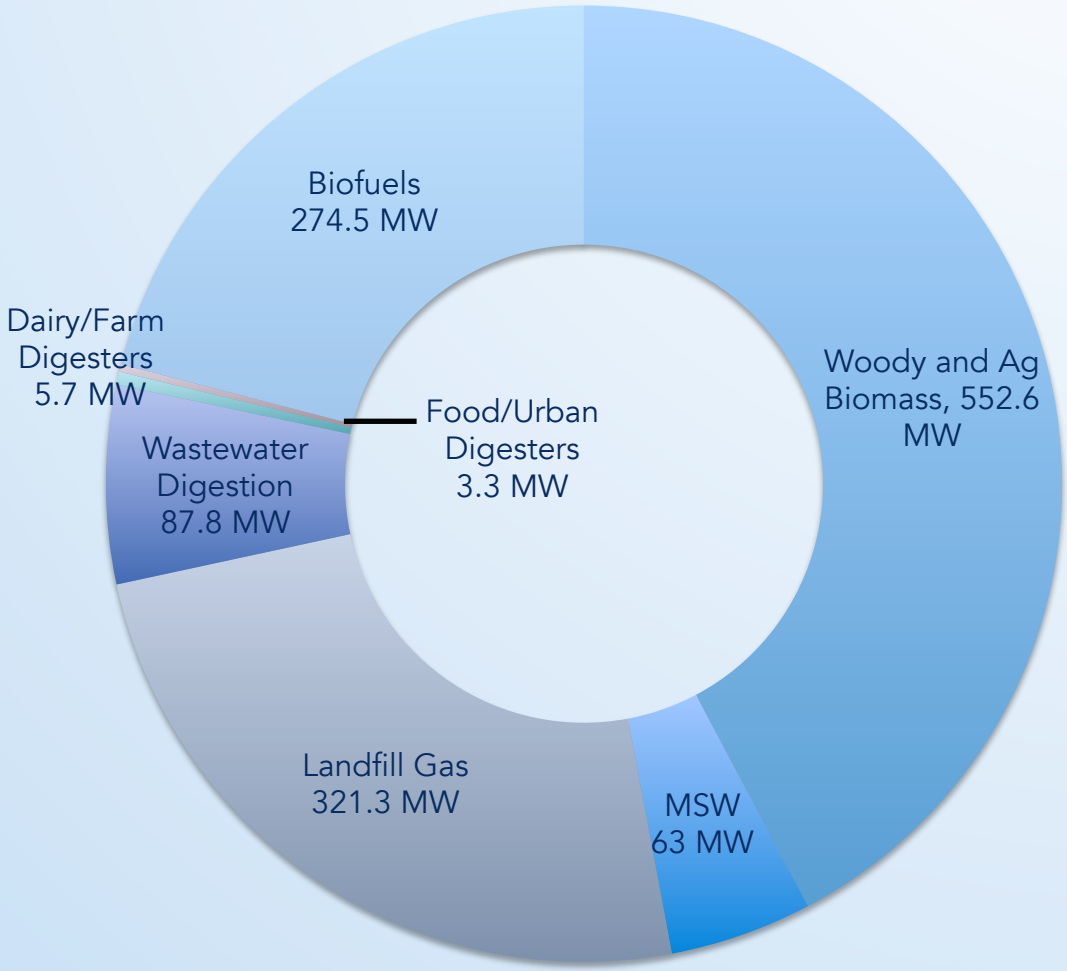
Wind – Research Needs

- Assess the life cycle health impacts of rare earth materials used in magnetized direct drive turbines
- Improved sound-pressure exposure and impact assessment at various turbine-receptor distances
- Epidemiological research on sleep disruption and annoyance from larger turbine design
- Assess effectiveness of various mitigation measures to address shadow flicker and sound-pressure
- Health and environmental life cycle assessments of offshore, floating, and deep-water turbine designs

Biomass

- **Woody/Forest Biomass**
  - Direct Combustion
  - Gasification
  - Plasma Arc
- **Agricultural Waste**
  - Anaerobic Digestion
  - Direct Combustion
  - Gasification
- **Landfill/Municipal Solid Waste**
  - Direct Combustion
  - Thermal Conversion
  - Anaerobic Digestion
  - Plasma Arc
- **Waste Water Treatment/ Animal Manure**
  - Anaerobic Digestion
  - Gasification

Operational Biomass Facilities in CA by Fuel Source, 2015



California Biomass Energy Collaborative, 2015

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Biomass

- Material Collection
  - Truck emissions and transport hazards related to transporting fuel source to facility
  - Hazards related to timber collection and transport
- Fuel Processing
  - Release carbon monoxide, NOx, SOx, and acid aerosols from wood processing
  - Exposure to bioaerosols during biomass fuel production (woody, agricultural waste, and municipal solid waste)

Oregon Dept of Forestry, 2013

Biomass

- Transportation
  - Release and containment of CO during woody biomass storage and transport
- Use and Maintenance
  - Fire, CO, and fall-related risks of fuel storage
  - Risk of fire from mechanical error or facility accident
  - Release of hydrocarbons, oxygenated organics, chlorinated organics, and inorganics
  - Particulate matter emissions
- Decommissioning
  - Toxic ash residues could leak into local aquifers
  - Leakage of solid and industrial wastes

Biomass – Research Needs

- Comprehensive assessment and/or modeling of life-cycle air quality impacts associated with different scenarios for the deployment of biomass
  - For biofuels, assess comparative impacts of centralized vs. distributed conversion facilities, including feedstock transportation
  - For biopower, assess impacts of transportation of feedstock to generation facilities
- Assess and monitor occupational exposures through the life cycle of fuel processing, combustion, and disposal

Geothermal

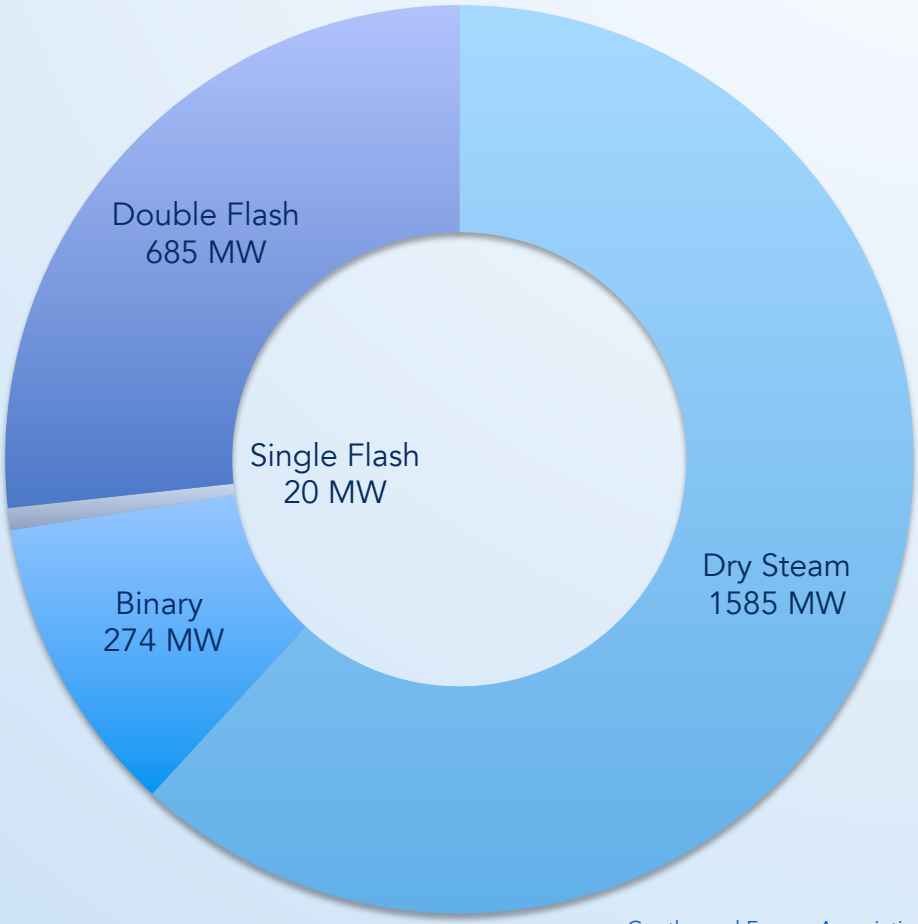
System Types

- Direct/Dry Steam
- Flash Steam
- Binary

Developments

- Enhanced Geothermal Systems
- Mineral recovery
- Use of spent oil and natural gas sites

Operational Geothermal Facilities in California by Type, 2013



Geothermal Energy Association, 2013

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Geothermal

- Installation
  - Occupational hazards related to trenching and excavations
- Use and Maintenance
  - Release of hydrogen sulfide due to facility accident
  - Exposure to antimony, arsenic, lead, and mercury to workers
    - Public exposures with system failure or leak
  - Re-injection could affect seismic activity
  - Radionuclide leaks in waste water and geothermal fluids
- Decommissioning and Disposal
  - Improper decommissioning could allow geothermal fluids to move into local aquifers

