U.S. Department of Energy
Energy Efficiency and Renewable Energy

Perspectives on Energy Storage and the Systems Driven Approach

Workshop on Systems Driven Approach
For Solar Applications of Energy Storage

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Sandia National Laboratories

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Acknowledgements

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- Ray Sutula, DOE
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- Tom Hund, SNL
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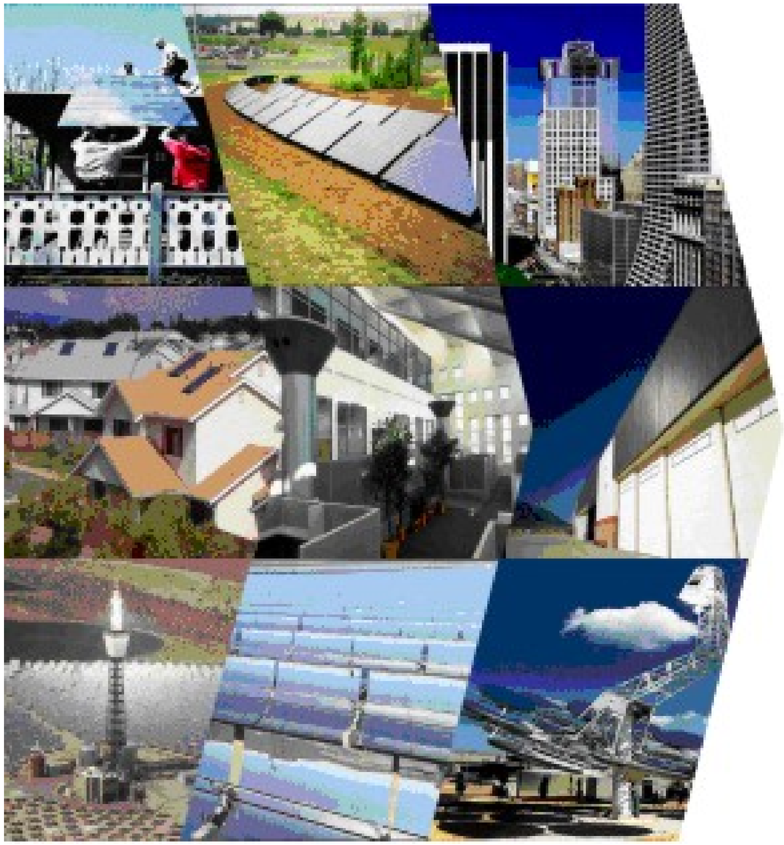
Outline of This Presentation

- Systems Driven Approach in DOE's solar program
- A vehicle model example: the ADVISOR package
- Progress on developing a solar decision-assist model
- Other progress in solar systems-driven approach
  - Benchmarking
  - Analysis
- Thoughts on the role of storage in solar and SDA

Objective of a Systems Driven Approach



- A framework and analysis tools that will allow us to explore alternative technology pathways and identify critical technology needs to guide planning and management of our entire solar technology portfolio.

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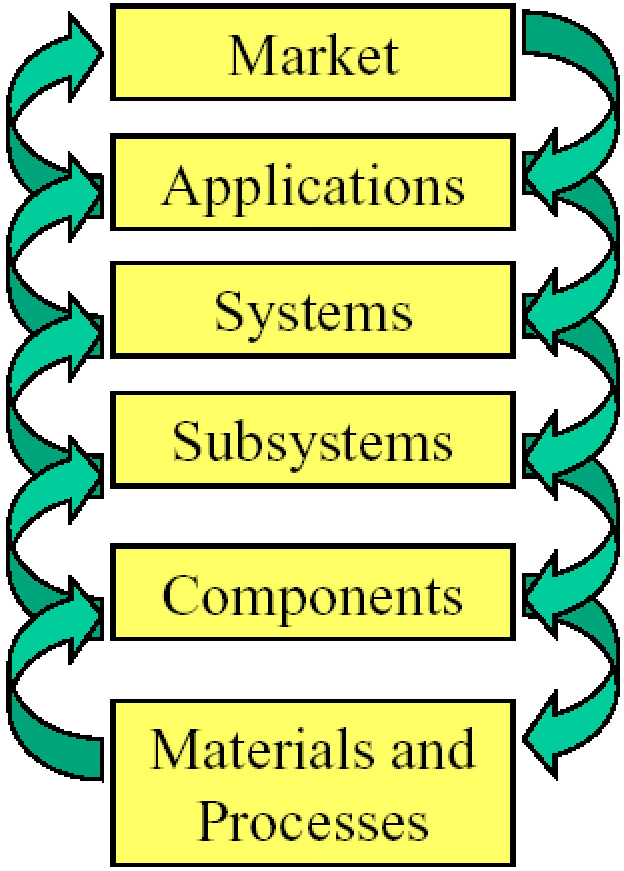
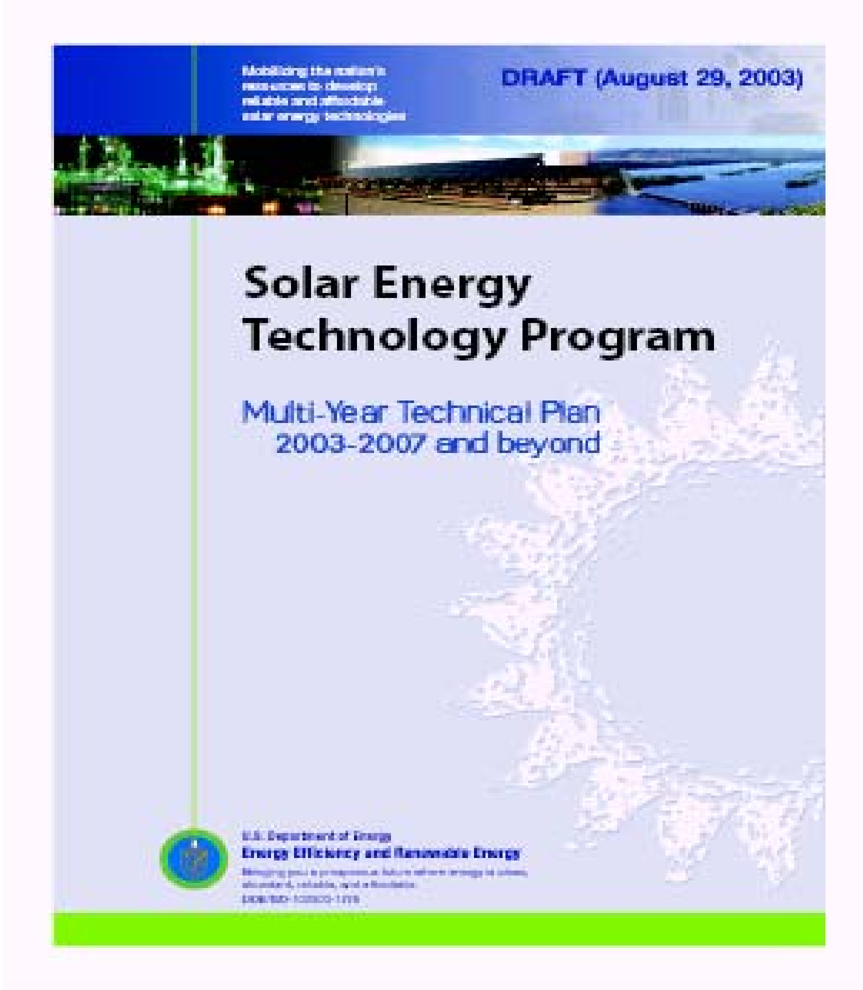
SDA used to determine technology pathways



