THE GEORGE WASHINGTON UNIVERSITY

SCHOOL OF ENGINEERING AND APPLIED SCIENCE

Determination of Solar Energy Transition Potential of Department of Defense (DoD) Facilities and Non-Tactical Vehicles

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Evolution of Energy/National Security Public Research

Oil shocks
- **Discussions relating to national security**

Fears subside
- **Little public research conducted – less on electric grid energy issues**

1970s

1980s

1990s

2000s

Tuesday, September 11, 2001

Post 9/11 research

Publications / research post 9/11:

- **Mostly strategic => more concentration on oil versus electric, however, more electric grid related research is being pursued**
- **Government has been most prominent source of publications that relate to DoD bases, although research does not offer an operational plan, models or public data => critical infrastructure data is typically all considered classified**
- **Pentagon, DoD, DHS, CRS and BRAC reports, former CIA Director (Woolsey) articles, Brookings Institute, RAND, etc.**
- **Industry awaiting major policy before investing**

Significance/Benefits of Research

Societal

1. **Saving military lives**
2. **Protecting critical infrastructure from our adversaries**
   - **China electronic warfare**
3. **Reducing fossil energy consumption**
4. **Improving environmental quality**
5. **Promoting a new renewable energy industry – growth in new technical discipline (integrates DoD & energy)**

Academic

1. **New area which integrates national security and environmental disciplines**
2. **Baseline data for future academic research is being developed as part of research**
   - **Little to no public source data exists – mostly classified**
3. **Analysis of data in the development of a decision model – envision an operational implementation plan across DoD bases**

Project Overview

- **Sponsor: GW Solar Institute**
- **Research period: 2009 – 2010**
- **Research phases:**
  1. **Energy and emissions analyses**
  2. **Benefits analyses**
  3. **Model development**

Facilities

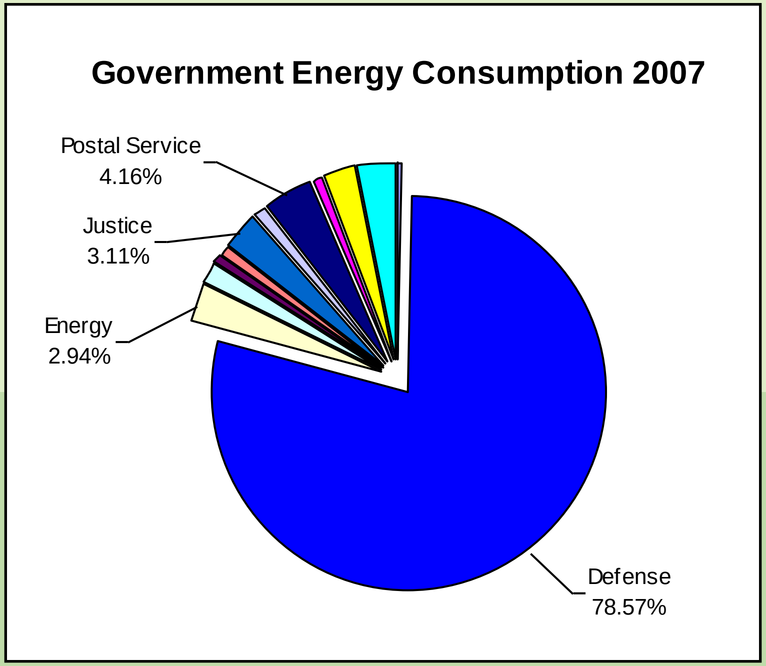
Wright Patterson AFB

Fort Belvoir

Non-Tactical Vehicles

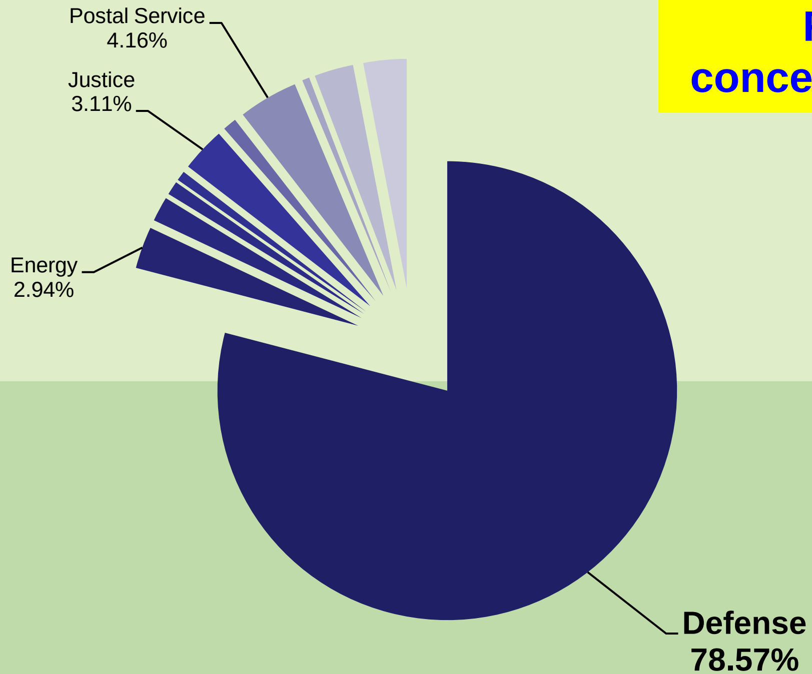
DoD Energy Consumption Overview

- **Largest energy consumer in the government and Nation**
- **Consumes 78% of total Federal energy usage**
- **Over 96% of energy consumption from fossil fuels**
- **577,500 facilities and 190,000 non-tactical vehicles**
- **$3.4 billion in annual facility energy consumption**
- **$250 million in annual non-tactical vehicle energy consumption**



