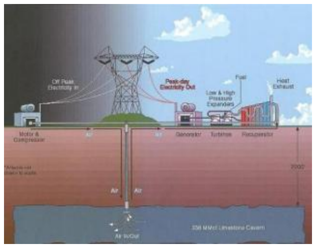

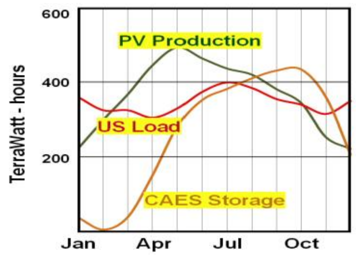

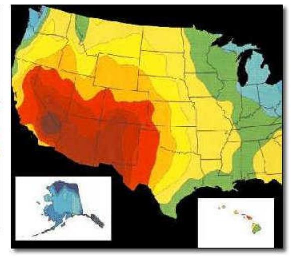

Solar Energy and Storage Technology Economics

Ardeth Barnhart and Dr. Joseph Simmons
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University of Arizona – www.azrise.org

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AzRISE
Research, Development, Outreach

- Formed September 2007 at the University of Arizona
  - Funding – ABOR, University of Phoenix, TEP , APS, DOE, SFAz
- Solar Energy Systems Development
  - Storage
  - Smart Grid
  - Demonstration Sites
  - Solar House, Solar Car, Desalination

- Basic Research
  - Seed Projects
  - New Photovoltaic Materials/ Solar Concentrators
- Testing – PV Test Site
- Economic and Policy analysis
- Education and Outreach

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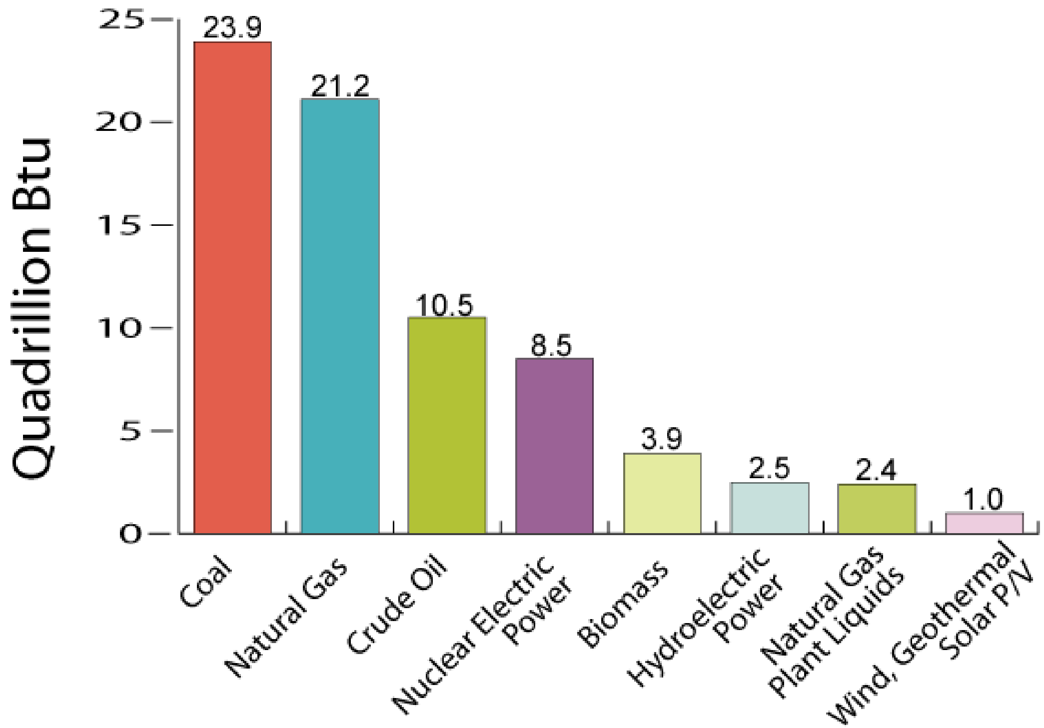
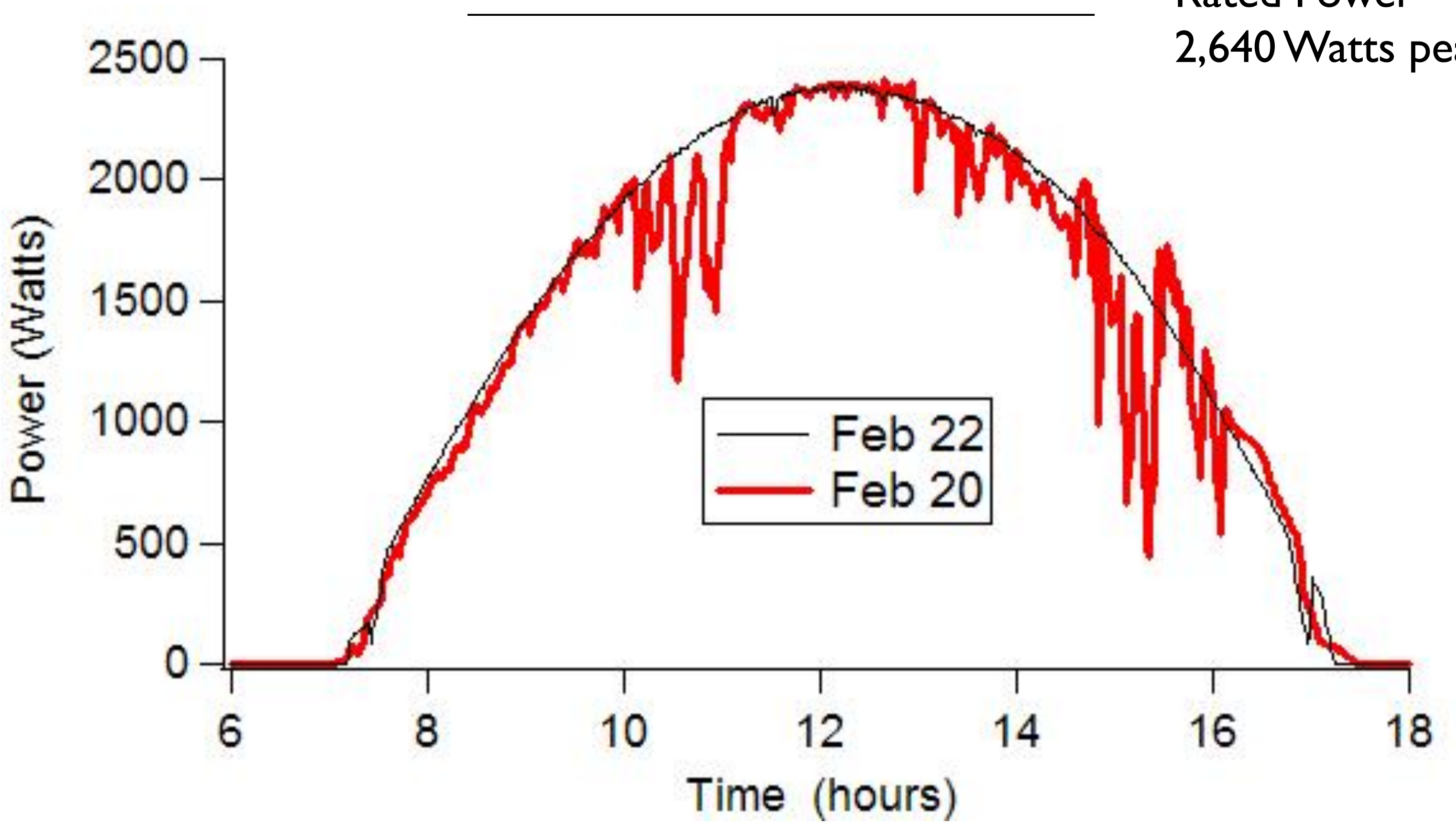
U.S. Primary Energy Production by Major Source (2008)



