NATIONAL ENERGY TECHNOLOGY LABORATORY

Role of Alternative Energy Sources: Solar Thermal Technology Assessment

Timothy J. Skone, P.E.
Senior Environmental Engineer
NETL Office of Strategic Energy Analysis and Planning
August 28, 2012

U.S. DEPARTMENT OF ENERGY

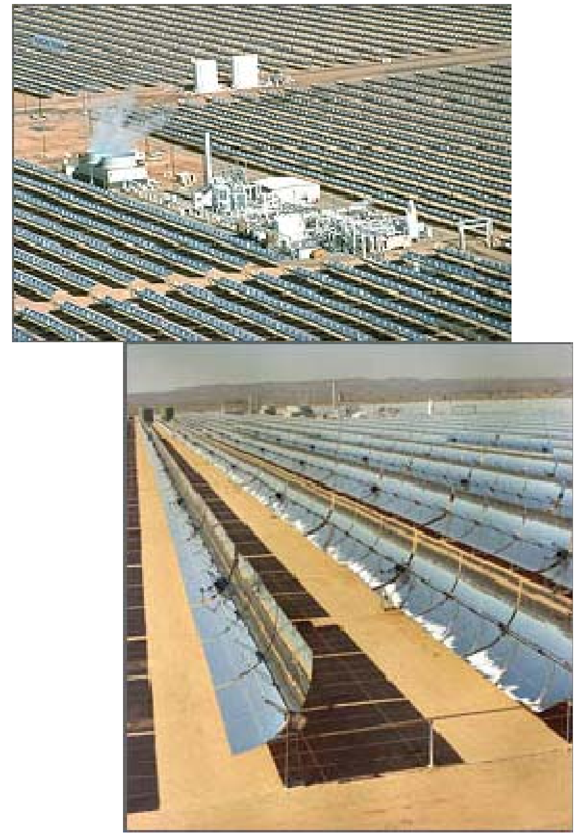
Agenda

- Technology Description
- Resource Base
- Growth of Solar Thermal
- Environmental Analysis
- Cost Analysis
- Barriers to Implementation
- Risks of Implementation
- Expert Opinions

Parabolic Trough Solar Field (NREL, 2011)

Technology Description: Solar Thermal

- **Parabolic Trough Solar Thermal**
  - Parabolic troughs track sun, concentrate incident light onto a centralized, tubular receiver that runs length of each trough
  - Thermal fluid circulates through all receivers in solar field
  - Thermal fluid brought to one or more centralized power production facilities
  - Heat transferred to a steam cycle, drives a steam turbine to generate power
  - Cooled thermal fluid is then recirculated through solar field
  - Wet cooling is common, dry cooling possible



Parabolic Trough Solar Thermal Power Plant and Solar Field (NREL, 2011)

Technology Description: Solar Thermal

- **Solar Thermal Power Tower**
  - Centralized collector situated on a tall tower
  - Field of heliostats (mirrors) reflect incident sunlight onto centralized tower
  - Heat transferred via thermal fluid (often molten salt, also various organics) to heat exchanger
  - Heat exchanger transfers heat to conventional steam cycle
  - Power generated via steam cycle at centralized plant
  - Cooled thermal fluid is cycled back through the collector
  - Wet cooling is common, dry cooling possible

Solar Thermal Power Tower (ANL, 2011; NREL, 2011)

Technology Description: Solar Thermal Performance Characteristics

- **Analysis focuses on parabolic trough systems**
  - Represent at least 75% of capacity of proposed installations in U.S.
  - Environmental & economic data limitations prevent accurate comparison between two primary types of solar thermal

- **Solar thermal plant in this analysis representative of parabolic trough technology; has a net capacity of 250 MW**

- **Plant requires 1,720 acres (2.7 square miles) of land area for solar field and generation block**