Department of Defense (DoD)
Energy Overview

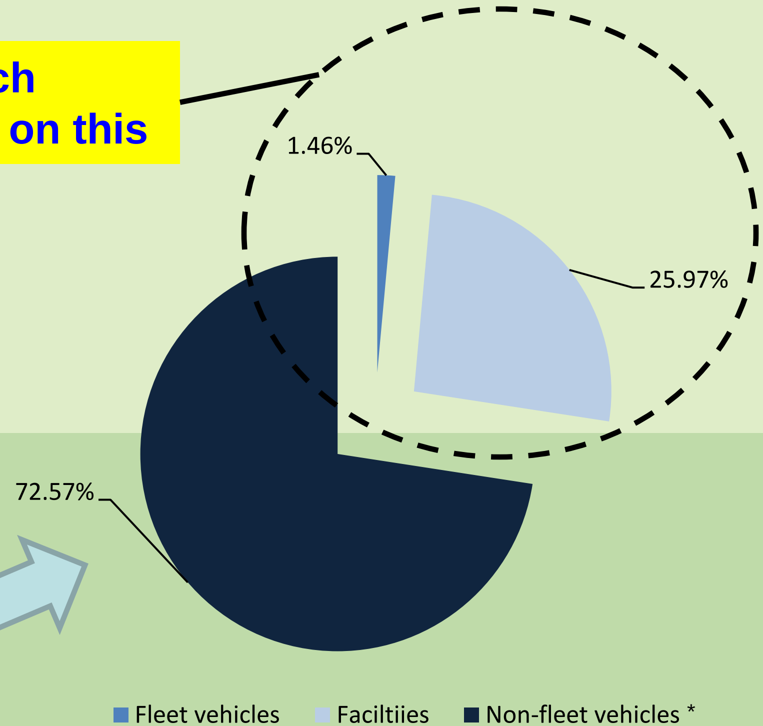
2007 Government Energy Consumption



Source: Energy Information Administration (EIA)

2007 DoD Energy Consumption

Research concentrates on this



Source: DoD Energy Management Data Report, 2007

**** Non-fleet vehicle consumption is fuel for operational forces.***

Research Phases

1. **Energy and Emissions Analyses**
2. **Benefits Analyses**
3. **Model Development**

Current Research Overview

1. DoD Energy and Emissions Research Analyses
   - High level DoD and Services facilities energy and emissions analyses
   - High level DoD and Services vehicles energy and emissions analyses

Deputy Under Secretary of Defense I&E

- Responsible for implementing goals of EPAct 2005 and EO 13423 in regards to facilities and non-tactical vehicles

Dept of the Army

Dept of the Navy

Dept of the Air Force

Marine Corps

GW Engineering

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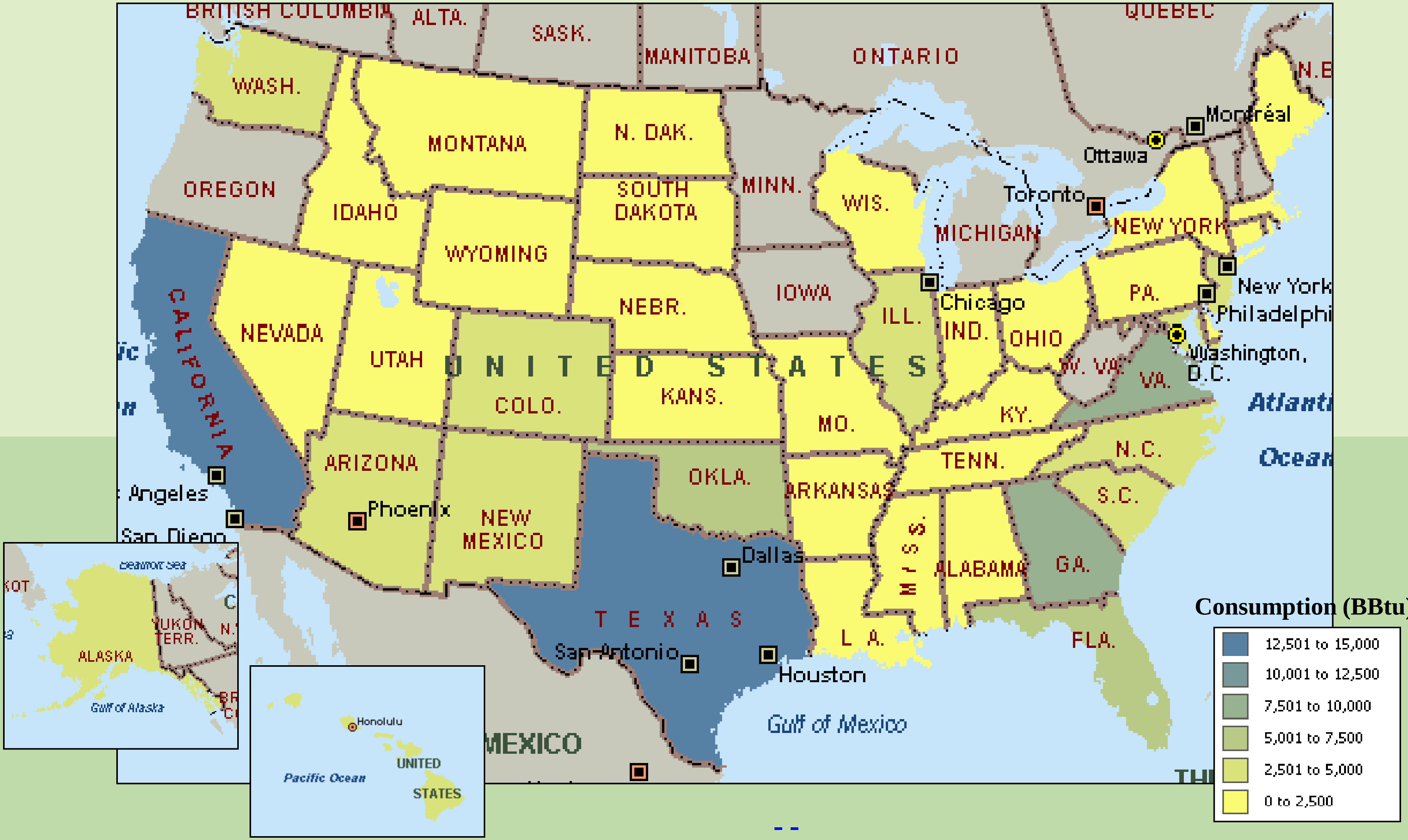
Preliminary Facility DoD Energy Consumption Analysis