Source: Energy Information Administration, *Annual Energy Review 2008*, Table 1.2. (June 2009)

Solar has short-term intermittency due to weather

Rated Power
2,640 Watts peak



Data from TEP Test Yard – Alexander Cronin

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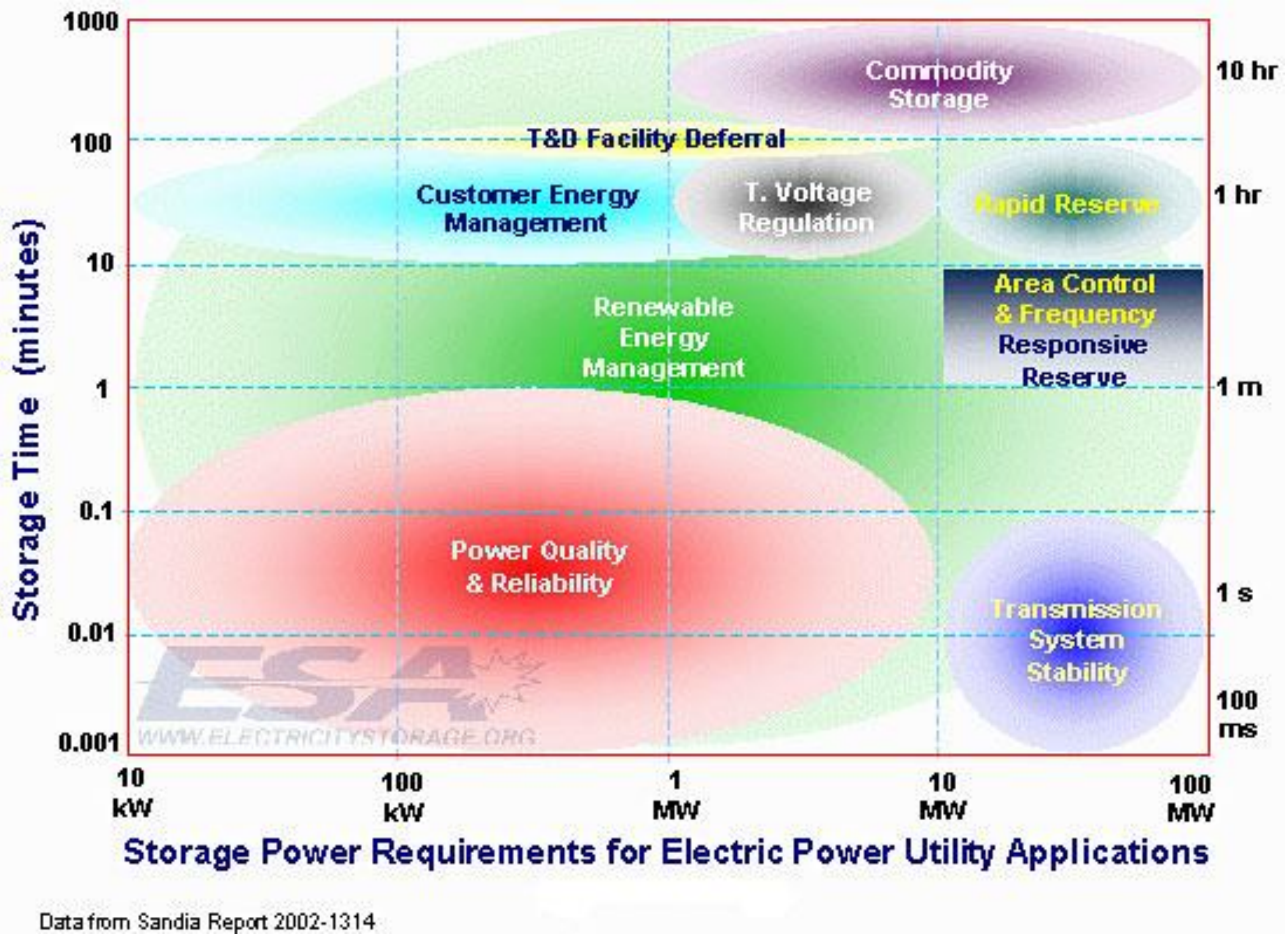