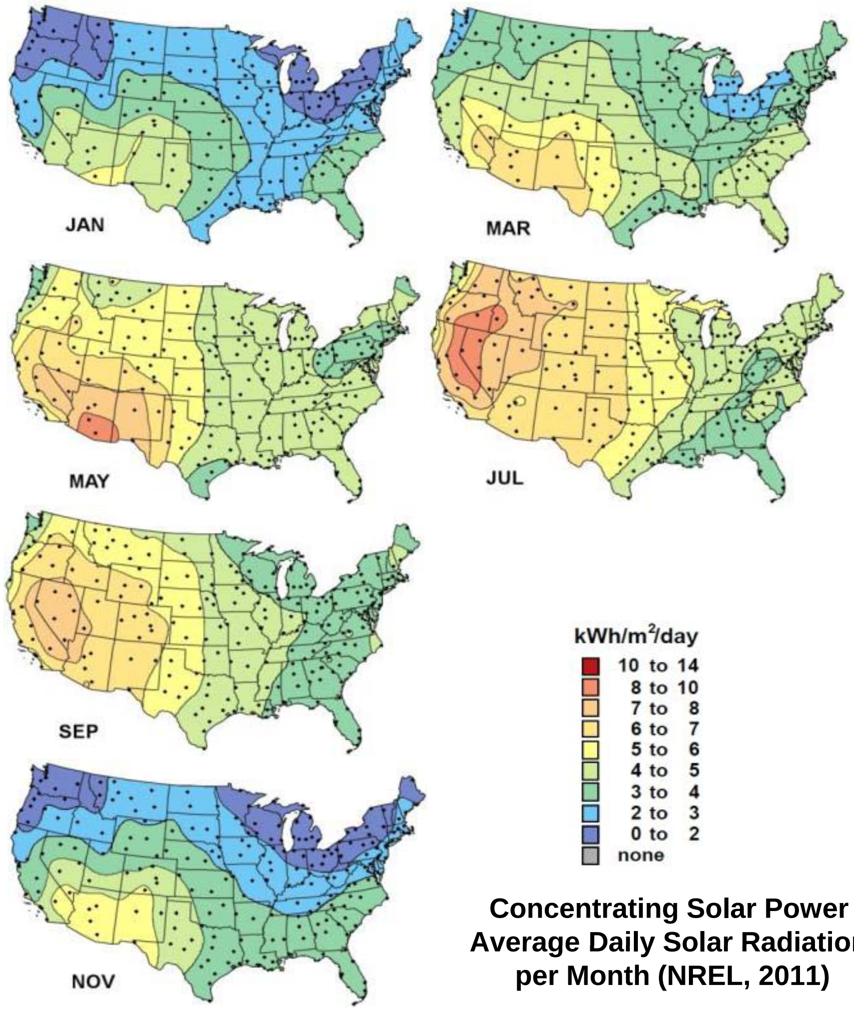
Parameter	Units	Expected Value	Reference
Plant Capacity	MW	250	Tidball et al., 2010
Capacity Factor	%	27.4%	Tidball et al., 2010
Capital (Solar Collectors & Power Plant)	2007$/kW	4,693	Tidball et al., 2010
Fixed O&M	2007$/MW-yr	56,780	Tidball et al., 2010
Construction Period	Years	2	BLM, 2010b
Plant Life	Years	30	BLM ,2010b

Resource, Capacity, and Growth

- **U.S. solar resources extensively studied by DOE, various universities, and government-university partnerships**
- **Deployment of solar thermal power across 1.5% of total land area in Southwest U.S. could:**
  - Generate 4 million GWh annually
  - Sufficient to meet entire U.S. demand (DOE, 2009)
- **Available solar thermal resources:**
  - Located in areas with sufficient incident solar energy (insolation)
  - Close proximity to grid tie-in to make grid connection economically feasible
- **Solar thermal resource availability differs from solar photovoltaic (PV) resource availability**
  - PV remains operable under scattered light (high humidity, light cloud cover)
  - Solar thermal requires direct sunlight in order for concentrating solar collectors to function

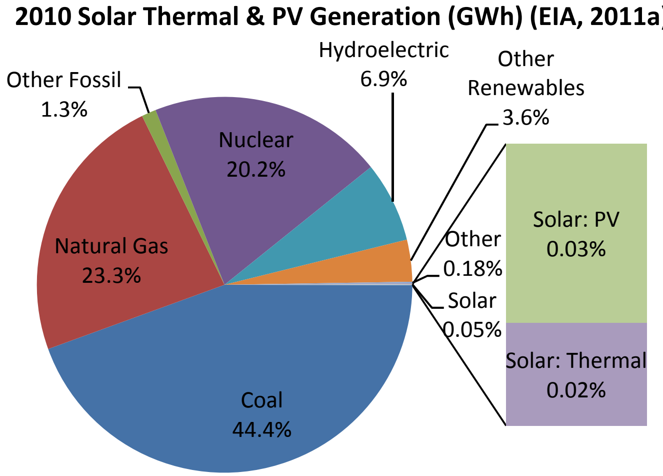
Resource, Capacity, and Growth

- **Resource availability varies spatially and temporally**
  - U.S. desert southwest has best overall resource
  - Temporal variation – seasonal, daily, hourly, subject to weather
  - Insolation reduced substantially during winter
  - Light scattering – strongly sensitive to cloud cover and haze; direct light needed
- **Annual average insolation ranges from 1-7 kWh/m²/d**
- **Peak local values can reach 10-14 kWh/m²/d on a seasonal basis**