Phase 2: Benefits Analyses Overview

- **Meeting Federally Mandated Policies**
- **Improving Mission Readiness**
  - **CO_2 Emission Reduction Benefits**
  - **Foreign Oil Reduction Benefits**
  - **Facility Fossil Energy Reduction Benefits**
    - **Base Level Mission Need**

Phase 2: Benefits Analyses

Meeting Federally Mandated Policies

- **Energy Policy Act of 2005 (EPAct 2005)**
  - Reduction targets: 2% reduction per year starting in FY06 and ending in FY15
  - Renewable energy goals: (1) not less than 3% from FY07 to FY09, (2) not less than 5% from FY10 to FY12, and (3) not less than 7.5% from FY13 and thereafter
- **Executive Order (EO) 13423**
  - Reduction targets: 3% annually through FY15
- **EO 13514**
  - Set a 2020 GHG reduction target within 90 days
  - 30% reduction in vehicle fleet petroleum use by 2020

Phase 2: Benefits Analyses

CO_2 Emissions Reduction Benefits

- ***National Security and the Threat of Climate Change*, 2007, CNA report**
  - "climate change trends pose grave implications for national security that will affect the organization, training, equipping, and planning of the military mission"
- ***Powering America's Defense*, 2009, CNA report**
  - "destabilization driven by ongoing climate change has the potential to add significantly to the mission burden of the US military in fragile regions of the world"
  - "climate change is about instability. It is a destabilizing activity, with murderous consequences."

Phase 2: Benefits Analyses

Foreign Oil Reduction Benefits

- **Reductions in foreign oil expenditures to Sunni fundamentalist Islamic movements and Wahhabis**
  - **US pays $3 to $4 billion to Wahhabism a year**
- **Saudi donors and charities linked to al Qaeda**
  - **CIA estimates $30 million per year for al Qaeda to sustain their capabilities**
  - **9/11 attacks are as little as $400,000 to $500,000**
    - **Equitable to roughly 7,500 Americans filling up their SUVs at $3.00 per gallon of gasoline with 22.5 gallon fuel capacity**
  - **Decade before 2002, al Qaeda and other jihadist organizations raised between $300 to $500 million through Saudi charities**

Phase 2: Benefits Analyses

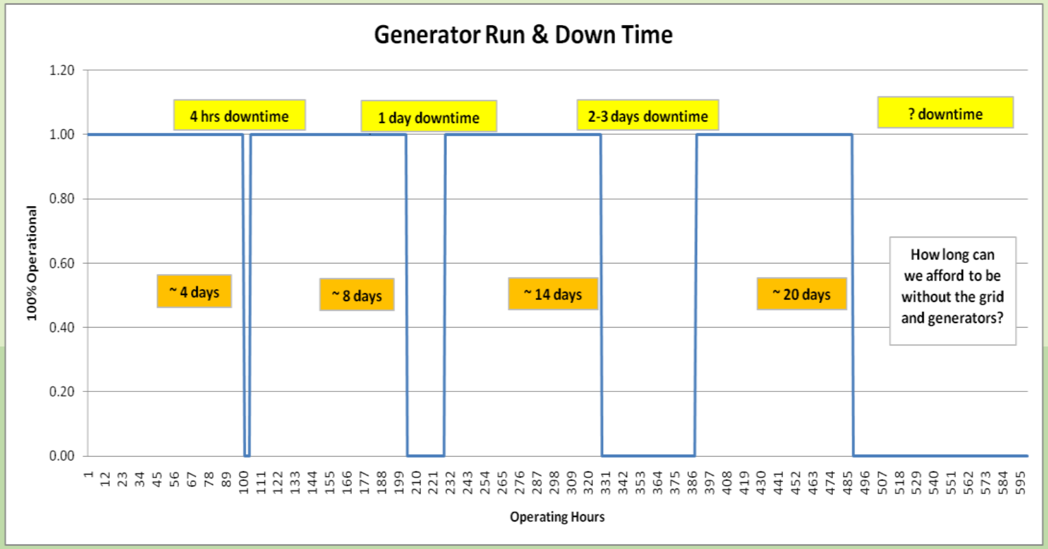
Facility Fossil Energy Reduction Benefits

- **Grid vulnerabilities due to system operator error, weather damage, terrorist, nuclear or EMP attack**
- **Cyber attacks advancing – China starting to map the US electric grid**
- **More Flight – Less Fuel report: distributed energy**
  - **Self-sustaining DoD bases on solar or renewable energy**
  - **Allows for distributed energy operations, avoids electric grid vulnerability challenges and provides continuous operational capability at a DoD base**