Energy Storage Technologies must be able to provide energy and power combinations

- Wholesale markets
- Upgrade deferral
- Retail markets
- Operating reserves

Benefits of Energy Storage

- Generation
  - Arbitrage
  - Renewable energy integration
- Delivery
  - Capacity upgrade deferral
- End Use
  - Renewable energy integration
  - Energy management
  - Backup power
  - Power quality

- Peak Demand Reductions
- Improved asset utilization
- Air emission reductions
- Improved reliability

Electricity network

A New Day: energy storage price & performance comparisons

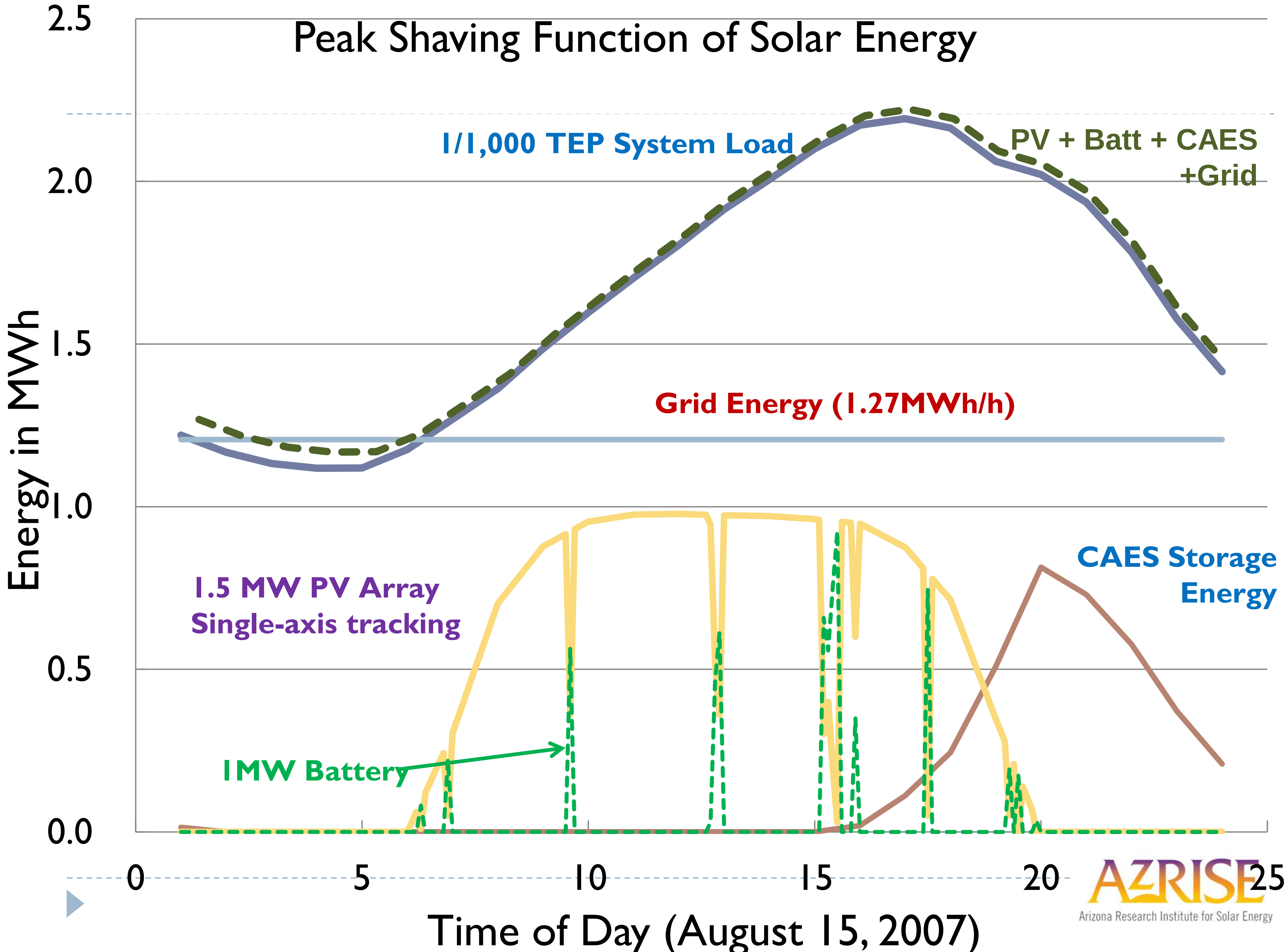
Storage Technologies Primarily for Energy (kWh) Applications