Geothermal – Research Needs

- Comprehensive mapping of subsurface seismic stress fields during initial simulation phase of geothermal plant
- Develop new technologies to prevent/reduce hydrogen sulfide emissions of flash steam facilities
- Assess health and environmental consequences of materials recovery (e.g. sulfur, lithium) from brine
- Life cycle assessment of planned facilities to assess variables in geology that could effect emissions

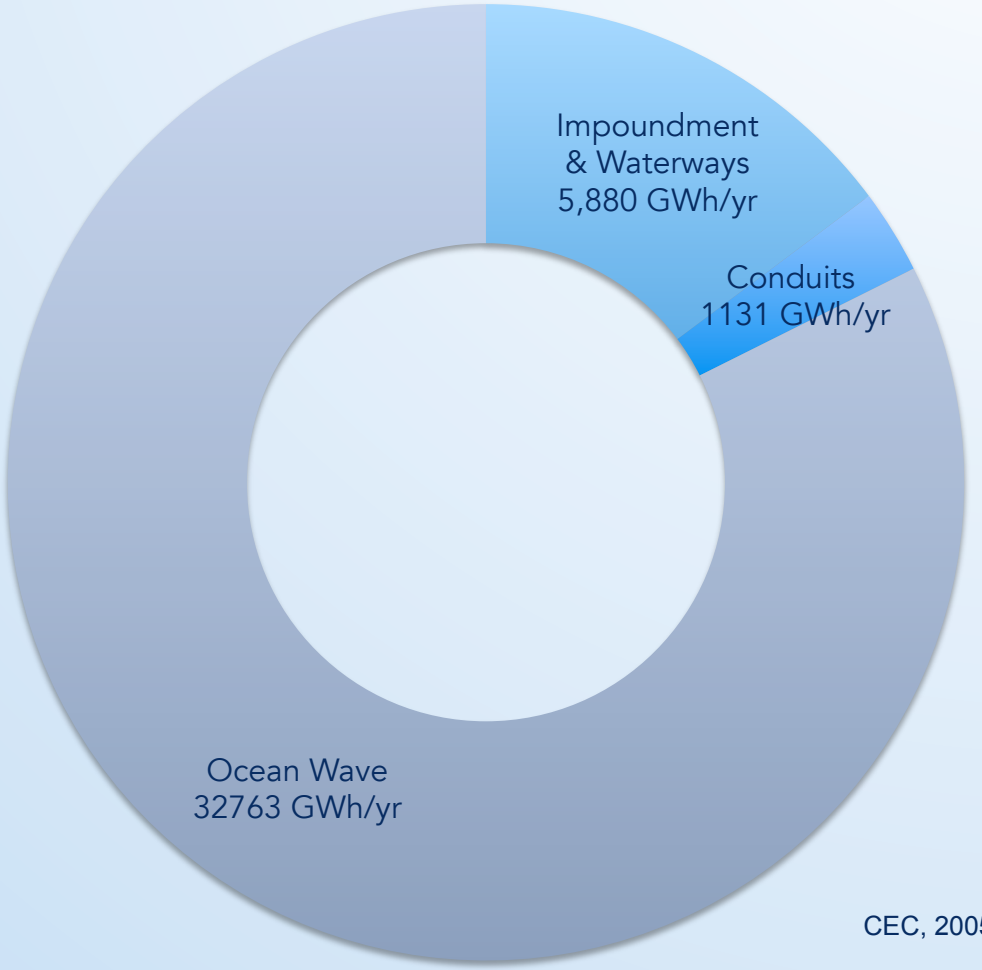
Small Hydro

- Small hydroelectric facilities with capacity less than 30MW
- Conduit systems with capacity less than 30MW

Ocean

- Wave Energy
- Tidal Energy
- Ocean Thermal Energy Conversion

CA Small Hydro and Ocean Wave Energy Resource Potential, 2005 Estimates



CEC, 2005

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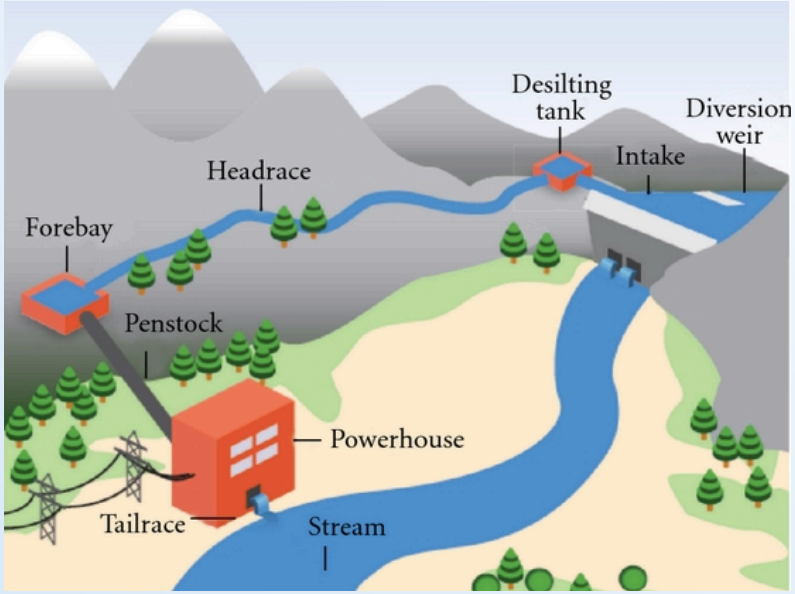
Small Hydro

- Maintenance and Use
  - Dam failure due to overtopping or foundation issue
  - Potential to affect water quality
  - Cumulative impact of projects on flood risks
  - Potential effect on disease vectors
  - Potential to create anoxic conditions and methyl mercury



IPCC, 2012

Small Hydro – Research Needs

- Assessment of potential health and environmental impacts of ocean wave energy technologies
- Assessment of potential water quality and vector impacts of small hydropower facility design and siting
- Assessment of planned or projected ocean and tidal systems on local fishery and coastal community economies

Storage

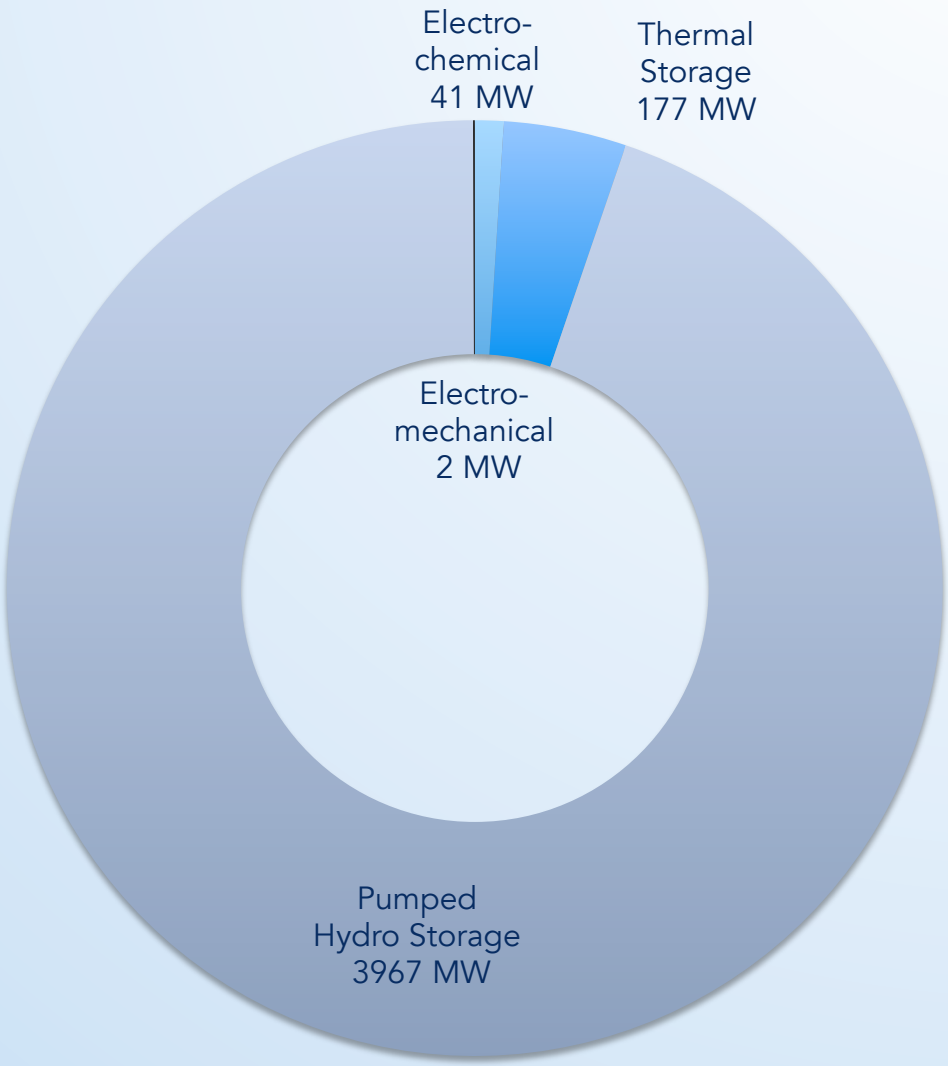
Storage
- Mechanical
- Pumped Hydro
- Compressed Air
- Flywheels