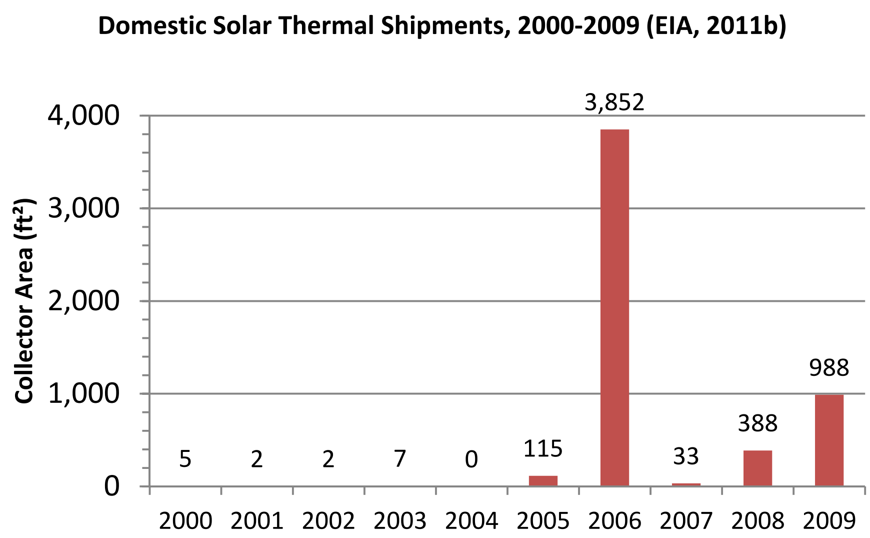
Concentrating Solar Power Average Daily Solar Radiation per Month (NREL, 2011)

Resource, Capacity, and Growth



- Fraction of U.S. power generation from solar (thermal plus PV) is approximately 0.05% in 2010
- Of that 0.05%, approximately 64% was PV, while the remaining 36% (744 GWh) was solar thermal
- No new solar thermal capacity installed in U.S. from 1990 to 2006

- 64 MW online in 2007 (Nevada Solar One), and 75 MW online in 2010 (Martin Next Generation Solar Energy Center, FL)
- Near term (through approx. 2016) proliferation of solar thermal projects anticipated:
  - 6,363 MW of anticipated solar thermal projects with high likelihood of implementation
  - At least 2,000 MW of additional proposed projects