- What market sectors will be key to PV in the future and to what degree will they depend on storage technologies?
- How might storage technologies improve the value of PV to utilities?
- How does a component like a battery impact costs for interconnection? System reliability?
- What are the near-term, mid-term, and long-term trade-offs in R&D on different storage technologies?
- From what other non-PV markets might storage development gain significant leverage?
- What are the implications of storage technologies on energy security? Microgrids?

First Application of SDA: Integrated Solar Multi-Year Technical Plan



http://www.nrel.gov/extranet/techplan/techplan.html

Solar MYTP: 2.0 Industry, Markets, and Applications

Major Themes:

•Nationa

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•Existin

•Existin

•Solar Systems Descriptions and Requirements

Table 2-1. Solar Technologies and their Applicability to Various Market Sectors

		Distributed Energy			Central Generation	Fuels and Chemicals
		Building-Integrated	Ground-Mounted	Off-Grid		
PV	One-Sun	● Electrical Generation	● Electrical Generation	● Electrical Generation	● Electrical Generation	● Transportation
PV	Concentrating		● Electrical Generation	● Electrical Generation	● Electrical Generation	● Transportation
Thermal	Dishes		● Electrical Generation	● Electrical Generation	● Electrical Generation	● Transportation
Thermal	Towers				● Electrical Generation	● Transportation
Thermal	Troughs	● Electrical Generation ● Thermal	● Electrical Generation ● Thermal		● Electrical Generation	
Thermal	One-Sun Thermal	● Thermal	● Thermal	● Thermal		
Thermal	Air[a]	● Thermal				
Thermal	Passive Solar[a]	● Thermal				
Hybrid Lighting		● Solar Lighting				

[a]DOE Solar Energy Technology Program does not conduct research in thermal air and passive solar collectors, and these technologies are not discussed further in this plan.

● Electrical Generation ● Thermal ● Solar Lighting ● Transportation

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Solar MYTP: 3.0 Systems Driven Approach

Solar-Systems Markets

• Utility-scale • Buildings • Distributed • Off-grid

Systems-Driven Approach

Systems Analysis	Technical Target Development	Benchmarking and Validation

↓ Market-Based Requirements

↑ Data Collection and Validation

Photovoltaics

Flat-Plate PV
- Silicon modules
- Thin-film and high-performance modules
- Systems integration
- Balance of system

Concentrating PV
- CPV cell R&D
- CPV receiver R&D
- CPV module R&D
- Systems analysis

Concentrating Thermal Power

Parabolic Troughs
- Solar-field technologies
- Thermal-energy storage
- Power-plant optimization
- Analysis and integration

Power Towers
- Heliostat R&D
- Power-plant optimization
- Analysis and integration

Dish Stirling
- Systems
- Performance and reliability
- Advanced component R&D
- Deployment

Solar Heating and Lighting

Water and Space Heating
- Passive solar-water heating
- Active solar-water heating
- Combined heating and cooling
- Cooling

Hybrid Lighting
- Collector
- Fiber optics
- Balance of systems
- Analysis and integration

Advanced Concepts

Beyond the Horizon and Future Generation PV

Advanced Building Integrated Concepts

Advanced Solar Conversion

Fundamental R&D

Solar MYTP: 4.1.1 Photovoltaic Systems

Goals:

Assist industry in developing PV systems that can provide quality performance and reliability at acceptable costs to the consumers.

Acceptable costs are determined by a number of factors and will be fine-tuned as part of the continuing analysis, target setting, and validation conducted within the context of the ongoing systems-driven approach.