Electrochemical
- Conventional Batteries (Lithium-ion, Lead acid)
- High Temperature (Sodium-Sulfur)
- Flow Batteries (Vanadium-redox, Zinc-bromide)

Thermal
- Molten Salts

Chemical
- Fuel Cells (PEMFC, SOFC)

Operational Storage Facilities in CA by Category, 2016



DOE Sandia National Laboratories, 2016

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Electrochemical Storage

- **Material Extraction**
  - Lithium (Chile)
  - Cobalt, Nickel (Congo)
  - Graphite (China)
  - Cathode active material (Japan)
  - Lead (China)
  - Antimony
  - Vanadium (Mining or petroleum recovery)
  - Copper
  - Sodium or trona dust

AES, 2016

Electrochemical Storage

- **Manufacture**
  - Hazardous exposures
    - Fluoroethylene, fluoroethylene ether, or HF during electrolyte synthesis (Li-Ion)
    - Formaldehyde, benzo[a]pyrene and dioxins from aluminum production (Li-ion)
    - Lead dust exposure oxide formation or transport (PbAcid)
  - Leakage of flammable components of electrolyte during synthesis (Li-Ion)
  - Fire risk of elemental sodium in NaS manufacture
  - Exposures related to ceramic and nanoparticles

Electrochemical Storage

- Use and Maintenance
  - Fire risk due to combustibility of batteries
    - Li-Ion, PbAcid, NaS
  - Acid burns due to leaking battery packs
    - Li-Ion and PbAcid
  - Chemical exposure to first responders
- Decommissioning and Disposal
  - Corrosive sodium polysulfide during disposal of NaS batteries

Chemical Storage

- Material Extraction
  - Mining waste from platinum mining
  - Rare earth mining
- Manufacture
  - Toxic Exposures
    - Fluorinated polymer electrolyte and precursors
    - Polybenzimidazole and precursors
  - Nanoparticles and nanotube
  - Ceramics
- Use and Maintenance
  - Fire and explosion risk

Mechanical Storage

- Installation
  - Hazards related to trenching and excavations
  - Exposure to heavy metals during trenching
- Use and Maintenance
  - Risk of flooding from reservoir overtopping and system breach in pumped hydro facilities
  - Potential water quality and vector borne illness impacts of pumped hydro
  - Risk of explosion and fire from breach in compressed air or flywheel factories

Storage – Research Needs

- Life-cycle health assessment of health and environmental impacts of battery technologies (NMC and NCA Lithium Ion, Vanadium flow, and emerging battery technologies)
  - Exposure to lithium brine and cobalt in Li-Ion manufacturing
  - Health assessments of vanadium flow manufacture
  - Health assessment of beta alumina ceramic manufacturing (NaS)

Storage – Research Needs

- Development of healthy and safe methodologies for battery and fuel cell component recycling
  - Assess comparative health impacts of battery recycling and hazards associated with materials extraction and processing
- Assessment of fuel cells technology potential to mitigate emissions of distributed biomass generation
- Research on health impacts of nanoparticles
- Health and hazard assessment of the construction and maintenance of pumped hydro, compressed air, and flywheel facilities

Distribution and Transmission

- Distributed Generation/ Microgrid
- Smart Grid / Smart Meter (new research from NTP)
- Transformers / Transmission Developments

Portland General Electric, 2009

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Smart Meters – Research Needs

- Health Concern
  - EMF exposure from smart meter and relay meters
  - National Toxicology Program's recent findings on cell phone radiofrequency exposure in rats

Research Needs

- Field monitoring of exposures to extra-low-frequency electromagnetic radiation under a range of real-world conditions including e.g. multi-unit housing, relay units

Distribution

- Energy Efficiency
  - Indoor air quality concerns from improper sealing and poorly planned energy efficiency remodels
- General Distribution
  - Toxic exposures, hazards, land use concerns from build out of transmission lines on land and offshore
  - Risks to overall system resiliency

4. OTHER HEALTH IMPACTS AND RESEARCH QUESTIONS

Hazards Across the Technologies

Transportation

- Emissions for workers and fence line communities related to technology transport and site installation and maintenance vehicles
  - Hazards related to heavy equipment transport, use, and installation for workers

Research Needs Across the Technologies

- Develop standardized methodologies for life cycle health impacts of emerging electricity generating technologies and strategies to implement and integrate as systems/technologies emerge

Utility Scale Projects

- Exposure to *coccidioides* fungal spores during construction and maintenance of ground-mounted energy facilities
  - Valley Fever
- Worker and fence line exposure to herbicides during installation and maintenance

Occupational

- Hazards related to heavy equipment transport
- Hazards of land clearing and heavy equipment handling

Equity

- Siting of large-scale facilities in poorly resourced areas
- Populations at greater risk for more severe Valley Fever illness

Utility Scale Projects – Research Needs

- Strategies to reduce the risk of *coccidioides* exposure associated with construction, maintenance, and operation of ground-mounted facilities:
  - Alternatives to land clearing practices
  - Comparative effectiveness of mitigation strategies
  - Improved methods to assess presence of *coccidioides* to facilitate risk-informed site selection
- Strategies to reduce the risks of occupational and near-by residential herbicide exposure related to facility installation and maintenance
- Assessments into the equitable siting and planning of future facilities due to these risks

Changing Workforce – Research Needs

- Assess direct and indirect impacts of emerging energy systems on social determinants of health
- Review worker knowledge, training practices, and current risks of rapidly growing installation industry
- Research the equity implications of occupational health risks and employment practices

US Department of Energy Solar Decathlon, 2015

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Equity

- Assess how changes in the energy system will affect disadvantaged communities specifically
  - How does this compare to effects and co-benefits statewide?
- Core project/system requirements to ensure equity?
- Strategies for increased meaningful community engagement
  - Community member participation in process
  - How to integrate community needs in projects
  - Assessment of alternatives

Global Health Impacts

- Non-U.S. impacts throughout the life-cycle
  - Extraction, production, transport, end-of-life disposal
- Possible health impacts
  - Occupational health
  - Local environmental health
  - Cultural health
  - Economic health

Global Health Impacts

- Accounting for offshore impacts not a new concept
  - California e-waste legislation in 2003
  - DTSC regulations for chemicals in products

- Recommendation
  - Account for offshore health impacts
    - Undertake analysis of current policies and regulations
    - More fully analyze:
      - Offshore health impacts
      - Existing private/public efforts/tools/resources
      - Possible mitigation strategies

Opportunity Costs

- Electrification of vehicles vs. active transport infrastructure build out
- Focus on dairy digesters for emission reduction vs. reduction in meat consumption
- Subsidies for home solar vs. increased focus on energy efficiency measures
- Use of biomass vs. fossil fuels vs. geothermal for peak capacity
- Exposures from biomass burning of woody fuel from dead trees vs. wildfires

Public Workshops

We are seeking public feedback to address the following questions:

- Are there key emerging technologies that should be added to our assessment?
- Are you aware of important research on the health impacts of emerging electricity technologies that is not reflected in our presentation?
- Are there additional areas of concern about potential health impacts that have not been addressed?
- Do you agree with our criteria for prioritization?

5. NEXT STEPS

Next Steps

- Technical Advisory Committee Meeting – April 13th
- MS Access Database
- Final Review and Application of Prioritization Criteria
- Draft Report
- Final Report