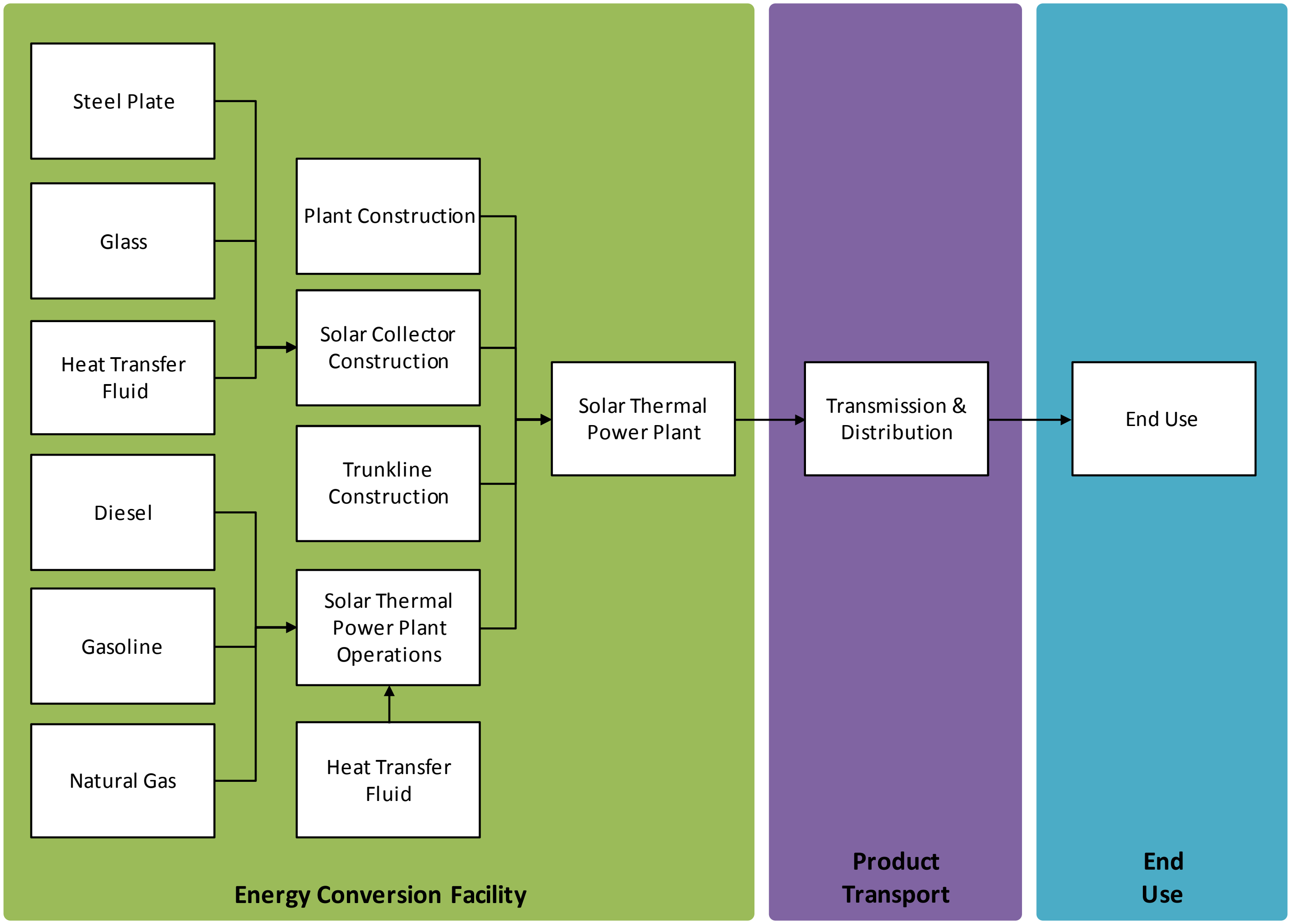
Environmental Analysis of Solar Thermal

- **Life Cycle Analysis (LCA) completed for Solar Thermal Power**
  - Screening level analysis involved select data development for solar thermal power construction and operation, plus reliance on similar/proxy data for specific components (i.e., switchyard and trunkline construction and operation)

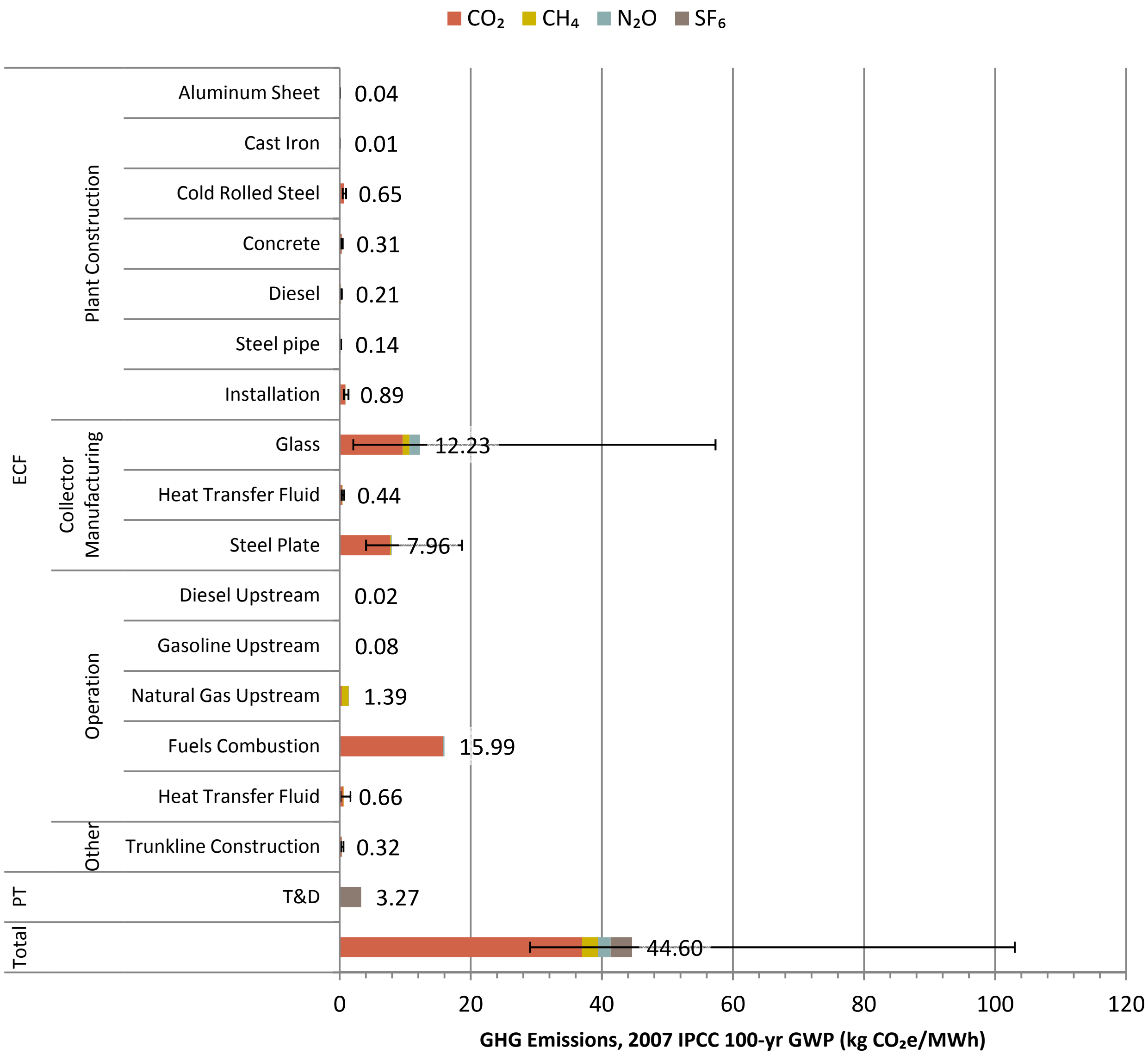
- **Model broken into life cycle stages:**
  - Stage 1 & 2: Raw Material Acquisition and Transport (not relevant to solar thermal power)
  - Stage 3: Energy Conversion – construction and operation of power plant, including solar collector plates, heat transfer fluid, balance of plant, fossil fuel combustion, etc.; output is electricity ready for transmission
  - Stage 4: Transmission and Distribution – grid transmission and association loss (7 %)
  - Stage 5: Electricity use by consumer – no losses or environmental burdens