Technology	$/kWh	Rater Power (MW)	Efficiency	Lifetime	Discharge Time (hours)
Pumped Hydro	250 – 260	20 – 2,400	78 – 83%	11,000+	10
CAES	550 – 650	110 – 290	50 – 75%	11,000+	10
Flow batteries	500 – 1,000	0.05 – 8	65 – 80%	500+	8
NaS batteries	2,500 – 3,750	0.05 – 50	70 – 80%	3,000+	7
NiCad batteries	610 – 1,700	0.01 – 27	60 – 65%	1,000+	4

Storage Technologies Primarily for Power (kW) Applications

Technology	$/kW	Rater Power (MW)	Efficiency	Lifetime	Max Discharge Time (minutes)
NaS batteries	3,000 – 4,000	0.05 – 50	70 – 80%	3,000+	300
Li-Ion batteries	1,000 – 4,500	0.005 – 1	90 – 95%	20,000+	15
NiCad batteries	1,560 – 3,780	0.01 – 27	60 – 65%	1,000+	15
Lead acid	1,050 – 1,890	0.01 – 10	70 – 75%	250+	15
Flywheels	2,500 – 4,000	0.5 – 1	90 – 95%	500,000+	15
Super capacitors	N/A	0.003 – 0.01	90 – 98%	500,000+	seconds

Energy Insights An IDC Company



Peak Shaving Function of Solar Energy
2.5
2.0
1.5
1.0
0.5
0.0
Energy in MWh
1/1,000 TEP System Load
PV + Batt + CAES +Grid
Grid Energy (1.27MWh/h)
CAES Storage Energy
1.5 MW PV Array Single-axis tracking
1MW Battery
0
5
10
15
20
25
Time of Day (August 15, 2007)
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PV and CAES Model

PV capacity	1.5 MW
PV conversion efficiency	15%
CAES natural gas heat rate	4300 Btu/kWh
CAES storage capacity	3.5 MWh/1 MW
Roundtrip efficiency	80%
Hours of storage	3

(SOLON Single Axis – www.solon.com)

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PV/CAES Cost Estimates	$/kW	Total Cost
Storage system		
CAES Equipment	$750	$1,800,0000
1MW/ 250 kWh Battery	$2000	$2,000,000
Photovoltaic system		
Installed cost	$4000	$6,000,000
O & M	$6	$9,000
Natural Gas	$/MMBtu	$/kWh
Natural gas	$6	$0.0258
Total Capital Costs		
PV and CAES		$9,809,000
Federal ITC		$1,803,150
AZ State Rebates		$25,000
Total		$7,386,850

•*All costs are estimates derived from published reports*

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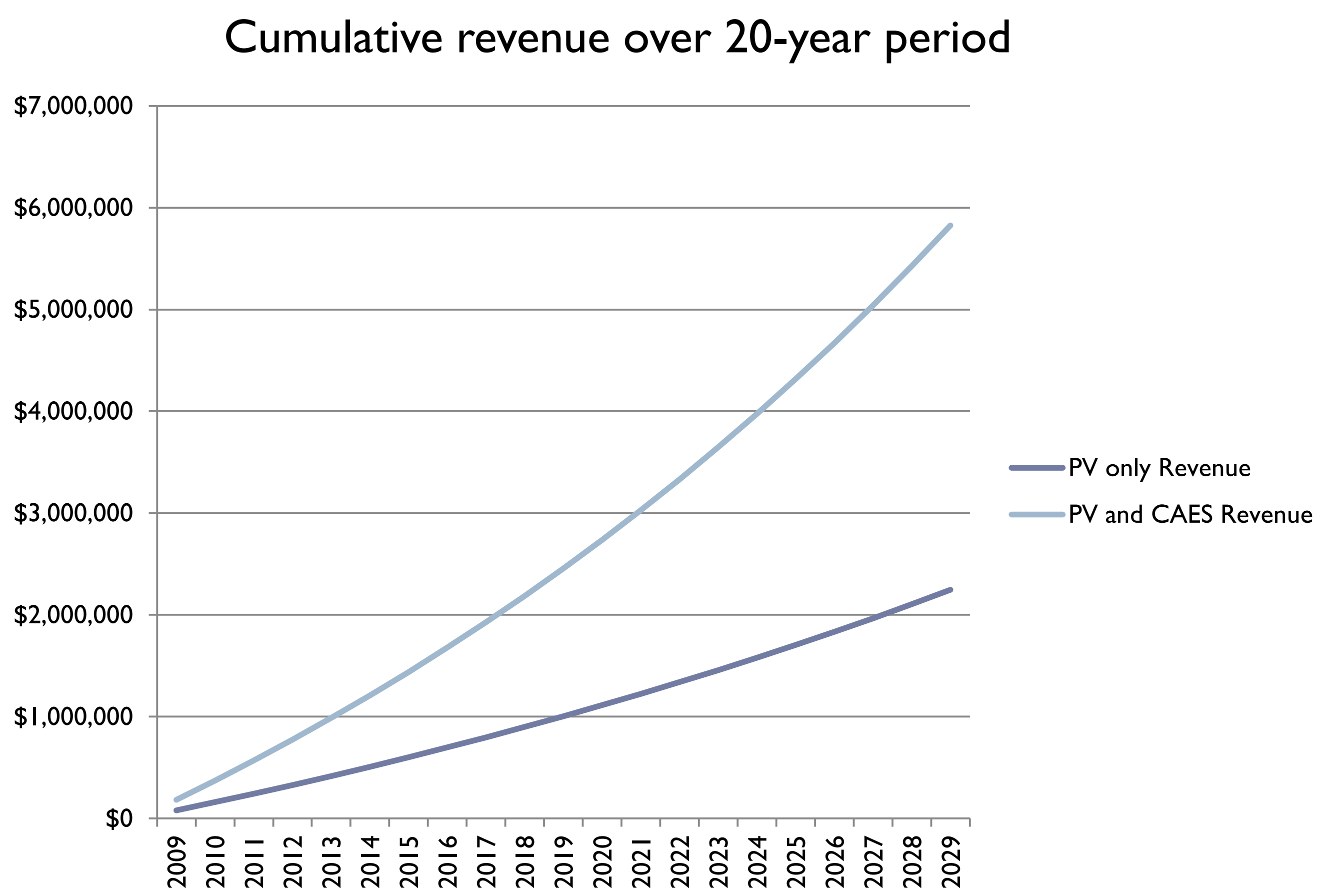
Energy Arbitrage Revenues