Phase 2: Benefits Analyses

Base Level Mission Need

Generator Run Time and Maintenance



Aurora Generator Cyber Attach Experiment

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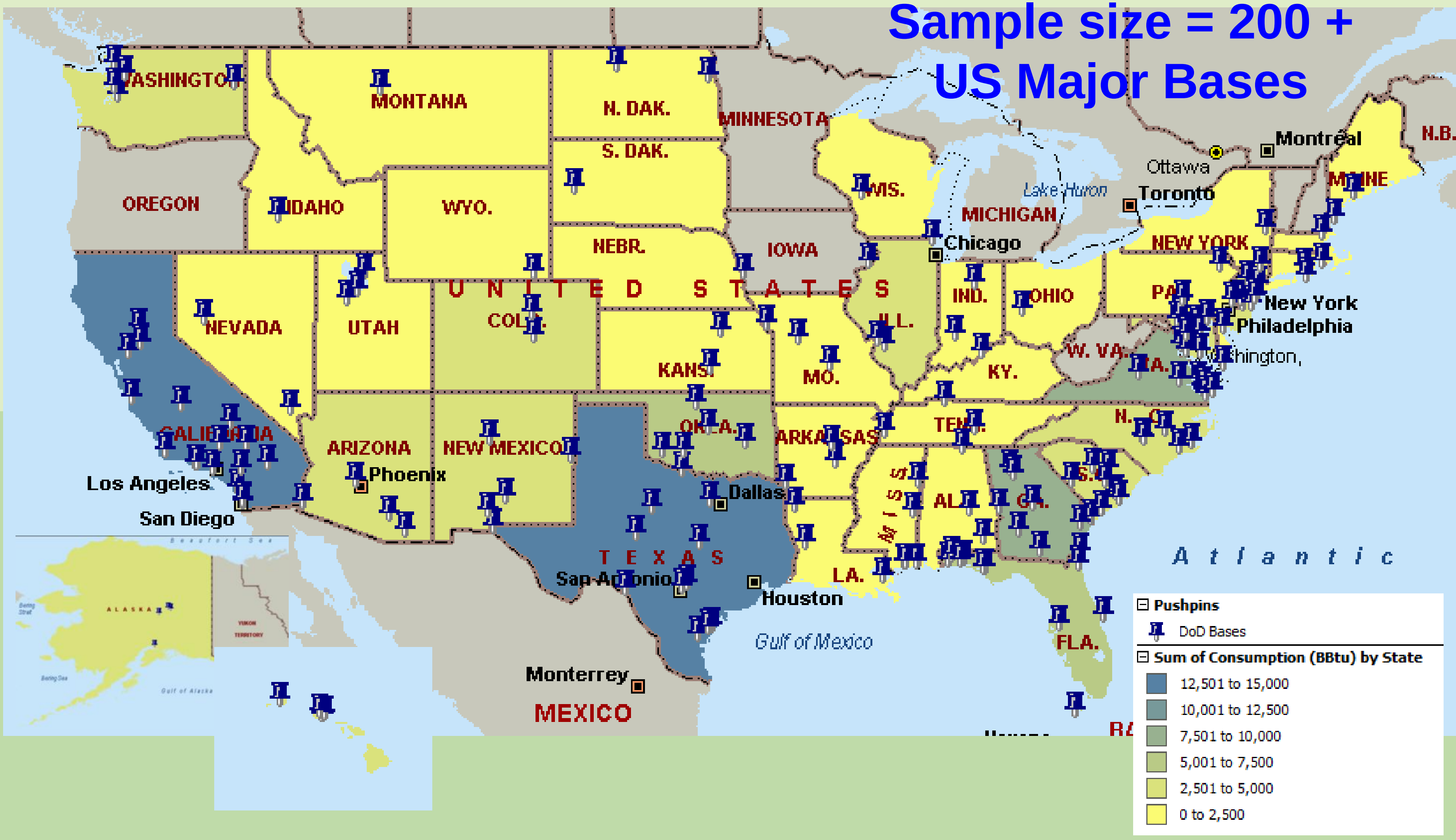
Phase 3 – Base Level Facilities Study

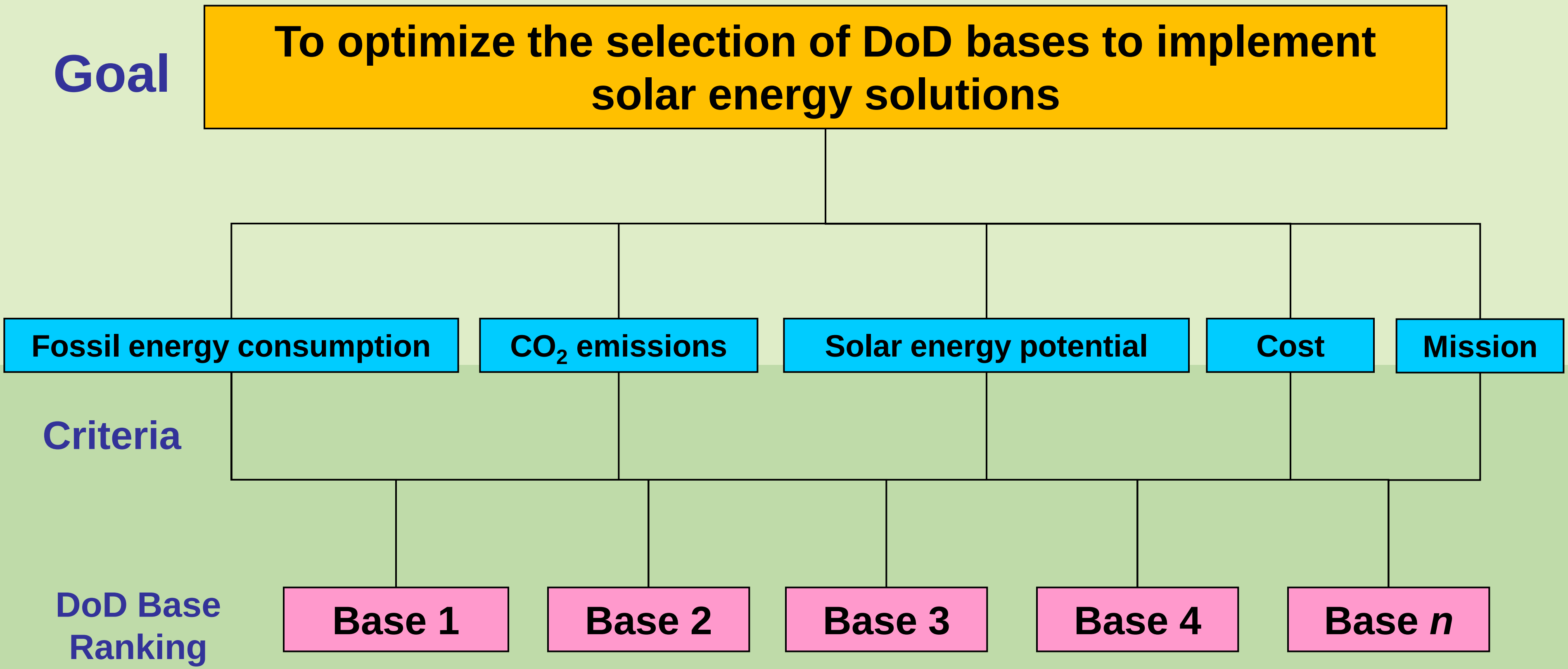


Phase 3: Model Development

- **<u>Problem:</u> Which are the most likely US military bases that warrant consideration for a solar energy implementation?**
- **Criteria (parameters under consideration):**
  - **Fossil energy consumption**
  - **CO_2 emissions**
  - **% land needed to meet energy requirement**
  - **Cost**
  - **Mission readiness**