- **Model comprised of interconnected network of modeled processes (unit processes)**

Environmental Analysis of Solar Thermal: LCA Modeling Structure

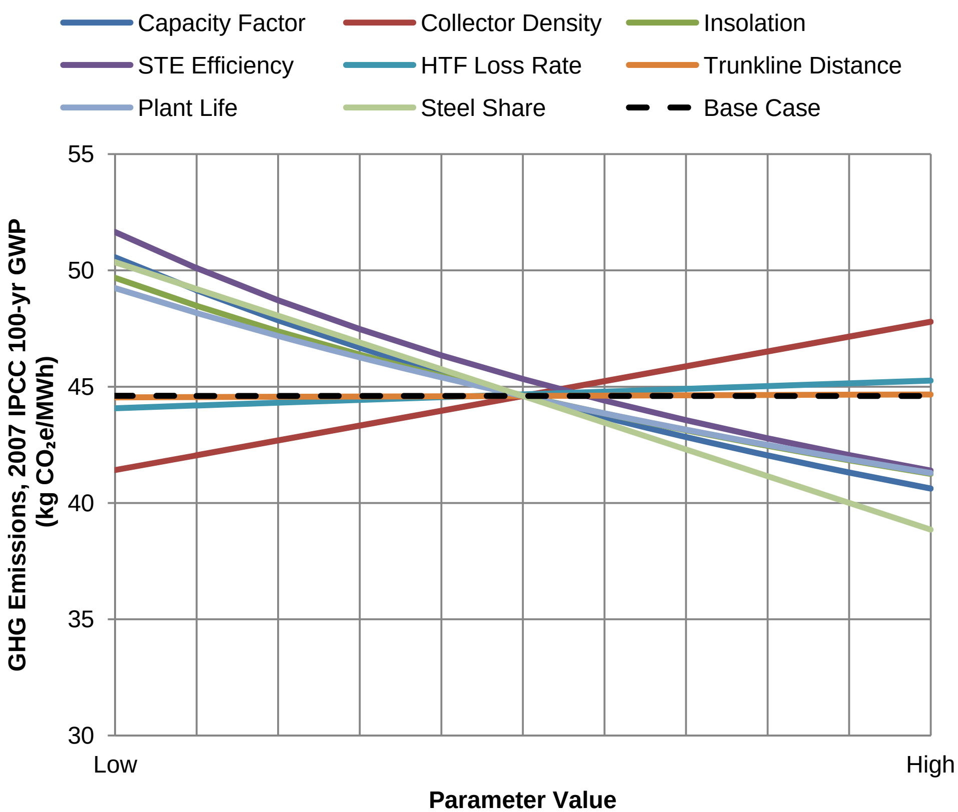


Environmental Analysis: GHG Results for Solar Thermal



- GHG emissions dominated by CO_2 emissions (83% of total GHG emissions) during collector manufacturing & plant operation
- Emissions from land use add an additional 4.4 kg CO_2e/MWh
- Solar collector manufacturing is 48% of life cycle GHG emissions
- Operation is 38% of life cycle GHG emissions

Environmental Analysis: Sensitivity/Uncertainty



Parameter	Units	Low Value	Expected Value	High Value
Capacity Factor	%	21.9	27.4	32.9
Collector Density	kg/m^2	24	28.5	33
Insolation	MW/m^2	2.69E-04	3.36E-04	4.03E-04
Efficiency	%	10.6	14.3	17.0
Heat Transfer Fluid Loss Rate	%	1	5	10
Trunkline Distance	km	32.2	40.2	48.2
Plant Life	Years	25	30	35
Collector Steel %	%	60	75	90

- Nominal base case result of 44.6 kg CO_2e/MWh is shown for reference (dashed line)
- Possible range of GHG results for solar thermal power: 38.9 to 51.7 kg CO_2e/MWh depending on value of indicated parameters

- Most sensitive parameters are solar to electric efficiency, intensity of solar radiation, capacity factor, and steel share of solar collector materials
- Parameters that affect power output are more sensitive than those related to construction alone