** Includes inflation rate for natural gas and discount rate of 9%*

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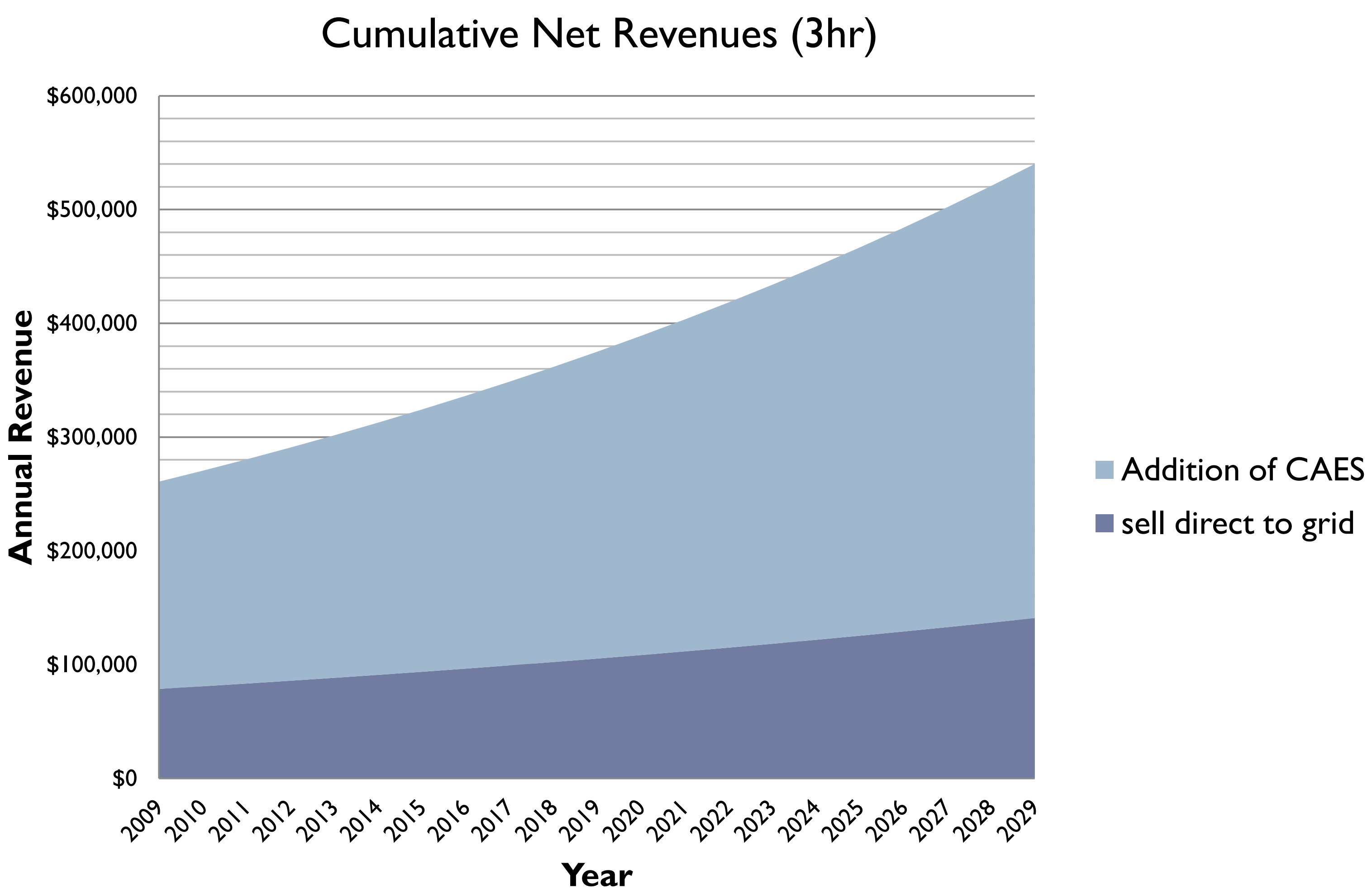
Energy Arbitrage Revenues