Solar MYTP: 4.1.1 Photovoltaic Systems

Table 3 Targets for Flat-Plate PV systems in residential applications (2-3 kW grid-connected with storage example)

System Element	Units	2003	2007	2020
Design	$/W$_{ac}$	0.55	0.30	0.20
Modules				
Conversion Efficiency	%	14	17	20
Direct Cost	$/m^2	420	280	67
	$/W$_p$	3	1.65	0.33
Price	$/W$_{dc}$	4.80	3.50	1.50
Inverters				
Price	$/W$_{ac}$	1.10	0.50	0.30
dc-ac conversion efficiency	%	94	96	97
Replacement	Years	5	10	20
Other BOS	$/W$_{ac}$	1.10	1.00	0.40
Storage	$/W$_{ac}$	0.75	0.75	0.75
Installation	$/W$_{ac}$	3.00	2.25	1.25
System Efficiency	%	11.5	14	16
Installed System Price	$/W$_{ac}$	11.30	8.30	4.40
Lifetime	Years	20	20	30
Degradation	%/Yr	1-2	1-2	1
O&M	$/kWh$_{ac}$	0.20	0.14	0.125
Levelized Cost of Energy	$/kWh$_{ac}$	0.59	0.42	0.25

Considerations:
LEC is cost to consumer.
2003 numbers taken from example of Figure 4.2.13, with storage added.
LEC is dependent on amount of kWh sunshine per year (2000 kWh/yr assumed here).
2003 data assumes retrofit market; 2007 and 2020 are for new construction.
Storage: 25 kWh of batteries.
O&M: inverter replace (5 yrs in 2003); battery replace (5 years +$400 labor); battery maintenance ($200/yr)

How do we determine these targets?
Continued analysis

How do we determine pathways to meet these targets?
Continued modeling and analysis

How do we assess progress and validate tools?
Continued benchmarking and baselining

Industry partnerships are key to success!