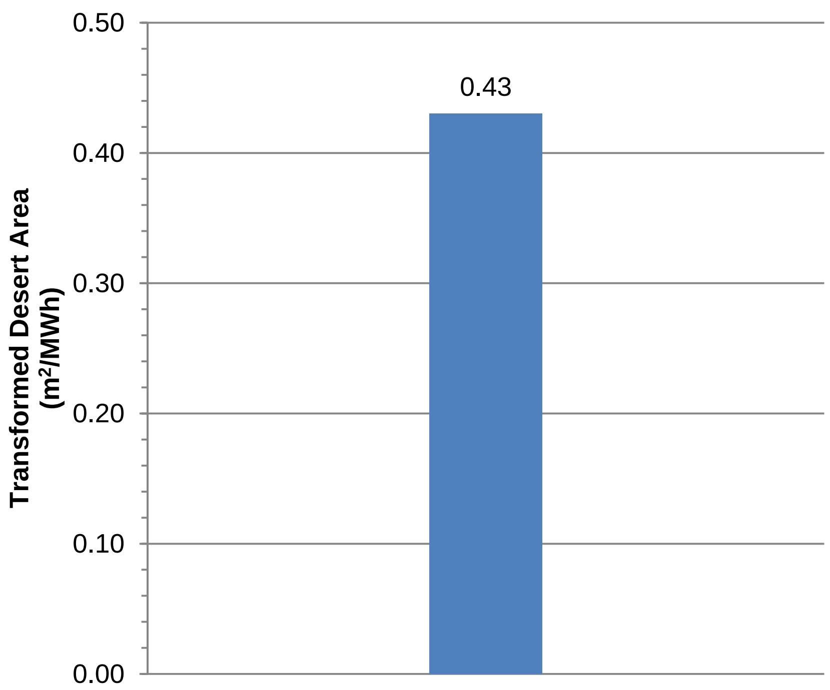
Environmental Analysis: Land Use

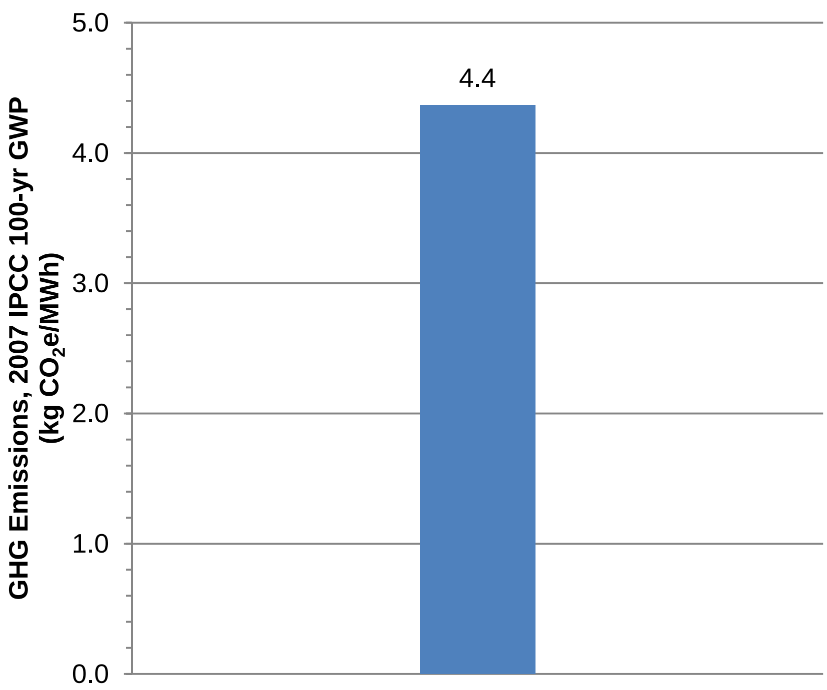
- **Transformed Land Area - Facility sizes**
  - Data from U.S. Bureau of Land Management EIS for Genesis Solar Energy Project in southwestern CA (BLM, 2010b)
  - Solar field, central generation block, roads = 1,746 acres @ 250 MW
  - Transmission lines require 9.3 acres @ 250 MW facility

- **Direct GHG Emissions**
  - BLM EIS (BLM, 2010b) included estimate of land use GHG emissions based on loss of on-site vegetation and lost sequestration.
  - Existing land use types apportioned based on land use data available from USDA, for U.S. desert southwest

- **Indirect GHG Emissions**
  - Indirect GHG emissions quantified only for displacement of agriculture (not for other uses)
  - Assumes 30% of lost agriculture indirectly converted from existing use to new agriculture
  - Emissions calculated based on EPA's GHG emission factors for land use conversion

Environmental Analysis: Land Use Results





- Solar field and generation block make up 98% of total transformed land area, with roads and transmission line making up the remaining 2%
- The primary existing land types are dominated by grassland, dry pasture, and desert scrub (considered together as grassland with no existing agricultural land use