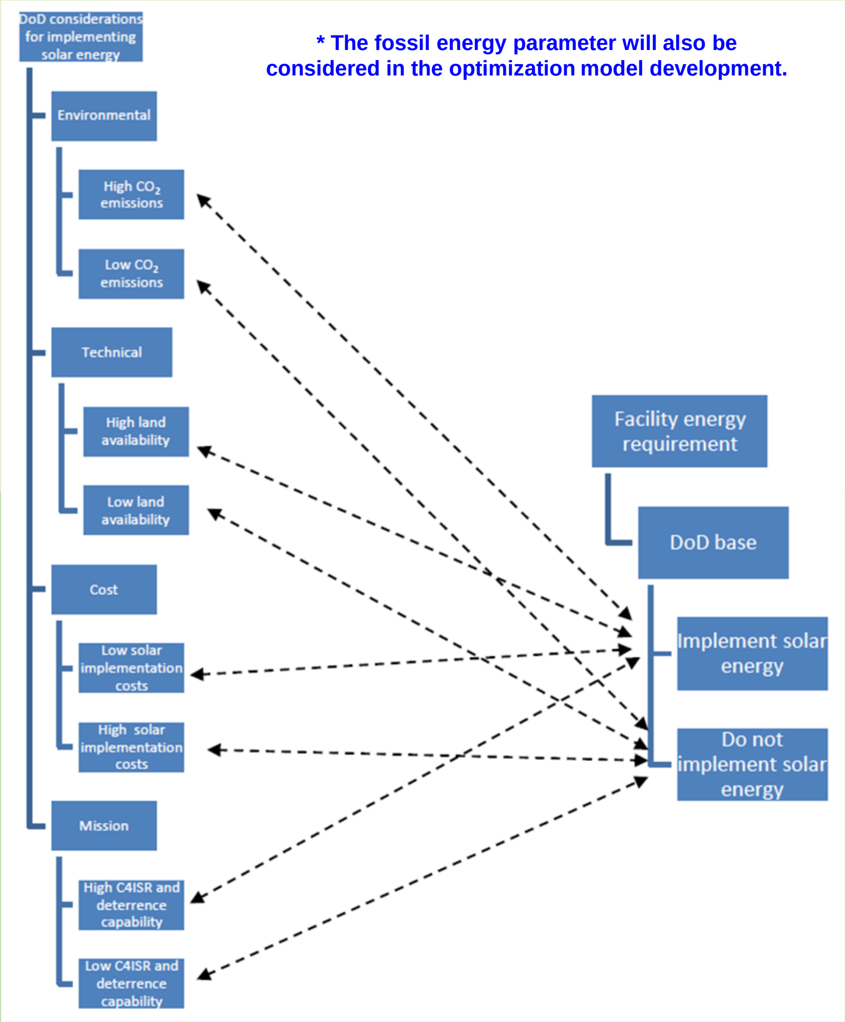
Model Hierarchy Rationale

Selecting DoD Bases to Implement Solar Solutions



Model Rationale – Key Parameters

Base Facility Engineering Model Theoretical Context Diagram (TCD)



- **Fossil Energy**
  - **EPAct 2005 and EO 13423**
  - **Fossil energy (kWh-yr)**
- **Environmental**
  - **EO 13514**
  - **CO_2 emissions (metric-tons/yr)**
- **Technical**
  - **Feasibility to implement solutions**
  - **Solar potential (kWh-yr)**
  - **Land availability (% of total)**
- **Cost (US$)**
  - **Budgetary requirements (US$)**
- **Mission**
  - **Manpower (# of personnel)**
  - **Strategic deterrence and C4ISR (post hoc research)**

*** Blue model parameters.**

Calculation Methods – Key Parameters

Table 1. Parameters, Primary Unit of Measure, and Calculation Method Utilized

Parameter	Units of Measure	Calculation Method Utilized
Fossil energy consumption	British thermal units (Btus), Megawatt hours per yr (MWh-yr), and kilowatt hours per year (kWh-yr)	fossil energy consumption$_{\text{base n}}$ = sqft$_{\text{base n}}$ × [BBtu / sqft]$_{\text{region}}$
CO_2 emissions	Pounds (lbs) and metric tons per year	lbs CO_2 emission$_{\text{base n}}$ = MWh$_{\text{base n}}$ × [lbs CO_2 / MWh]$_{\text{state}}$
Land needed to meet energy requirement	%	See table 2 rationale
Costs of implementation	$	Cost to implement solution = *$/W$_{\text{solar solution}}$ × (Wh-yr$_{\text{base n}}$ ÷ [energy delivered × solar rating ×365.25 days]) = $/W$_{\text{solar solution}}$ × (Wh-yr$_{\text{base n}}$ ÷ [~78% × 4,800 Wh/m^2/day ×365.25 days])
Mission critical base	# of military personnel	Independent intelligence gathering of each of 200 DoD bases (BSR and public documents)

***$/W$_{\text{solar solutions}}$ ~$3.00/W**

- **Photovoltaics (PVs): CdTe ~ $2.50/W, a-Si ~ $3.50/W, CIGS ~$3.20/W, and multi-Si ~ $2.65/W**
- **Concentrating solar power (CSP): Through ~ $3.50/W and tower ~$3.85/W**

Calculation Methods – Key Parameters

Table 2. Rationale for Solar Potential and Land Availability Calculation

Questions	Quantitative Approach Responses
How much land is available at a base?	BSR acreage or square meters ($m^2_{base\ n}$)
How much solar radiation is available on a base for energy?	energy divided by meters squared per year $[kWh \div m^2\text{-}yr]_{region}$
What are current solar cell efficiencies?	measured in percent (%) of total solar radiation convertible to energy – average efficiency of a solar cell = 10%
What are typical module numbers in a solar panel?	solar cells have 1 to n modules; an average solar cell can have 3 modules per panel which reduces efficiencies (10% ÷ 3)
What is my solar energy potential on a DoD base?	solar potential$_{base\ n}$ = land available$_{base\ n}$ × (solar radiation × [efficiency ÷ modules])$_{region}$ = $m^2_{base\ n} \times (kWh \div m^2\text{-}yr \times [10\% \div 3])_{region}$
What is the % of land needed to meet my current fossil energy consumption at a DoD base?	% land needed = fossil energy consumption$_{base\ n}$ ÷ solar energy potential$_{base\ n}$