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Vehicle Systems Analysis

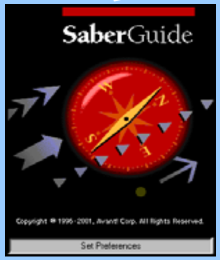
Energy Security: Reduce Vehicle Oil Use

National Fuel Use

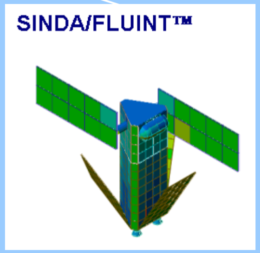
Packaging

Market Penetration

Fuel Economy

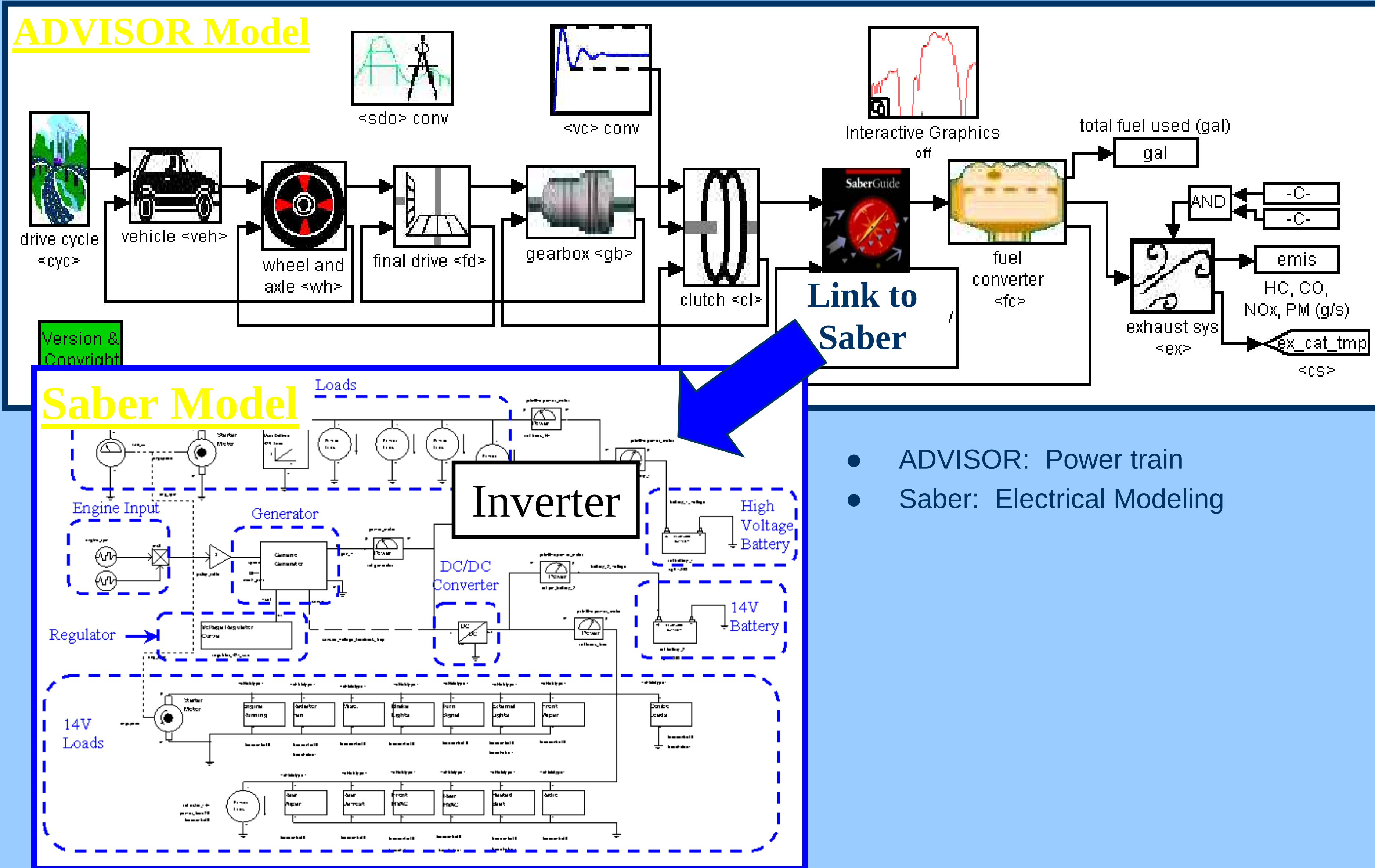


Electric Modeling



Thermal Modeling

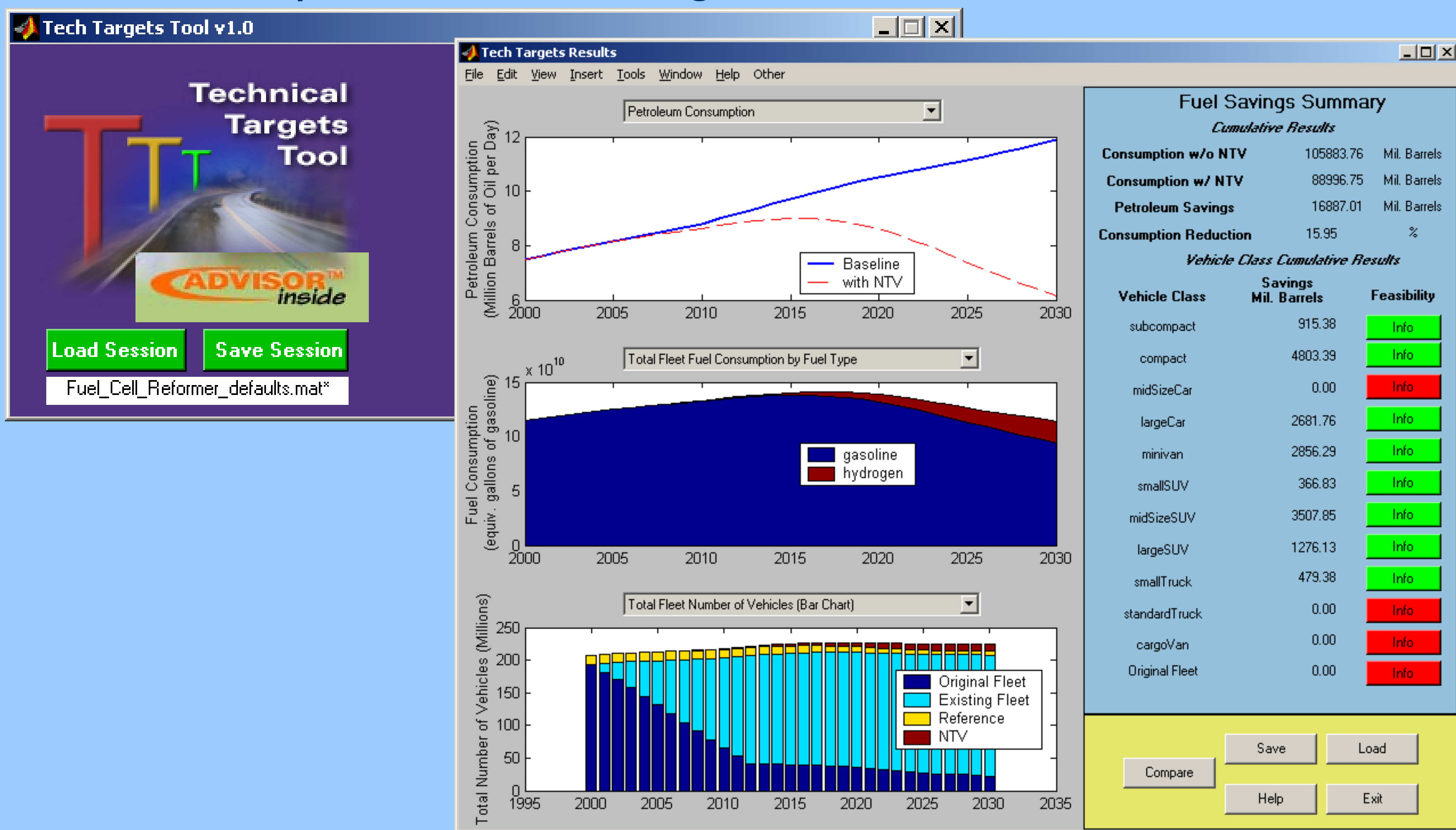
Linking ADVISOR to Saber



- ADVISOR: Power train
- Saber: Electrical Modeling

Approach to Vehicle Systems Analysis

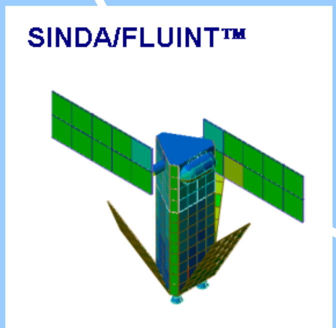
- Map models to end goals

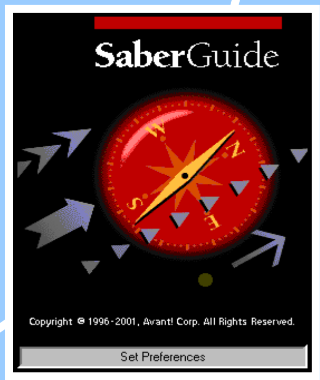


Vehicle Issues and Modeling Solutions

Issues

- Efficiency
- Cost
- Performance
- Thermal Management
- Packaging
- Safety
- Voltage regulation
- Emissions
- Configuration





Storage Issues and Modeling Solutions

Electric Power Modeling

Finite Element Analysis (FEA)

Issues

- Reliability
- Efficiency
- Cost
- Power quality
- Modularity
- Thermal management
- Packaging
- Safety
- Voltage regulation
- Equipment protection

Continuous Fluid Dynamics (CFD)