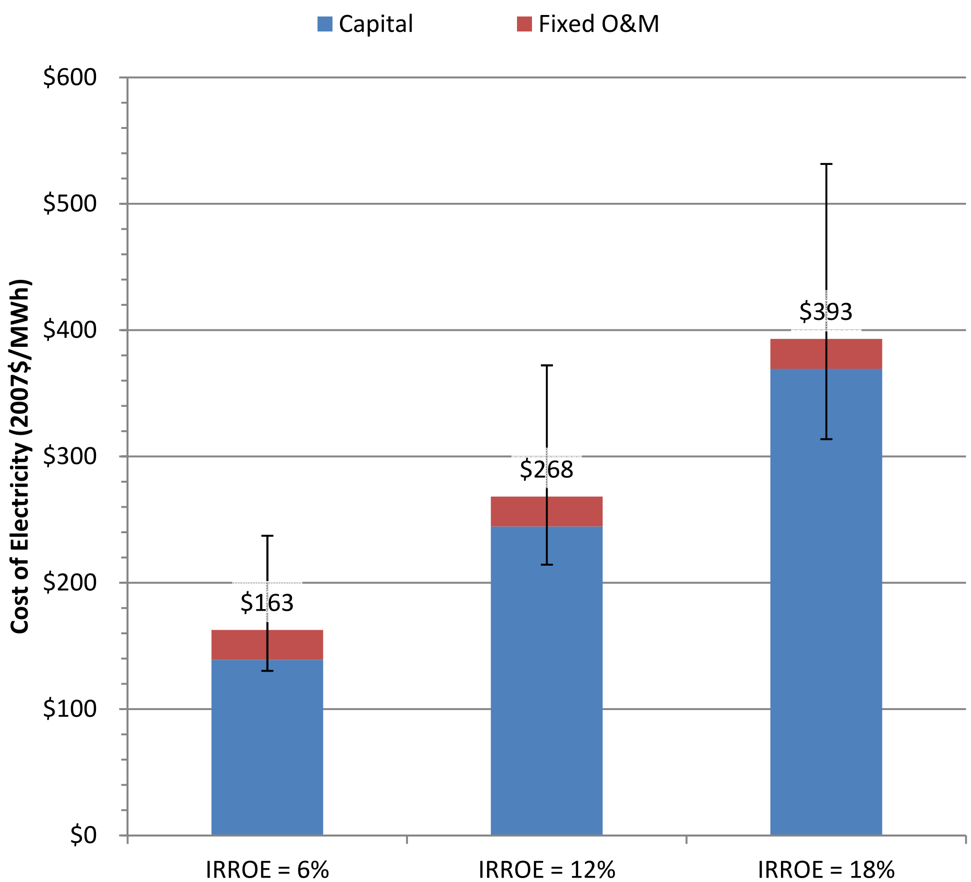
- Indirect land use GHG emissions are minor due to minimal proportion of agricultural use within the facility's disturbance area
- Direct land use GHG emissions result primarily from loss of desert scrub and dry pasture, per BLM (2010b)

Cost Analysis: Financial and Cost Parameters

Financial Parameter	Low Cost Case	Expected Value Cost Case	High Cost Case
Financial Structure Type	Low-risk Investor-owned Utility with Low Return on Equity	Low-risk Investor-owned Utility	Low-risk Investor-owned Utility with High Return on Equity
Debt Fraction (1 - equity), %		50%	
Interest Rate, %		4.5%	
Debt Term, Years		15	
Plant Life, Years	30	30	25
Depreciation Period (MACRS)		20	
Tax Rate, %		38%	
O&M Escalation Rate, %		3%	
Capital Cost Escalation During the Capital Expenditure Period, %		3.6%	
Base Year		2007	
Required Internal Rate of Return on Equity (IRROE)	6.0%	12.0%	18.0%

Cost Parameter	Units	Low Cost Case	Expected Value Cost Case	High Cost Case
Capital (Solar Collectors and Power Plant)	2007$/kW	4,500	4,693	5,000
Capital (Trunkline)	2007$/kW	72.9	91.2	109
Decommissioning	2007$/kW	457	478	511
Fixed O&M (Annual)	2007$/MW-yr		56,780	
Plant Life	Years	30	30	25
Net Plant Capacity	MW net		250	
Capacity Factor	%	32.9%	27.4%	21.9%

Cost Analysis: LCC Results for Solar Thermal



- Solar thermal power does not require purchase of fuel, so O&M costs are low relative to power technologies that use fossil fuel or other non-renewable energy sources
- Capital costs make up 91.2% of COE for nominal case
- Cost characteristics are site specific, which contributes to uncertainty in COE
- Uncertainty in COE for solar thermal power includes ranges in capital costs, plant lifetimes, O&M costs, and capacity factors
- For 12% IRROE, uncertainty results in a COE range of $214.4 to $372.1/MWh

Barriers to Implementation

- **Cost**
  - Collector cost can vary, with reported ranges from $25 to $55 per square foot of collector surface area
  - 1 GW of capacity can require more than 10 square miles of solar fields
  - High capital costs translate to high debt servicing costs, or demand for significant investor capital
  - Work-arounds include partnerships between solar thermal development firms and large engineering/construction corporations, which can finance solar thermal projects in exchange for a portion of profits