Optimization / Scoring Model – Preliminary Analysis

Optimization / Scoring Model Preliminary Results

Research Factor	Energy	Environment	Technical	Technical	Cost	Mission
Research Subfactor	Fossil Energy	CO2 Emissions	Solar Potential	Land Availability	$	Strat. Det. & C4ISR
Variable or Constraint	Variable	Variable	Variable	Constraint	Variable	TBD
Why important?	EPAct & EO	EO	Feasibility	Feasibility	Budget/POM	DoD Mission
Totals (200 US bases)	34,171,119,077	28,488,159	4,185,774,722,273	0.82%	$ 82,228,992,197.31	-
Base Identification Number	Est. Fossil Energy Consumption Regionally Adjusted (kWh-yr)	Est. CO_2 Emissions Regionally Adjusted (metric tons-yr)	Solar Energy Potential by Base (kWh-yr)	% of Land Needed to Meet Base Energy Requirement via a Solar Solution (assume regional adjustment)	Average Cost to Meet 100% of Energy Requirement via a Solar Solution - assume regional adjustment (US$)	Mission Readiness - Strategic Deterrance and C4ISR
1	179,946,053.31	156,937.94	1,060,317,822.34	16.97%	$ 433,020,135.52	
2	21,864,907.90	14,192.94	2,140,054,699.66	1.02%	$ 52,615,465.62	
3	145,884,016.60	94,696.19	3,702,717,477.38	3.94%	$ 351,053,637.88	
4	196,210,847.21	127,364.33	2,516,687,861.96	7.80%	$ 472,159,550.54	
5	244,476,452.41	232,861.60	4,180,414,413.17	5.85%	$ 588,305,353.80	
6	181,925,153.05	173,282.05	1,773,318,165.28	10.26%	$ 437,782,618.63	
7	99,436,226.62	94,712.10	2,037,819,086.64	4.88%	$ 239,282,204.50	
8	115,727,558.54	66,406.71	7,230,033,226.85	1.60%	$ 278,485,480.29	
9	235,784,247.51	135,297.55	94,762,782,517.40	0.25%	$ 567,388,530.79	
10	25,502,498.67	14,633.83	18,276,757.63	139.54%	$ 61,368,922.66	

Aggregate parameter results across ~200 DoD bases

- Fossil energy consumption = 34 billion kWh-yr
- CO_2 emissions = 28.5 million metric tons-yr
- Solar potential = 4 trillion kWh-yr
  - 0.82% of land to meet 100% of energy requirement
- Cost = $82 billion to meet 100% of energy requirement

Integration of mission parameter in-progress

- Manpower and # of personnel will be integrated
- Strategic deterrence and C4ISR will be considered post hoc research

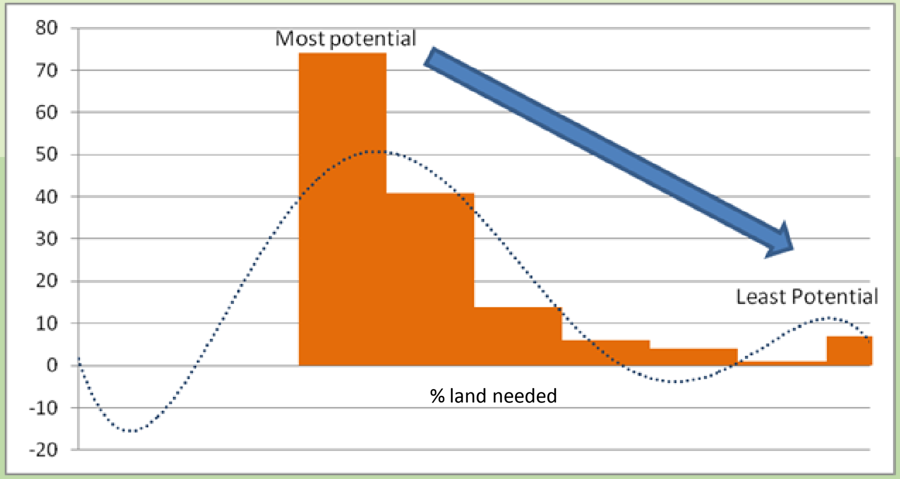
Optimization / Ranking Model

How will model work?

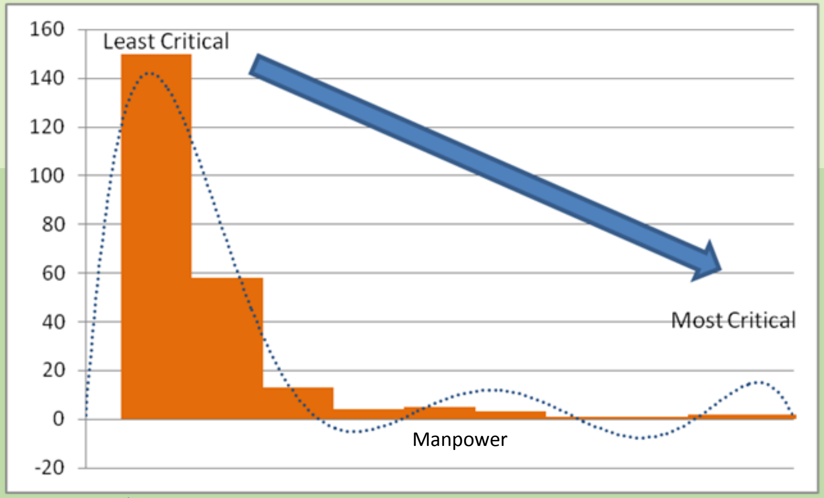
- **Model characteristics are deterministic, static, and multi-objective**
- **Optimization by: scoring and weightings**
  - **Decision theory, ordinal ranking and ratio analysis**
  - **May be possible to categorize base criticality**
- **Quantitative data: energy consumption, CO_2 emissions, % land to meet energy requirement via solar, cost, and mission (manpower)**
  - **Allows for statistical interpretation**
  - **Parameter submodels feed overall model**