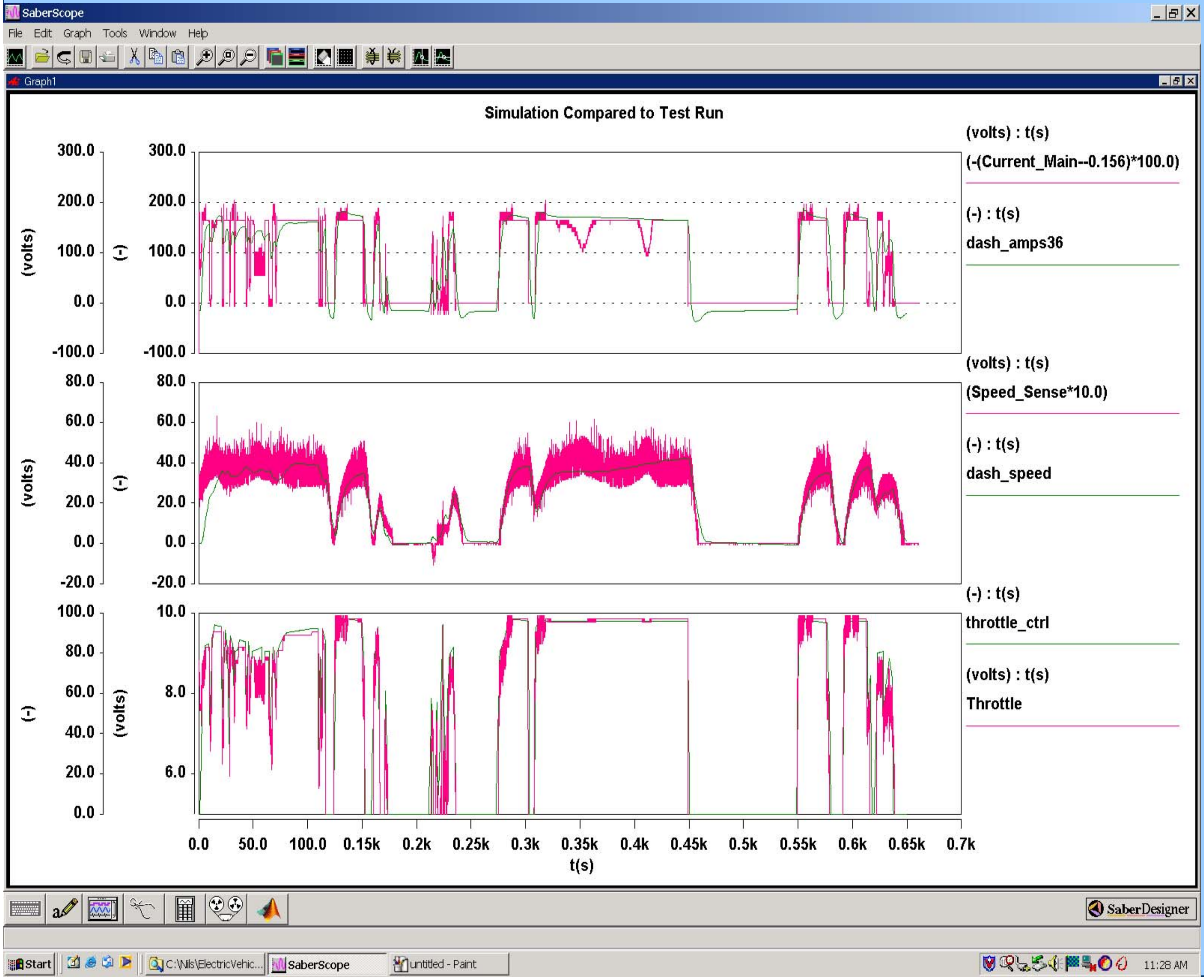
Solid Modeling

Model Abstraction Level

- Depending on task different abstraction levels necessary

Abstraction Level	Effects	Accuracy	Simulation Speed	Modeling Effort
Behaviour (functional) Level	none	low	high	low
Physical Level	dyn. thermal, ripples, spikes,...	high	low	high