- **Water use and consumption**
  - Can be a constraining factor in desert areas – Blythe project (1GW) would require 4,100 acre-feet of water for construction, plus an additional 600 acre-feet per year during operation (BLM, 2010a)

- **Grid Connection**
  - Best resources are located distant from existing population centers and power transmission lines
  - New transmission lines are expensive and difficult to permit

Risks of Implementation

- **Habitat loss/biological resources loss**
  - Habitat/biological resources loss can be substantial.
    - 1,000 MW Blythe Solar Power Project (recently approved) would disturb ~11 square miles (BLM, 2010a)
  - Loss of vegetation, habitat for listed species such as desert tortoise
- **Water resources consumption**
  - Water consumption associated with cooling cycle, also mirror washing, dust control, and construction activities
  - Operational water consumption in line with other technologies that use cooling towers
  - Water resources severely limited in desert
    - Drawdown of groundwater,
    - Possible interference with surface flows
- **Aesthetic concerns**
  - Installations can be very large, alter existing visual character of natural/remote areas
  - Select corridors (such as the Interstate 10 corridor in southeastern CA) are receiving multiple applications in close proximity

Expert Opinions

- **Significant market ramp-up during 2011-2012, largely based on the long term extension of federal solar tax investment credit (ITC), and deadline to initiate project construction by the end of 2011**
  - Many new projects anticipated operational during 2012-2014 (IREC, 2011)
  - Government “fast-track” programs provide expedited permitting (without slackened environmental compliance) (SEIA, 2011)
- **Fossil/solar thermal hybrid facilities are being reviewed and permitted; at least 2 plants in CA**
  - Biomass/solar thermal hybrids proposed in 2008, but no longer moving forward (GTM Research, 2009)
- **Uncertain market future may follow near term ramp up**
  - Near term buoyed by ITC
  - After ITC: Will manufacturing costs drop enough to support a self-sustaining market?
  - Some estimates predict that by 2015, solar thermal per kWh production costs could drop to $0.05/kWh (ENN, 2008), but accuracy of this is questionable

References

BLM. (2010a). Plan Amendment/Final EIS for the Blythe Solar Power Project. U.S. Bureau of Land Management

BLM. (2010b). Plan Amendment/Final EIS for the Genesis Solar Energy Project. U.S. Bureau of Land Management

DOE. (2009). Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation. U.S. Department of Energy Retrieved October 19, 2011, from http://www1.eere.energy.gov/solar/pdfs/csp_water_study.pdf

EIA. (2011a). September 2011 Monthly Energy Review. U.S. Energy Information Administration Retrieved October 24, 2011, from http://205.254.135.24/totalenergy/data/monthly/pdf/mer.pdf

EIA. (2011b). Solar Thermal Collector Manufacturing Activities 2009. U.S. Energy Information Administration Retrieved October 20, 2011, from http://205.254.135.24/cneaf/solar.renewables/page/solarreport/solar.html

Environmental News Network. (2008). Utility Scale Solar Thermal Growing Fast Retrieved October 21, 2011, 2011, from http://www.enn.com/sci-tech/article/37486

GTM Research. (2009). Emerging Trends in the U.S. Solar Market. Retrieved October 21, 2011, from http://www.greentechmedia.com/content/images/resources/resource_center/Emerging-Trends-in-the-US-Solar-Market.pdf

IREC. (2011). U.S. Solar Market Trends 2010. Interstate Renewable Energy Council Retrieved October 21, 2011, from http://www.greentechmedia.com/content/images/resources/resource_center/Emerging-Trends-in-the-US-Solar-Market.pdf

NREL. (2011). U.S. Solar Radiation Resource Maps: Atlas for the Solar Radiation Data Manual for Flat Plate and Concentrating Collectors. National Renewable Energy Laboratory Retrieved October 20, 2011, from http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/

SEIA. (2011). Utility-Scale Solar Power of Federal Lands. Solar Energy Industries Association Retrieved October 21, 2011, from http://www.seia.org/galleries/FactSheets/factsheet_BLM_permitting.pdf

Contact Information

Office of Fossil Energy

www.fe.doe.gov

NETL

www.netl.doe.gov

Timothy J. Skone, P.E.
Senior Environmental Engineer
Office of Strategic Energy
Analysis and Planning
(412) 386-4495
timothy.skone@netl.doe.gov

Robert James, Ph.D.
General Engineer
Office of Strategic Energy
Analysis and Planning
(304) 285-4309
robert.james@netl.doe.gov

Joe Marriott, Ph.D.
Lead Associate
Booz Allen Hamilton
(412) 386-7557
joseph.marriott@contr.netl.doe.gov

James Littlefield
Associate
Booz Allen Hamilton
(412) 386-7560
James.littlefield@contr.netl.doe.gov