THANK YOU

Laura Buckley – laura.buckley@phi.org

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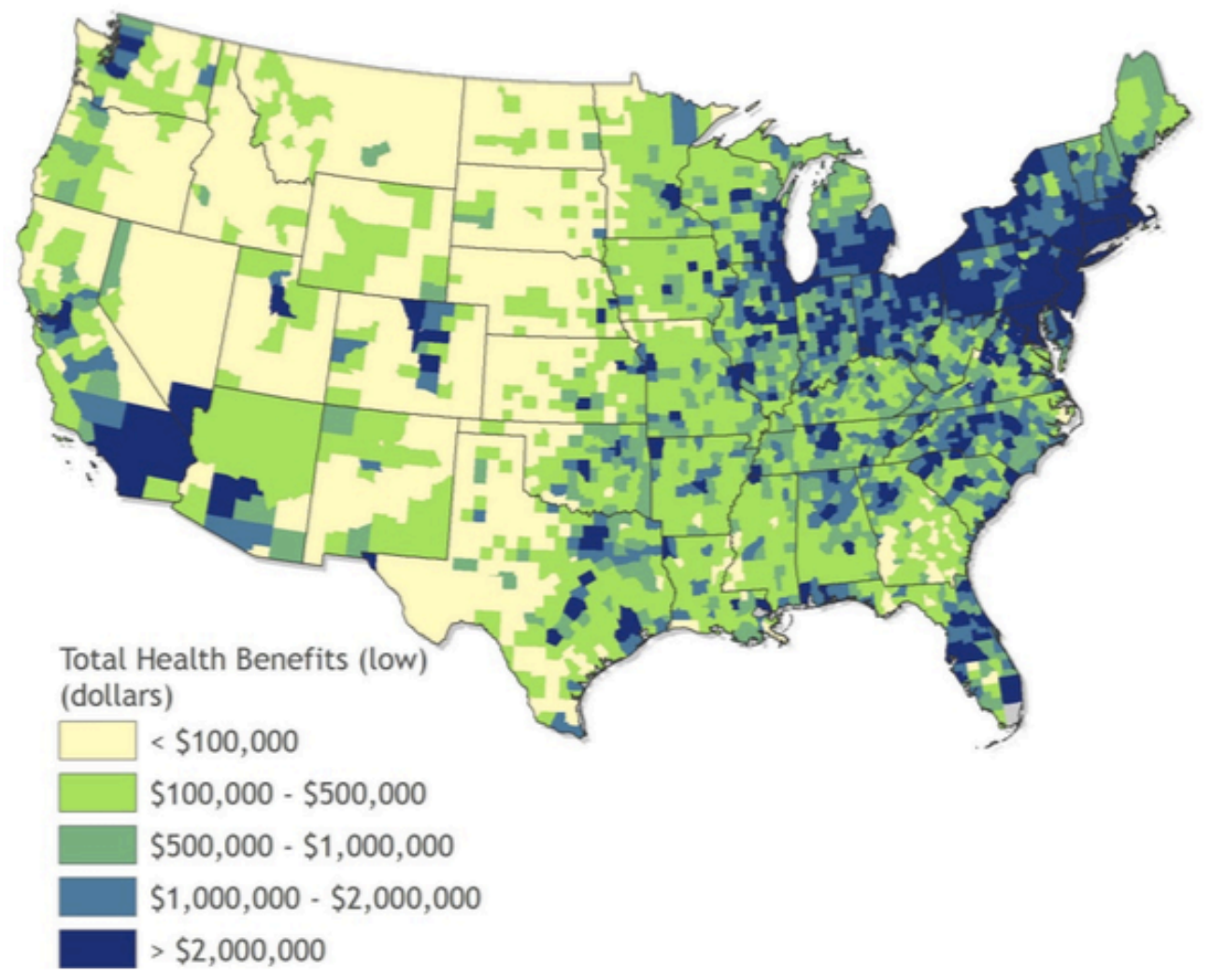
Estimated Monetized Health Benefits due to $PM_{2.5}$ Reductions from RPS Compliance



NREL, 2016

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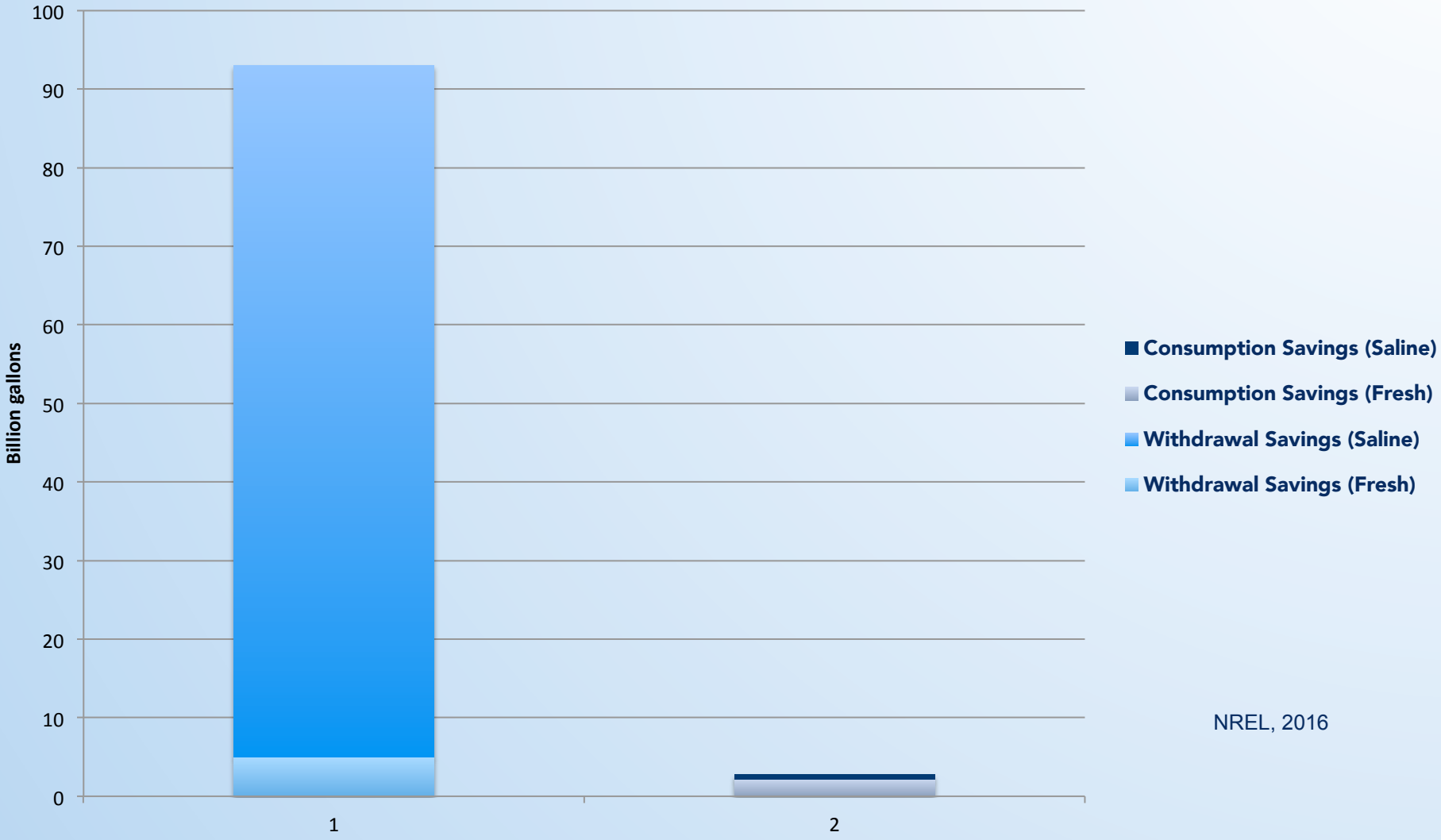
Fresh and Saline Water Withdrawal and Consumption Benefits of RPS Compliance



NREL, 2016

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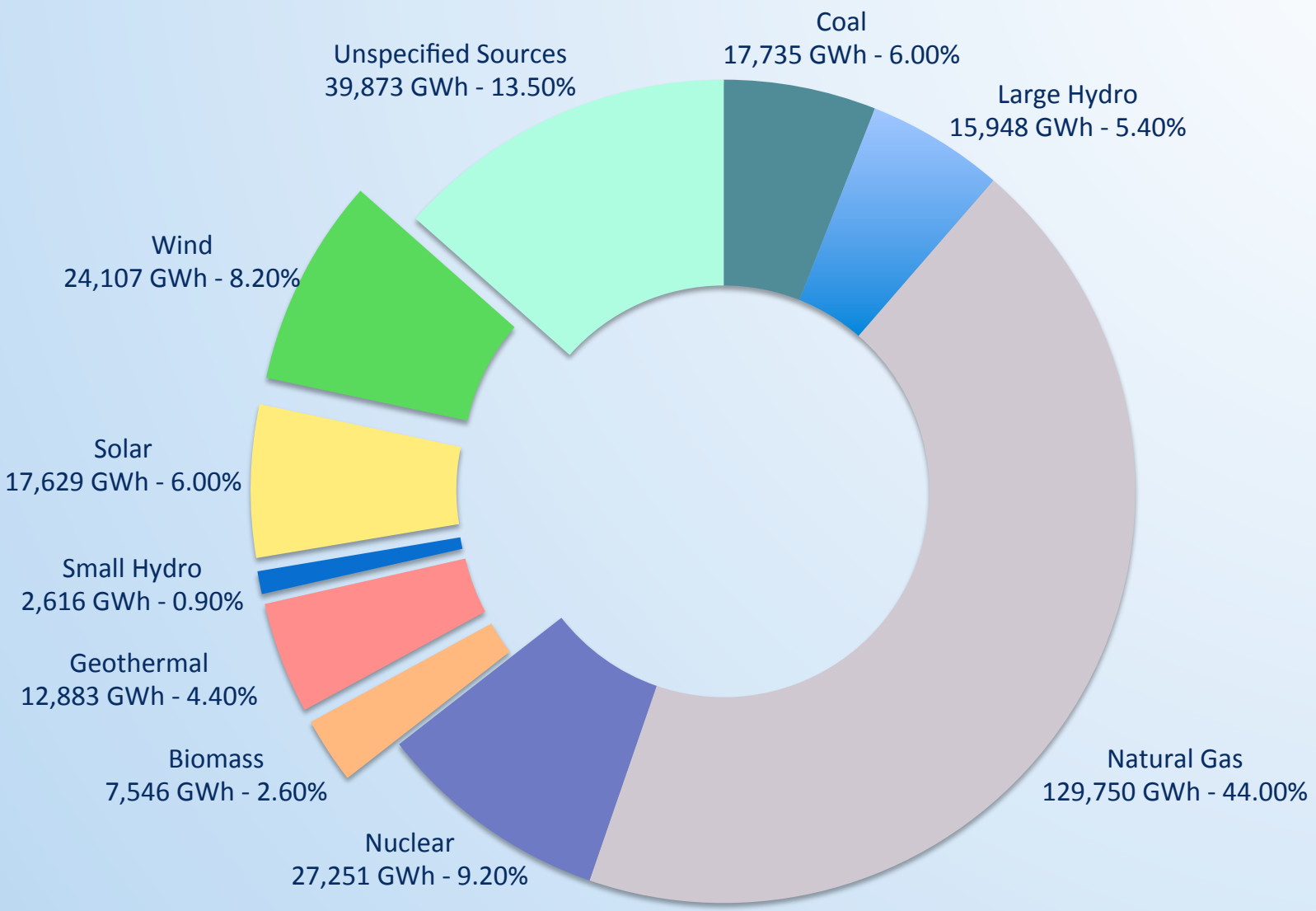
2015 California Energy Mix