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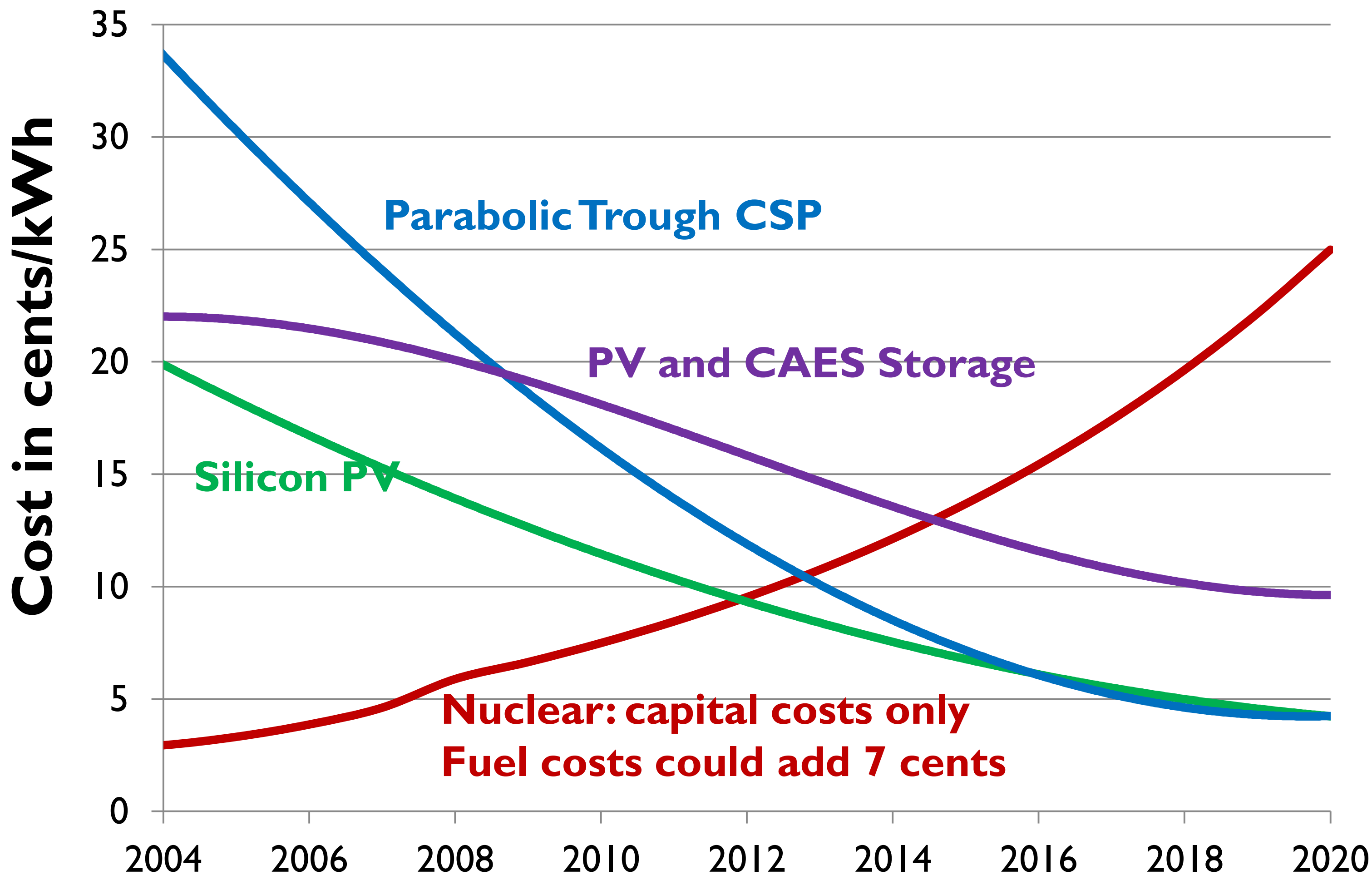
LCOE Projections