Simulation and Measured Data Compared



Measured data shown in Red and Simulation data shown in Blue

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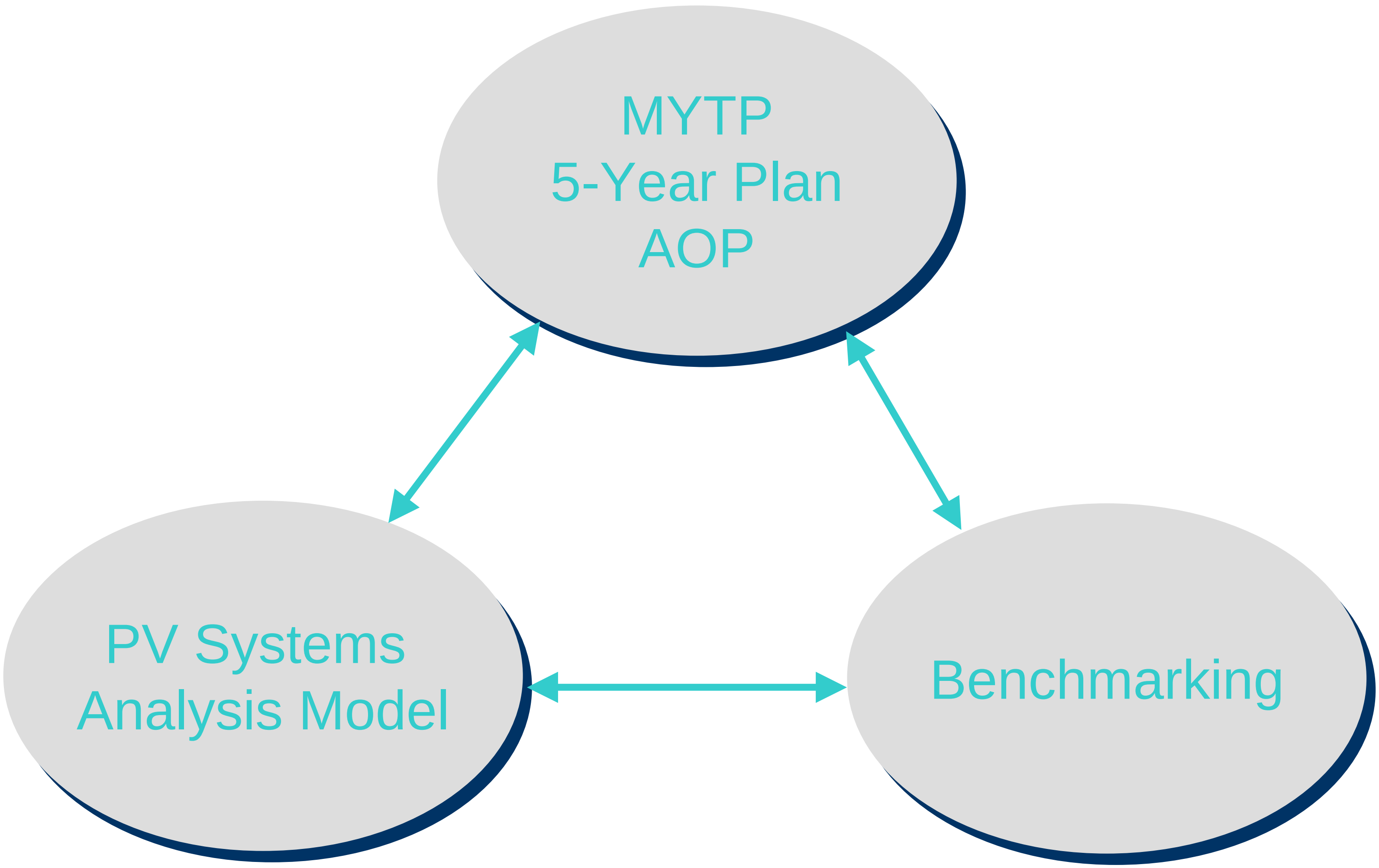
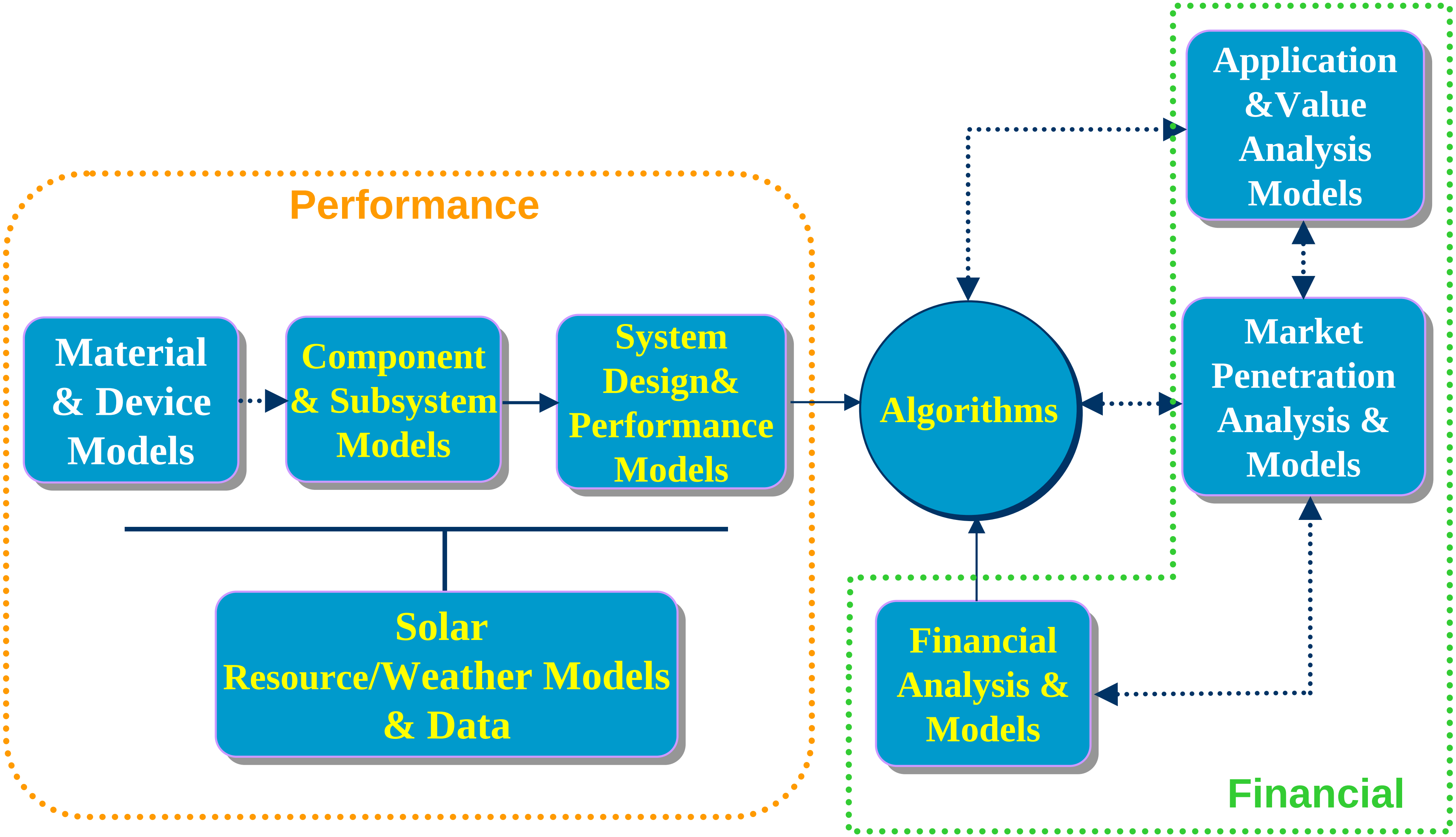
Solar Model Considerations