(Includes Imported Energy)



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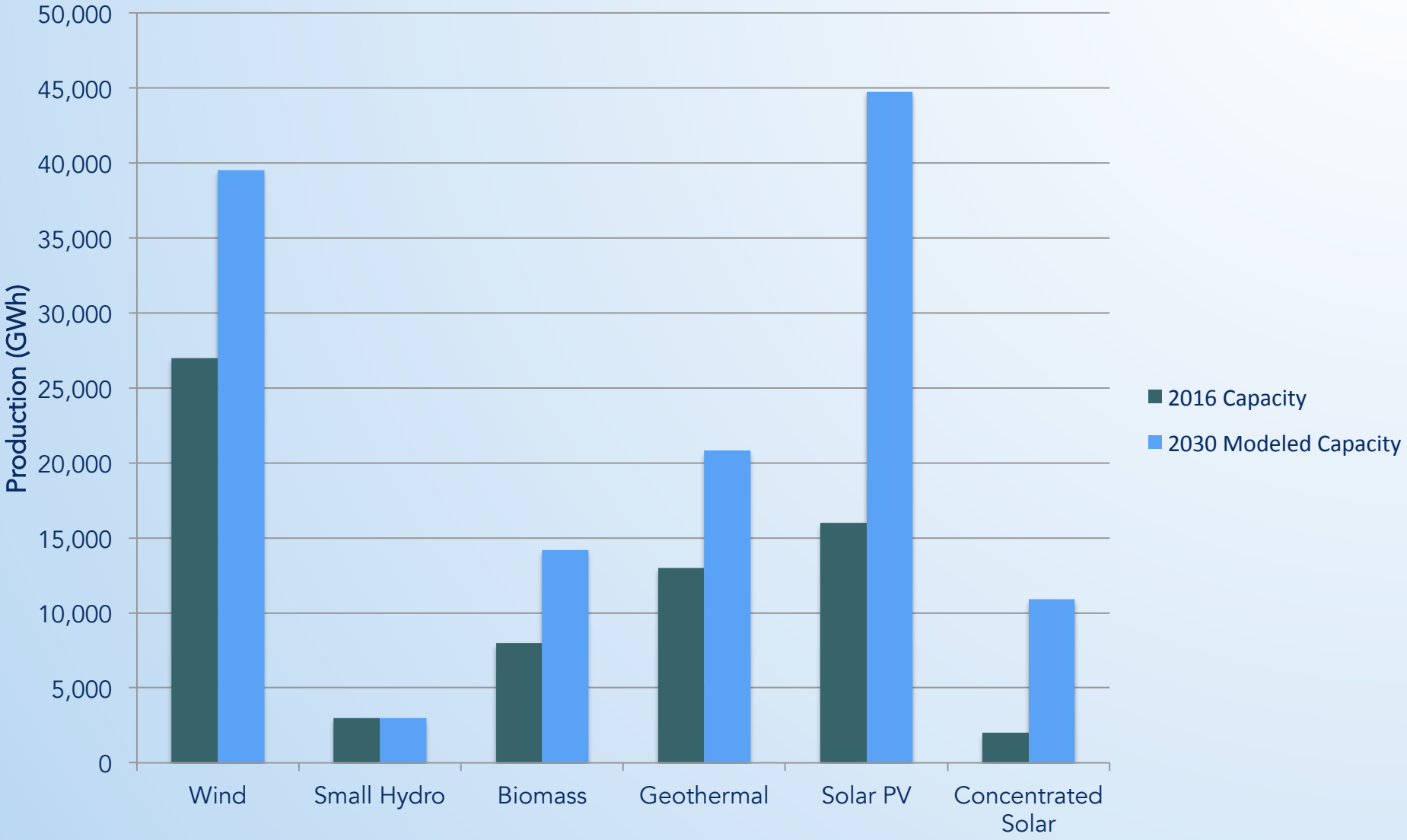
http://www.energy.ca.gov/almanac/electricity_data/total_system_power.html

2016 Renewable Generation Serving CA v. 2030 Modeled Portfolio to Achieve 50% RPS



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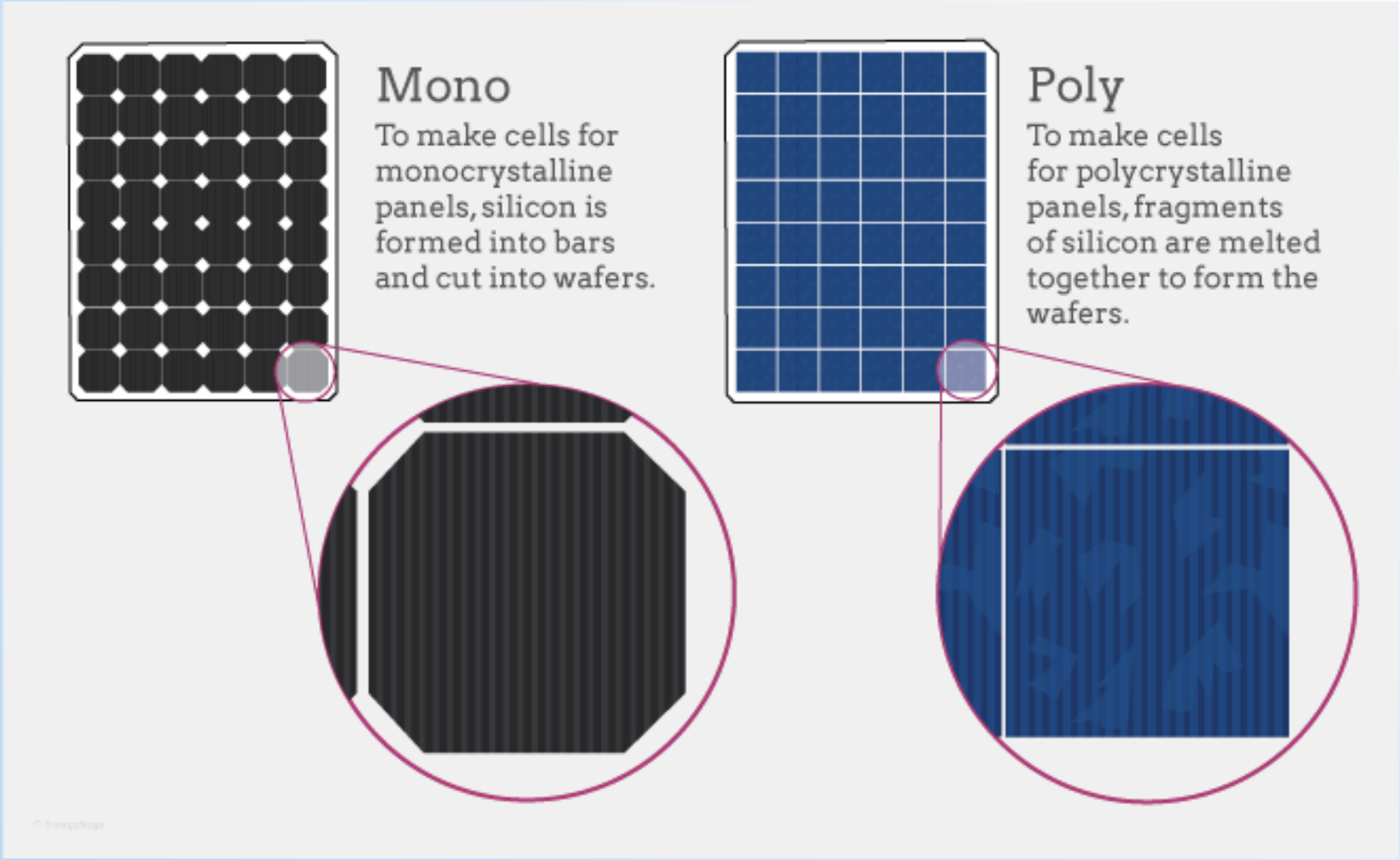
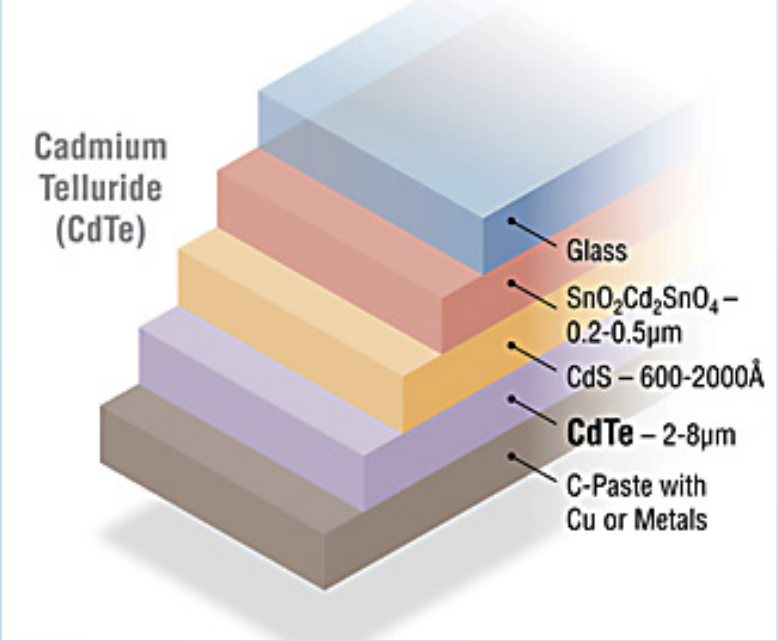
http://www.energy.ca.gov/renewables/tracking_progress/documents/renewable.pdf
https://www.ethree.com/wp-content/uploads/2017/01/E3_Final_RPS_Report_2014_01_06_ExecutiveSummary-1.pdf