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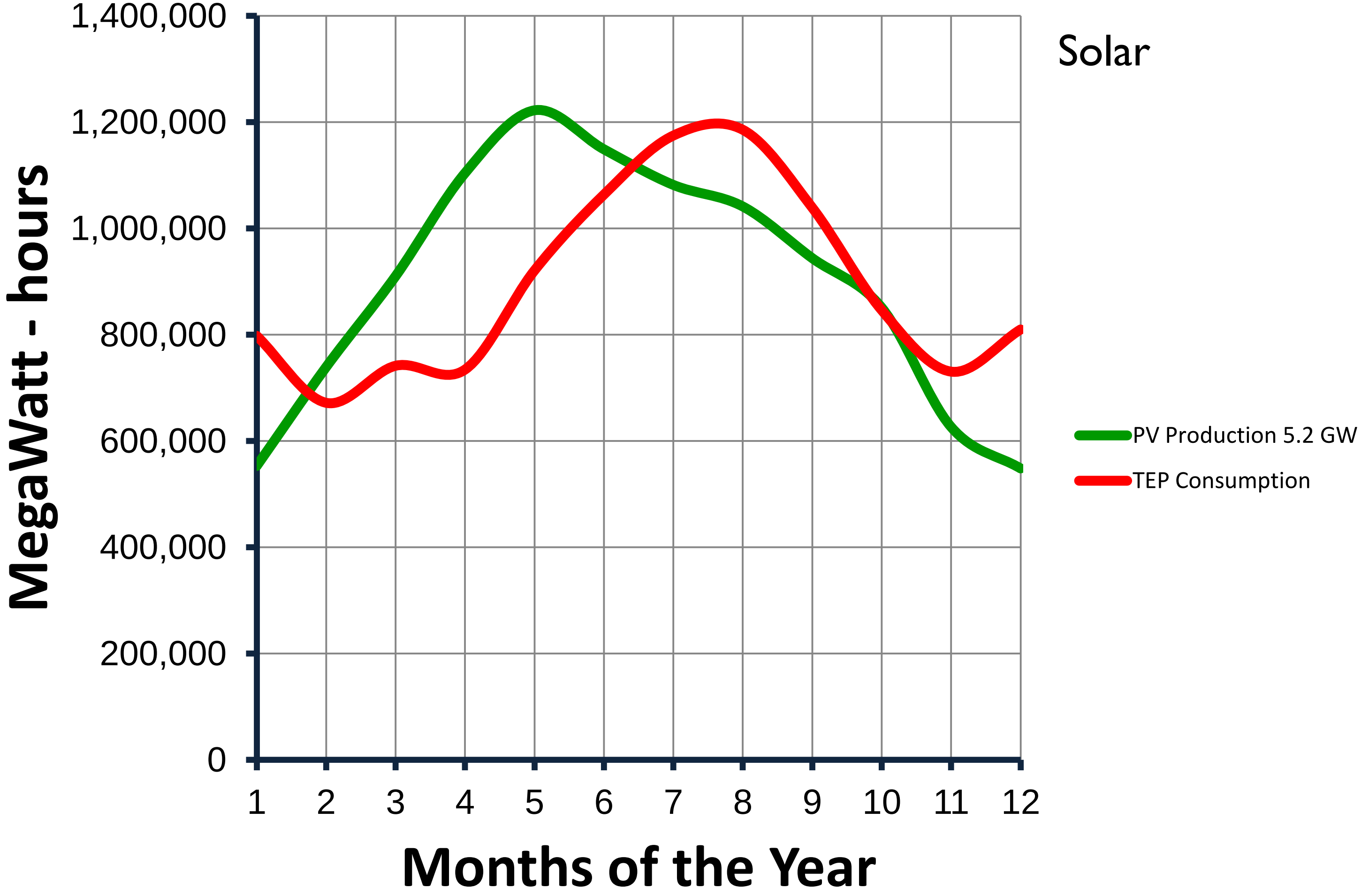
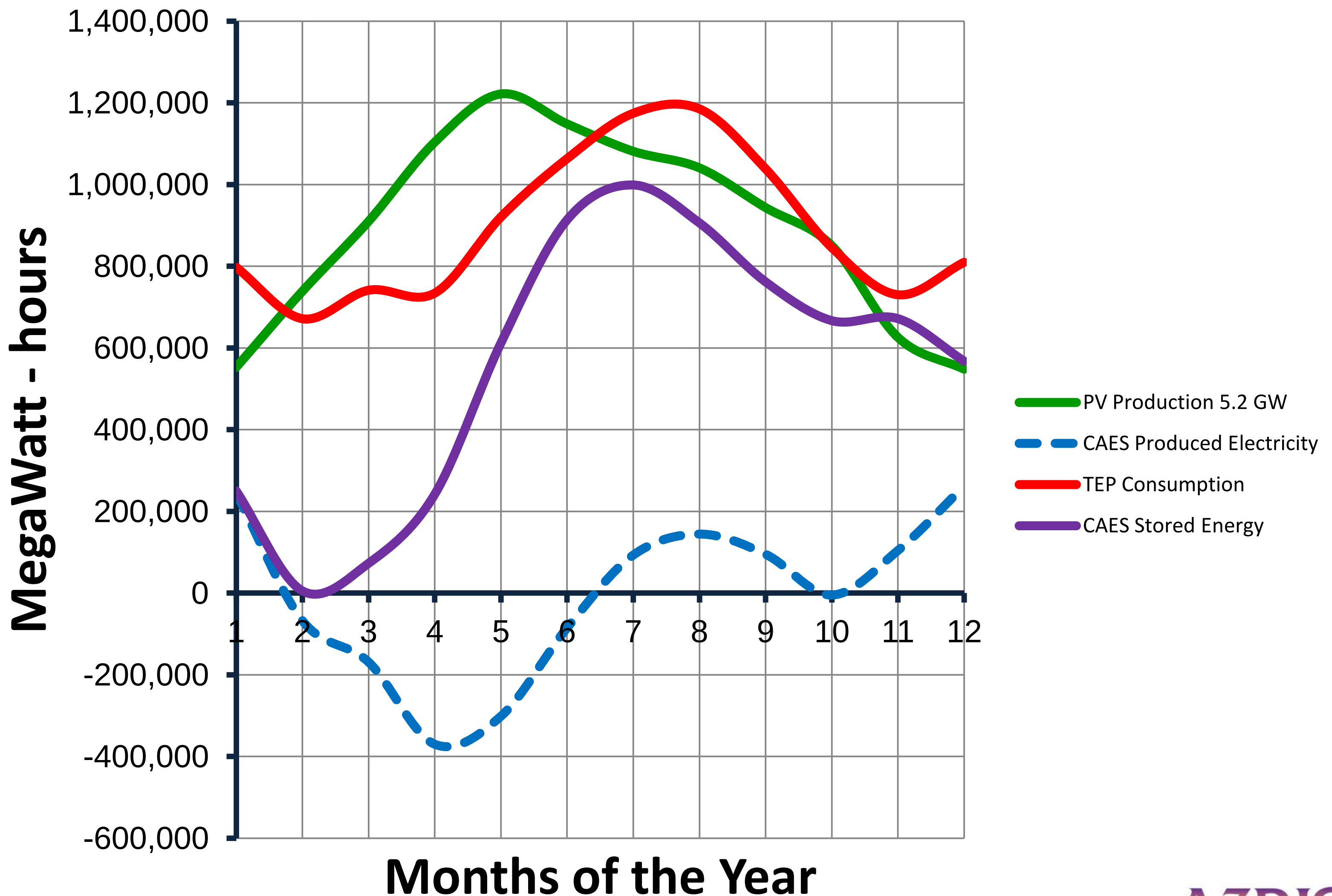
Seasonal Mismatch Between Demand and Production