- Two levels of consideration:
  - Overall solar program
  - PV Systems Analysis Model
- Component-level sensitivity analysis *from system and market perspective*
- Utilize analysis to inform R&D investment decisions
- Comprehensive model to accurately predict system performance
- Benchmarking effort critical to model credibility

PVSAM: Programmatic Context



PVSAM Concept



PVSAM Concept

PERFORMANCE MODULE

Inputs (Either fixed or variable)

- **Module efficiency**
- **Module and inverter efficiency degradation rate**
- **Module and Inverter failure rates**
- **Inverter efficiency**
- **Electrical losses in wiring and connections, degradation**
- **Module mount angle**
- **Tracked or fixed**
- **System lifetime**
- **Solar resource**

System Output

FINANCIAL MODULE

Inputs (Either fixed or variable)

- **Cost of Module**
- **Cost of BOS**
- **O&M**
- **Financing terms and costs**
- **Incentives (buy downs, tax credits, CO_2 credits)**
- **Cost of land/siting**
- **Cost of permitting**
- **Local utility rate structure**

Capital and yearly costs

Algorithms

OUTPUTS

- **Levelized cost of energy**
- **Cost of electricity vs. time**
- **Summary data (cost of system, cost breakdown of components and labor)**
- **Amount of electricity delivered for system life, per year, etc.**
- **System payback for a given location**

Multi-variable graphing to show sensitivity of different inputs and optimized conditions