Silicon-Based Photovoltaic Panels



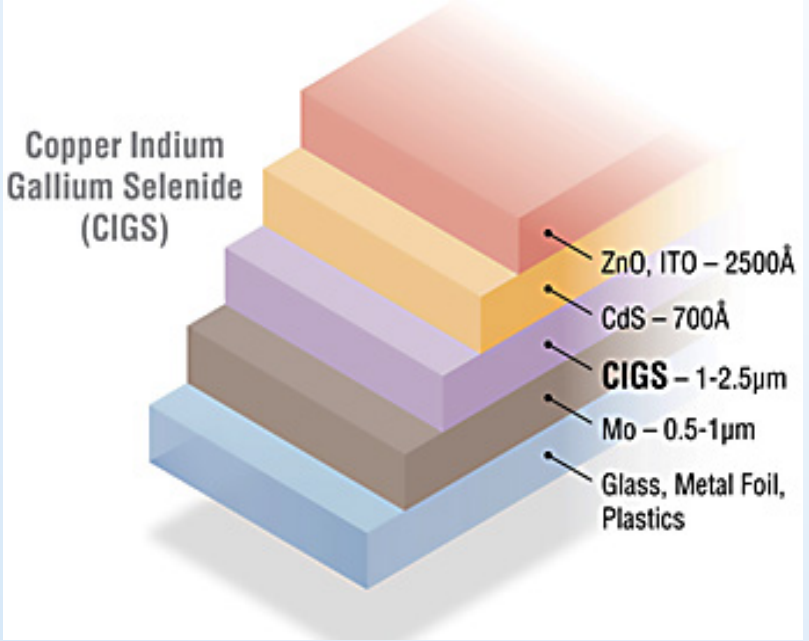
Taylan and Berberoglu, 2013

Thin Films



NREL, 2016

CdTe Structure



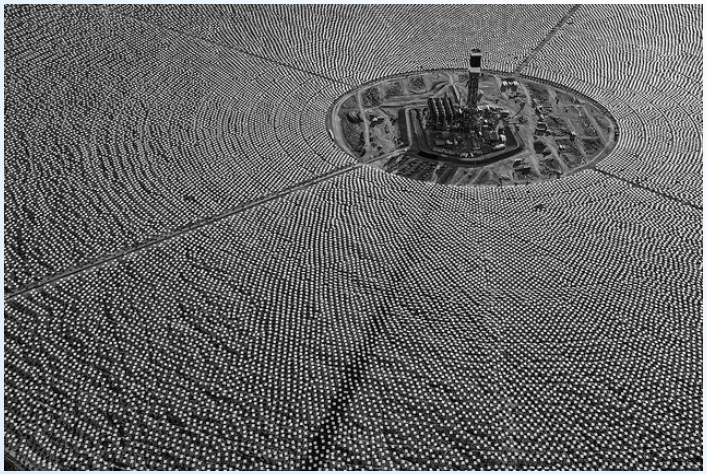
NREL, 2016

CIGS Structure

Concentrated Solar – Types

Kuraymat, 2011

Parabolic Trough



Stillings, 2012

Central Receiving Tower

Solar Dawn, 2014

Linear Fresnel

Taylan and Berberoglu, 2013

Parabolic Dish

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Wind

Onshore

Dombrowski, 2008

Offshore

Untrakdrover, 2012

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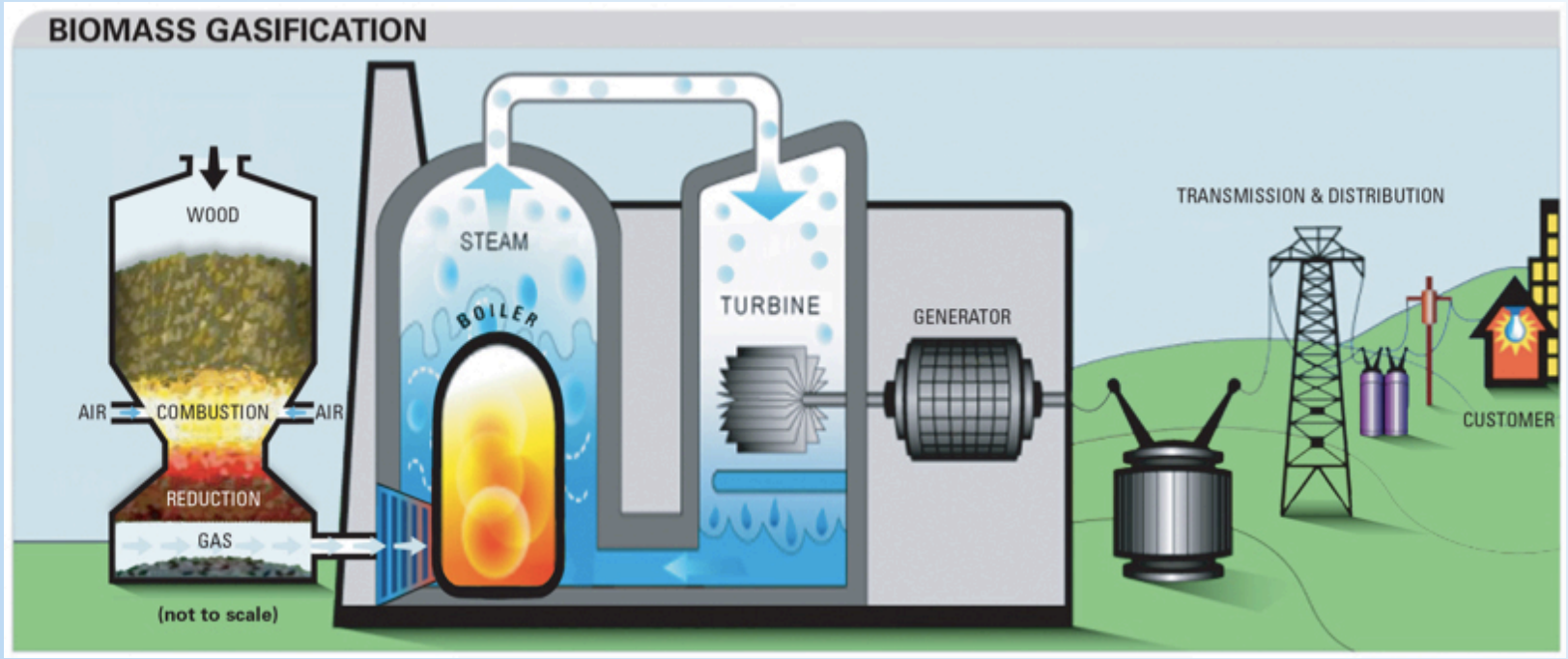
Biomass – Gasification



Top left: Oregon Dept of Forestry, 2013 Top Right: Alan Levine, 2013 Bottom: Frost & Sullivan, 2011