Optimization / Scoring Model Preliminary Results for Mission Manpower

% Land Needed (Potential to Meet Energy Requirement from Solar) – χ^2 Distribution Results for Sampled Data



Manpower – χ^2 Distribution Results for Sampled Data



Overall base score = (score$_{energy}$ * weight$_{energy}$) + (score$_{CO2}$* weight$_{CO2}$) + (score$_{land\ availability}$ * weight$_{land\ availability}$) + (score$_{cost}$* weight$_{cost}$) + (score$_{mission}$* weight$_{mission}$)

Base ranking categories

- High
- Medium
- Low
- Minimal

Next Steps

- Apply ordinal scoring and ratio analysis for ranking of each individual parameter across each DoD base
- Apply “what if” weightings to parameters for consideration and to analyze ranking sensitivity
- Package and provide finalized results to subject matter expert (SME) committee for approval
- Defend research proposal, submit publication and defend dissertation

Future Areas of Research – Post Hoc

- **Continue model approach to other renewable energy sources (wind, tidal, etc.) – systems engineering, holistic approach**
- **Conduct case studies for base specific solar integration**
  - **Grid ties, state policies, etc.**
  - **Document possibilities for implementation standards**
  - **Nellis AFB**
- **Study potential to integrate research into tactical/operational mission**
  - **Production of synthetic fuels at bases or near point of use**
- **Continue to share and collaborate with DoD and Services**
  - **Hand over decision model to key stakeholders in government**
  - **Include actual data from bases in model (i.e., from Defense Utility Energy Reporting System (DUERS) & AEWRS (Army Energy and Water Reporting System)) – may require evaluation of source data since not a centralized DoD repository**
    - **Excel sheets reported to DoD Installations and Environment from Services**

FINIS

Nellis Air Force Base Solar Review

- **14 MW project, cost = $100M**
- **Initial cost sharing exercise**
- **Utility company owns the rights**
- **Sells back electrical to the base**
- **Discount on electrical for base**
- **Continued grid connection**
- **RECs sold by utilities to make up remaining costs**
- **No environmental benefit of solar energy for the Air Force**
- **Cannot use solar to meet renewable energy policy targets**
- **Solar meets 25% of demand**

Parameter 1. Fossil Energy Consumption

Approach

- Utilized square footage data in DoD's base structure report (BSR)
- Developed DoD fossil energy consumption per square foot factor from actual DoD data
- Adjusted DoD fossil energy consumption per square foot factor by regional application of Department of Energy (DOE) Commercial Building Energy Consumption (CBEC) factors

Parameter 2. Carbon Dioxide Emissions

Approach

- Utilized Environmental Protection Agency (EPA) eGrid factors
- Only utilized fossil energy consumption factors
- Excluded renewable energy to develop appropriate calculations

Parameter 3. Solar Energy Potential

Approach

- Base acreage data collected from DoD BSR
- Regional solar radiation data from NREL Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors
- Solar cell efficiencies from GWU Solar Energy Institute and crosscheck with NREL reports (assumed ~ 10%)

Parameter 4. Cost of Implementing

Approach

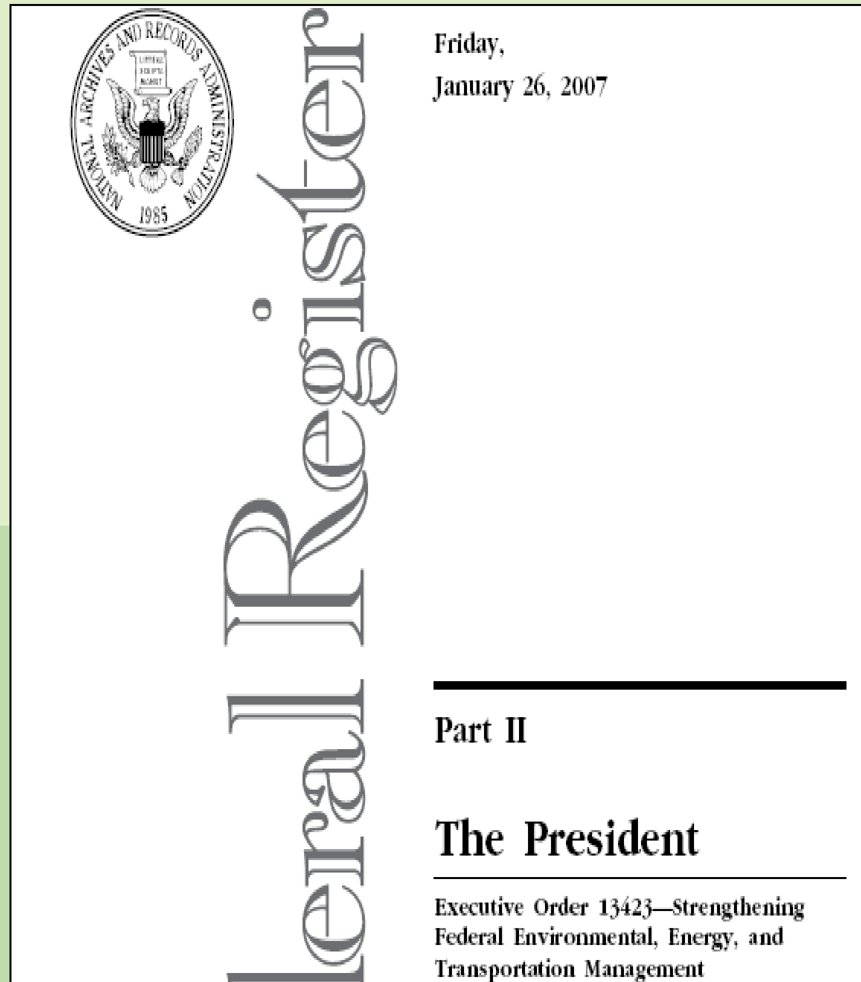
- Considered photovoltaic (PV) and concentrating solar power (CSP) average costs
  - PV average costs $2.89 per watt in 2010 (GWU Solar Institute)
    - Includes multiple PV technologies
  - CSP average costs $3.68 in 2010 (NREL report)
    - $3.68 was a forecast in NREL report
    - Current systems cost from $5,000 to $8,000 per kW
    - Expected $4,290 per kW cost in 2015