Solar Base-load Utility Scale Capability



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Conclusions

- Energy storage technologies have no emissions with the exception of CAES.
- Constraints
  - Current technologies have demonstrated capabilities for limited storage
  - Cost is perceived as high
  - Need to develop long-term models to enable project financing
  - Lack of targeted credits
  - Cost recovery – valuing efficiency
  - Ownership uncertainties

Energy storage technologies enable renewable energy integration

- Goals
  - Reduce cost of deployment
  - Support R&D
  - Accelerate market entry
- Direct support
  - Current DOE Programs to fund R&D and deployment
  - Needs to receive direct R&D support (CCS)
    - Development of energy storage and renewable energy generation as a baseload generation option
  - Storage-integrated renewable energy needs to receive direct support
    - Production tax multiplier
    - Climate legislation needs to reflect storage technologies
    - Dedicated incentive for dispatchable renewable energy

Conclusions

- Solar energy technologies integrated with Energy Storage can match peak demand and base-load requirements
  - Experts agree with this and calculations show feasibility
  - Critical need is a demonstration facility that can give utilities technical and economic assessments of performance of various components.
- Cost of solar energy technologies, especially PV, is driven down by increased manufacturing capacity and open competition and will soon (2012) fall below the minimum capital cost of building a coal or nuclear power plant before they become operational.

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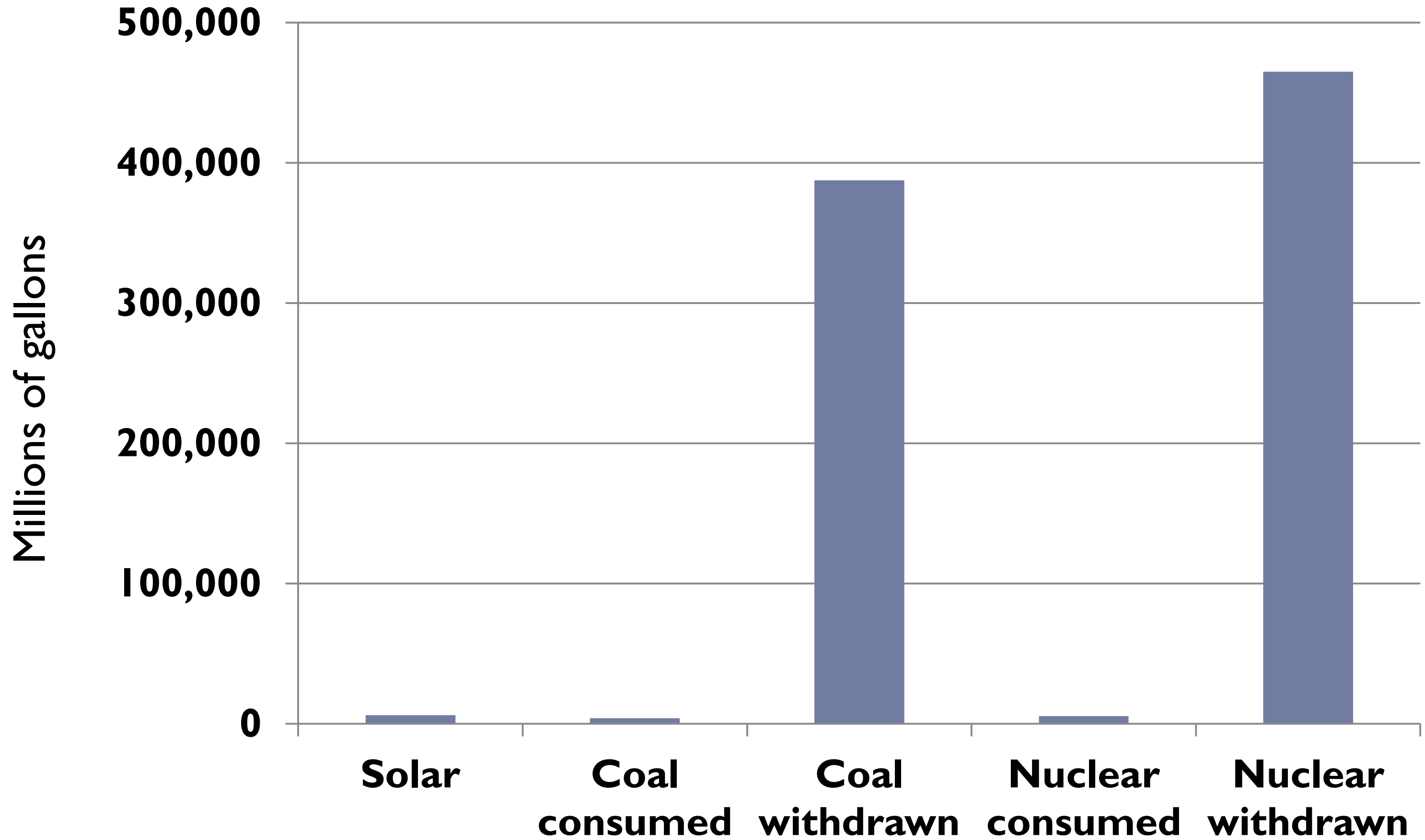
Comparison of water use by energy technology for the same energy production



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