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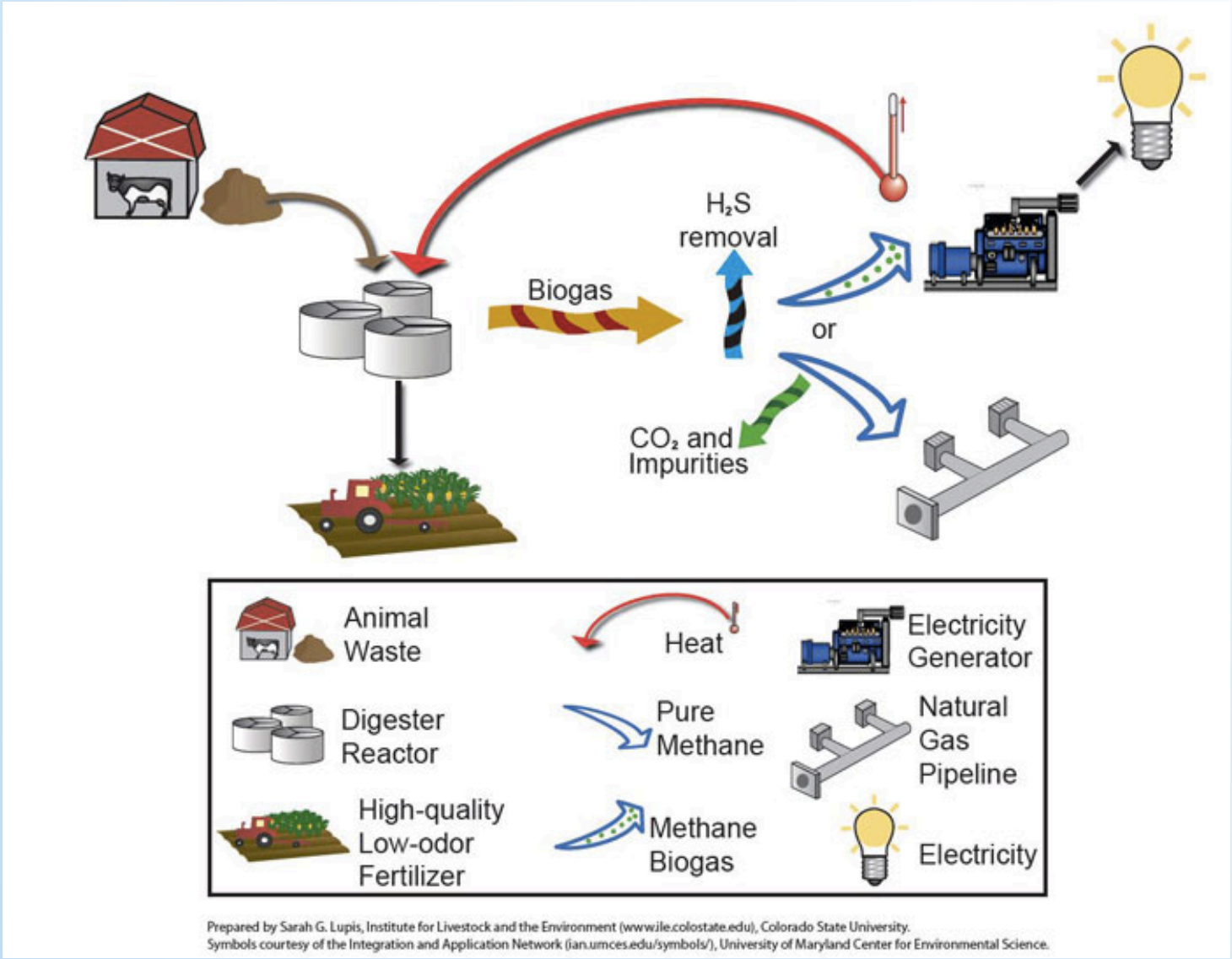
Biomass - Anaerobic Digestion



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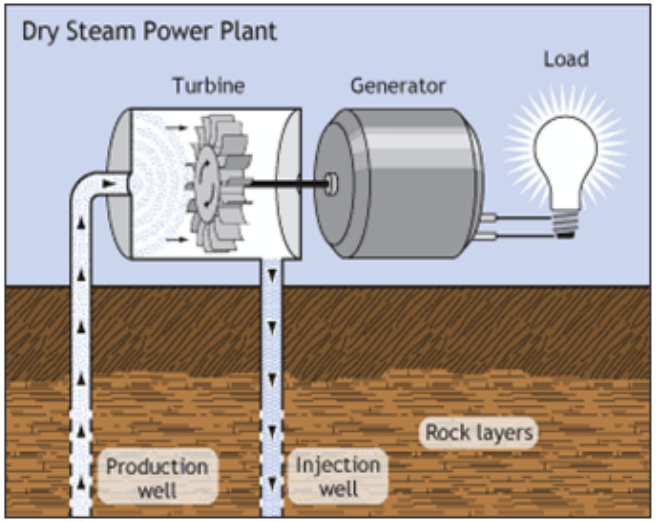
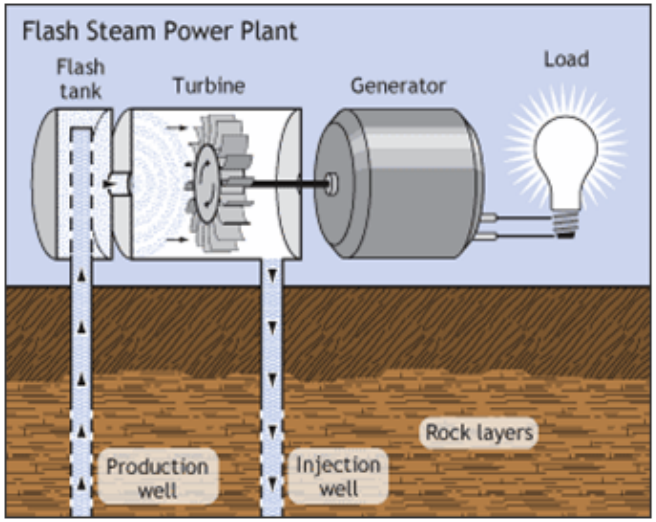
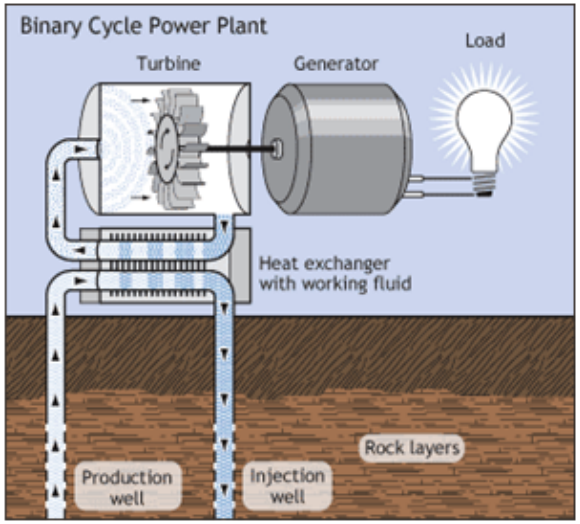
Geothermal







US DOE, 2010

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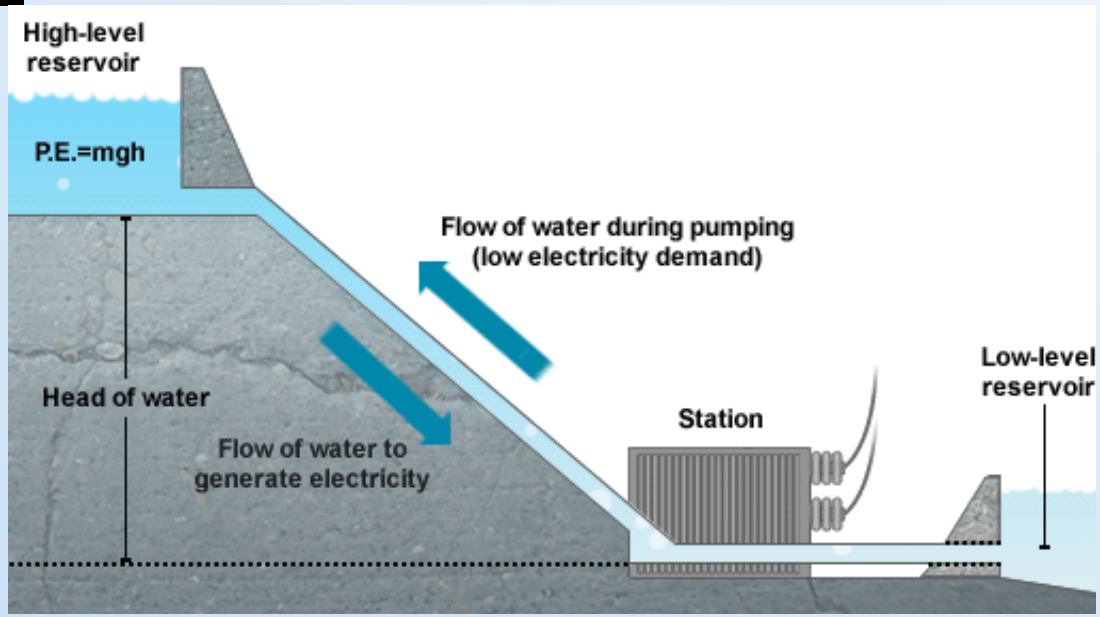
Pumped Hydro