Mission Benefits of Research

- **Islanding**
- **Energy dependability**
- **Impact on terrorism**
- **Climate change**
- **CO2, AFV and AF**

Other National Benefits

- **Catalyst and market driver of technologies**
- **Decreased oil imports**
- **Decreased GHG emissions**



leral Register

Friday,
January 26, 2007

Part II

The President

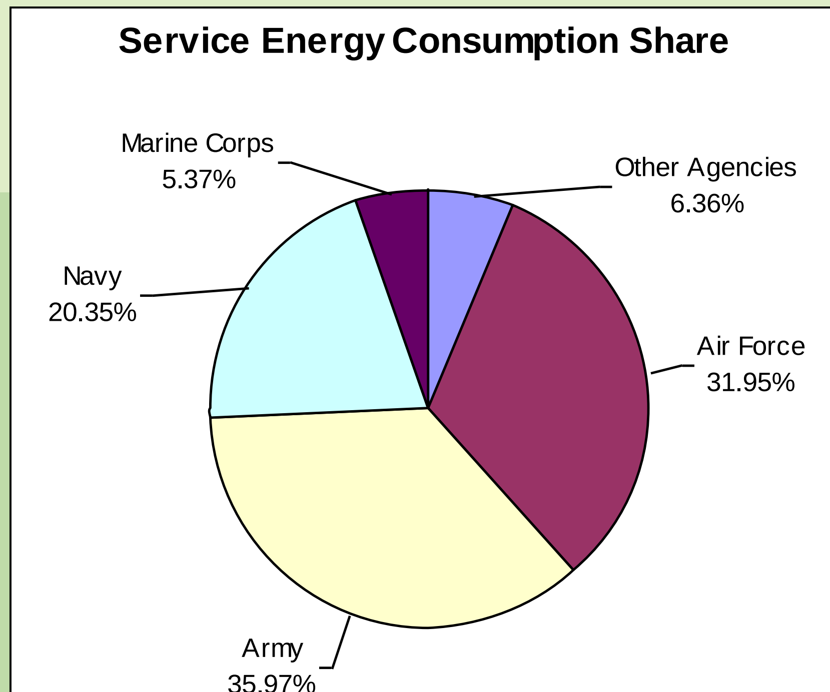
Executive Order 13423—Strengthening Federal Environmental, Energy, and Transportation Management

Facility Energy Consumption

Initial Data Analyses for FY07

Department	Covered Facilities Site Delivered (BBtus)	% of DoD
Army	73,778.9	35.97%
Air Force	65,545.1	31.95%
Navy	41,750.3	20.35%
Marine Corps	11,008.6	5.37%
Other agencies	13,037.6	6.36%
Total	205,120.5	100.00%

Nellis AFB, Nevada Solar System

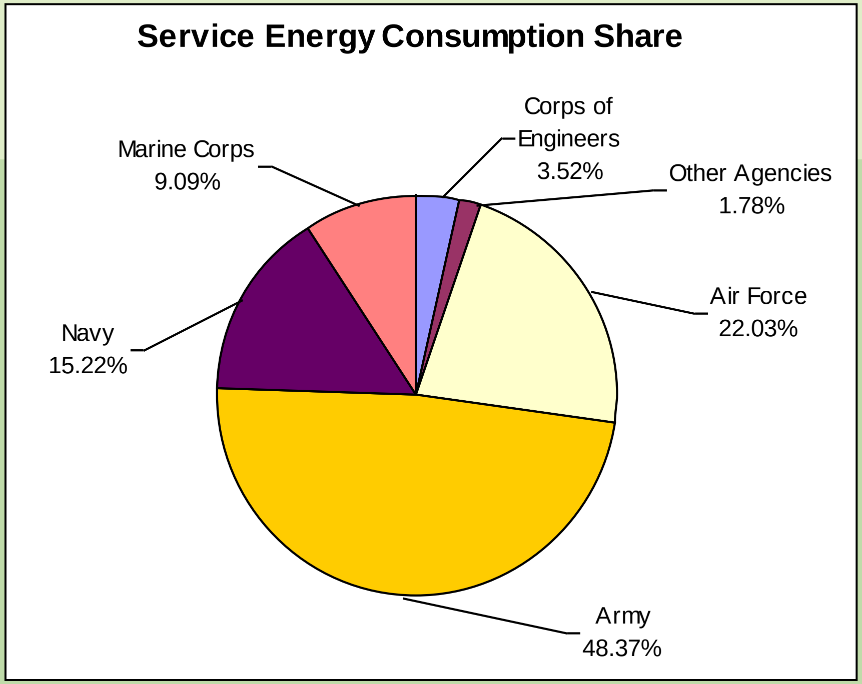


Non-Tactical Fleet Vehicles

Initial Data Analyses for FY07

* GGE = Gasoline Gallon Equivalent

Department	Non-tactical Fleet Vehicles (GGE)	% of DoD
Army	49,214,231	48.37%
Air Force	22,411,762	22.03%
Navy	15,481,033	15.22%
Marine Corps	9,245,494	9.09%
Corps of Engineers	3,578,184	3.52%
Other Agencies	1,808,892	1.78%
Total	101,739,596	100.00%



China Lake, CA Geothermal System

Cooperating Offices

- Deputy Under Secretary of Defense for Installations and Environment (DUSD/I&E)
- Assistant Secretary of the Air Force for Installations Environment and Logistics (SAF/I&E)
- Deputy Assistant Secretary of the Army for Installations and Housing (DASA/I&H)
- Assistant Secretary of the Navy for Installations and Environment (ASN/I&E)