BBC, 2014

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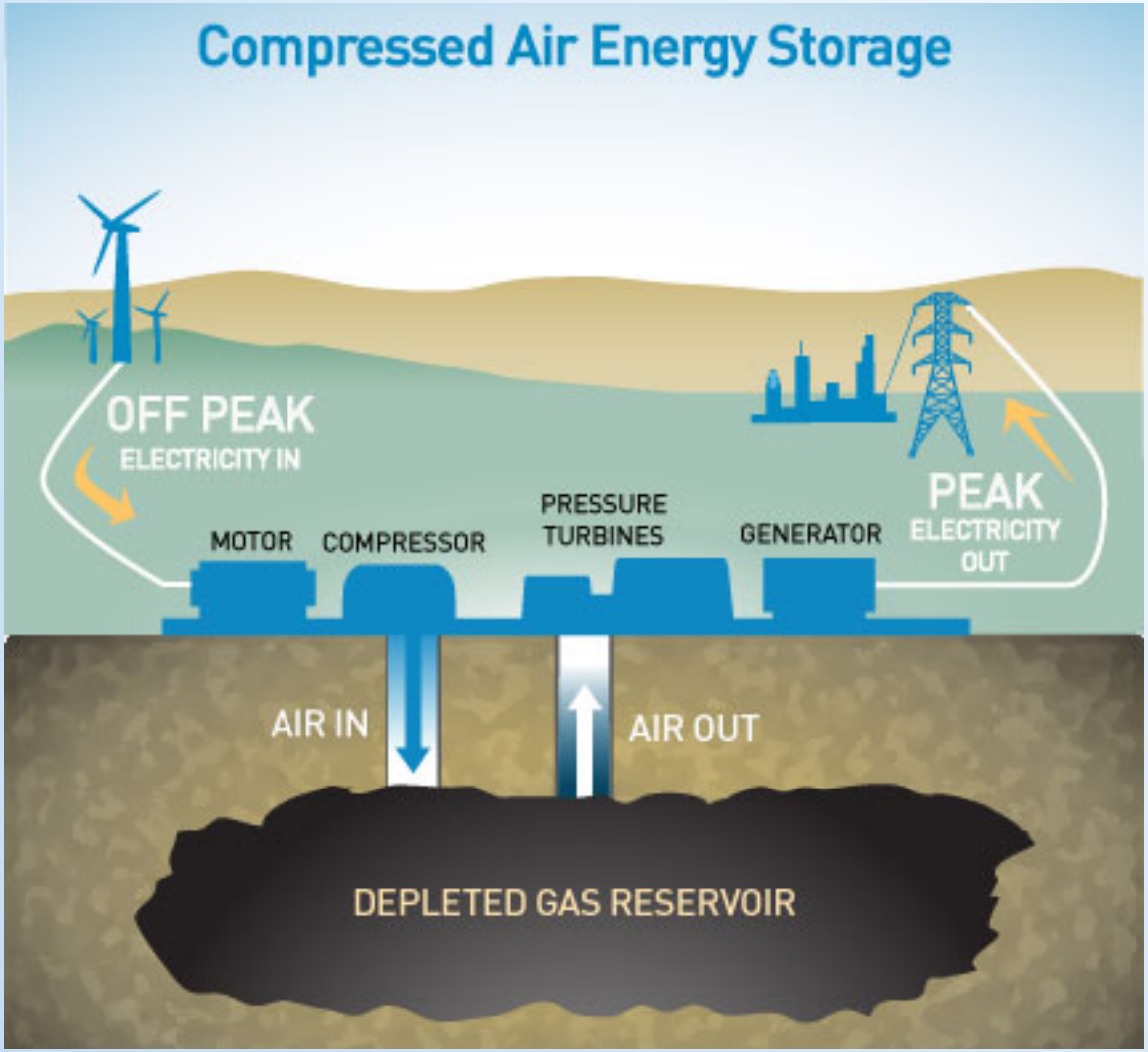
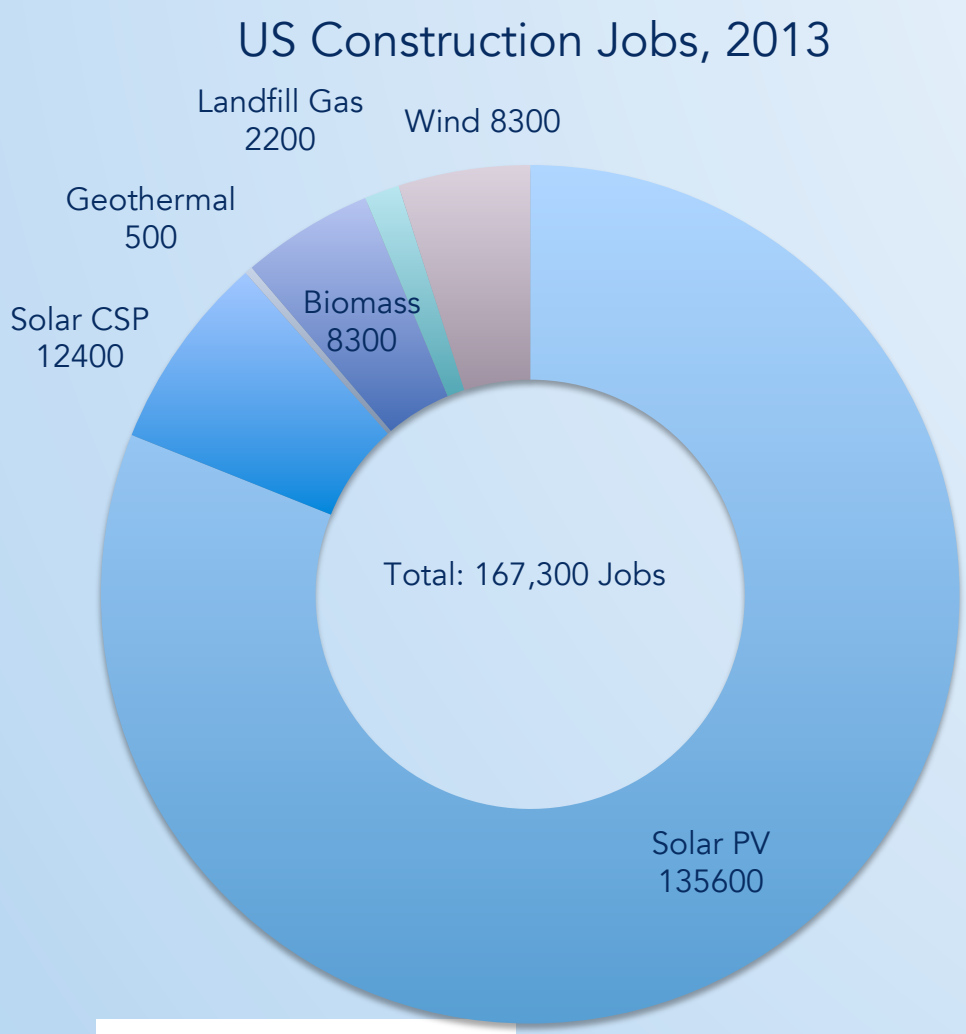
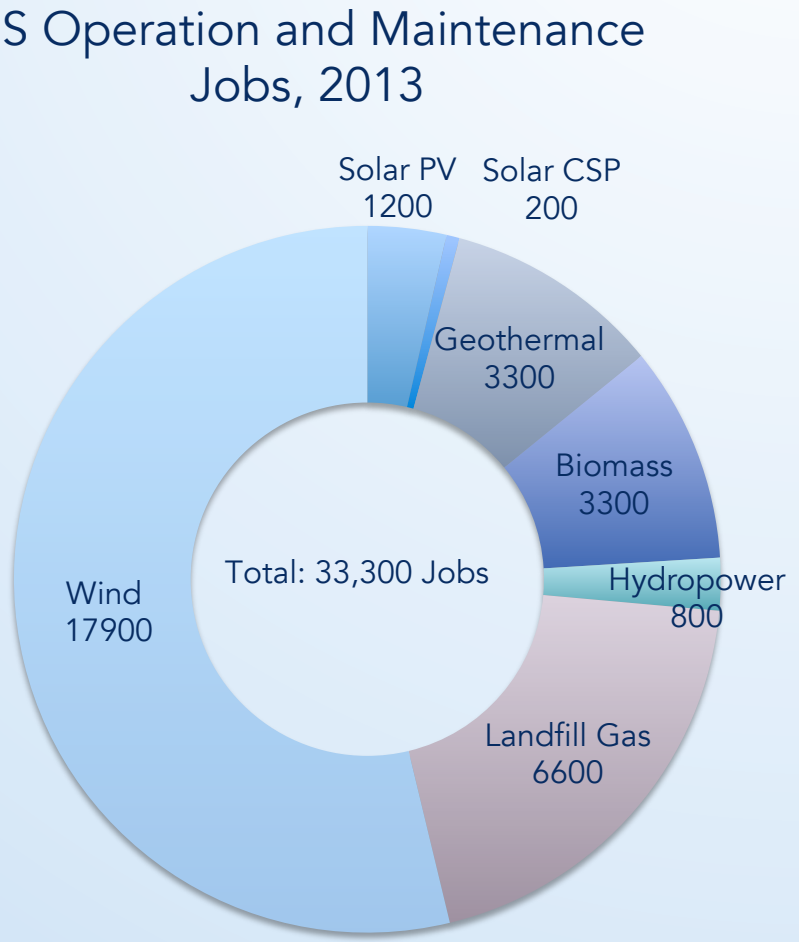
Compressed Air



PG&E, 2016

Gross Domestic Construction and Operation & Maintenance Jobs from RPS Compliance





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NREL, 2016