PV Systems Analysis Model

- **Select/Modify a Default System**
- **Build your Own System**

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Select System Type

Utility Scale

BIPV

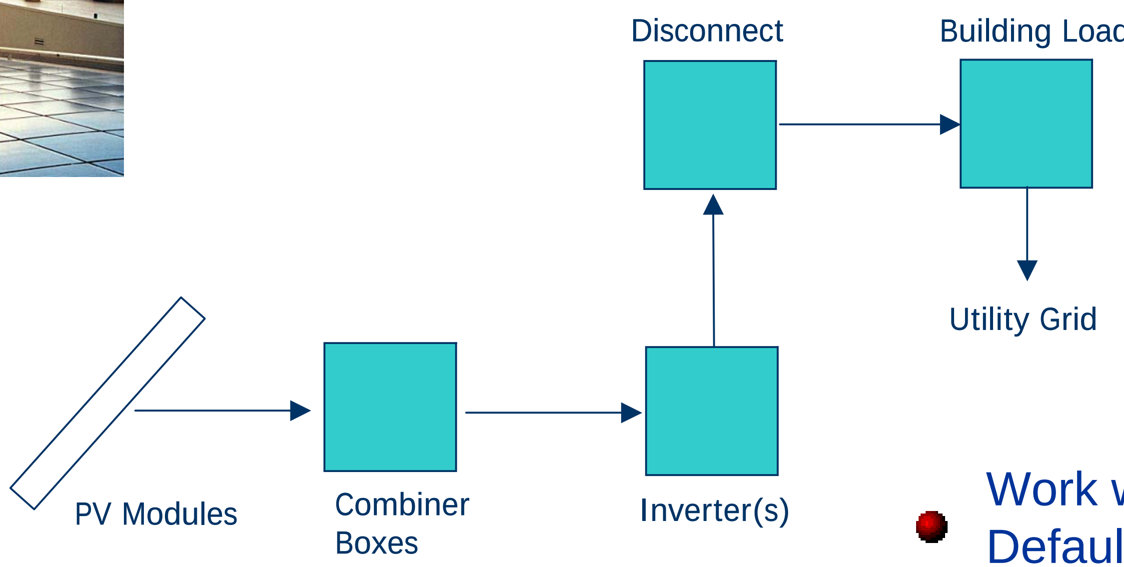
Commercial

Small-scale
Stand Alone

Residential Grid-tied

Large Load
Stand Alone

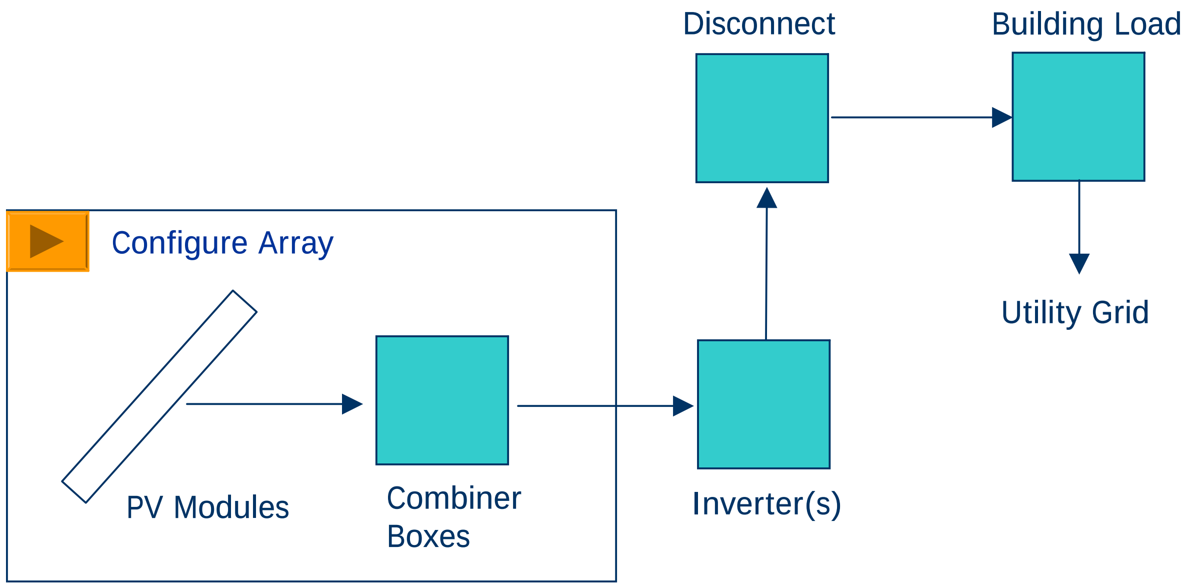
Commercial Scale System

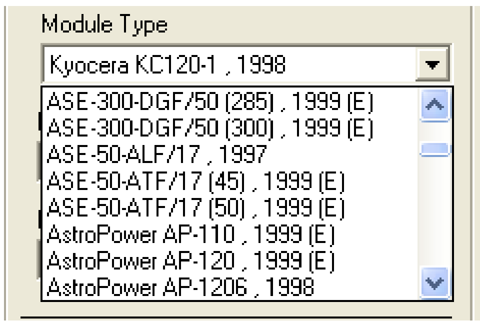


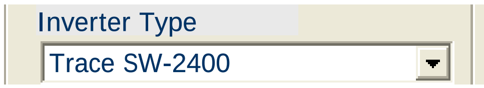
Calculate System Performance and Cost

- Work with Default System
  - View Systems Specs
- Modify System Specs

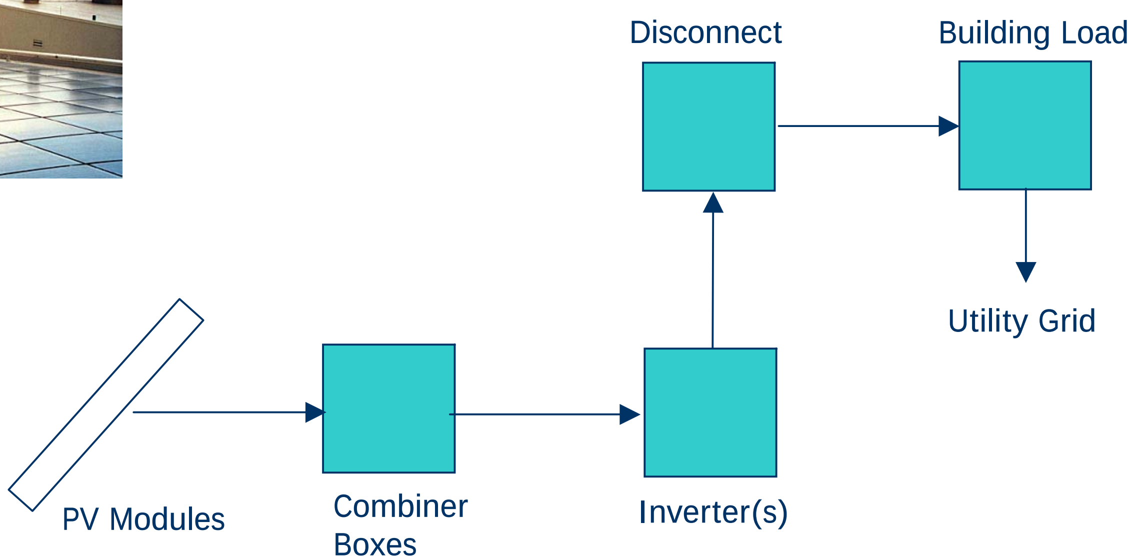
Commercial Scale System







Commercial Scale System



- PV Module Performance Parameters
- PV Module Financial Parameters

Module Specs

Module Performance				
Fixed Module Efficiency	13%	Fixed Module Efficiency		
Module Efficiency Degradation Rate (relative %/yr)	0.50%			
Module Failure Rate (average # per year)	0.5			
Soiling Losses	2%			

Module Size	
Total Area (m^2)	0.87
Active Area (m^2)	0.64

PV Cell Performance Parameters

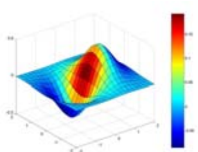
Go back to systems schematic

PV Module Financial Parameters

PV Systems Analysis Model

Outputs

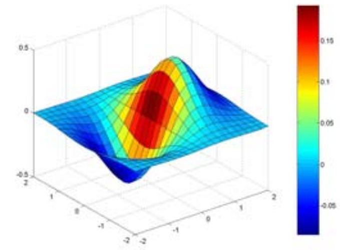
	Energy Cost per Year														
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15
Levelized Cost per Year	$ 0.43	$ 0.43	$ 0.42	$ 0.42	$ 0.41	$ 0.41	$ 0.40	$ 0.40	$ 0.39	$ 0.39	$ 1.01	$ 0.38	$ 0.37	$ 0.37	$ 0.36
Energy Output (kWhr)	29,567	29,272	28,980	28,691	28,405	28,121	27,841	27,563	27,288	27,016	26,746	26,480	26,215	25,954	25,695
Payments+O&M	$12,757	$12,469	$12,189	$11,916	$11,650	$11,392	$11,140	$10,894	$10,656	$10,423	$26,997	$9,976	$9,762	$9,553	$9,350
AVERAGE ANNUAL COST OVER LIFETIME			$11,251												
AVERAGE ANNUAL ENERGY OUTPUT			26,926												
LEVELIZED COST OF ELECTRICITY			$ 0.42												



Go to Graphing Module

PV Systems Analysis Model Graphing Module

Select Items You Wish to Plot



Performance Parameters

- [x] **Annual AC Output**
- [ ] **Annual DC Output**
- [ ] **Monthly Output**
- [ ] **Array Max Power**
- [ ] **Module Output**
- [ ] **Inverter Efficiency**
- [ ] **Irradiance**

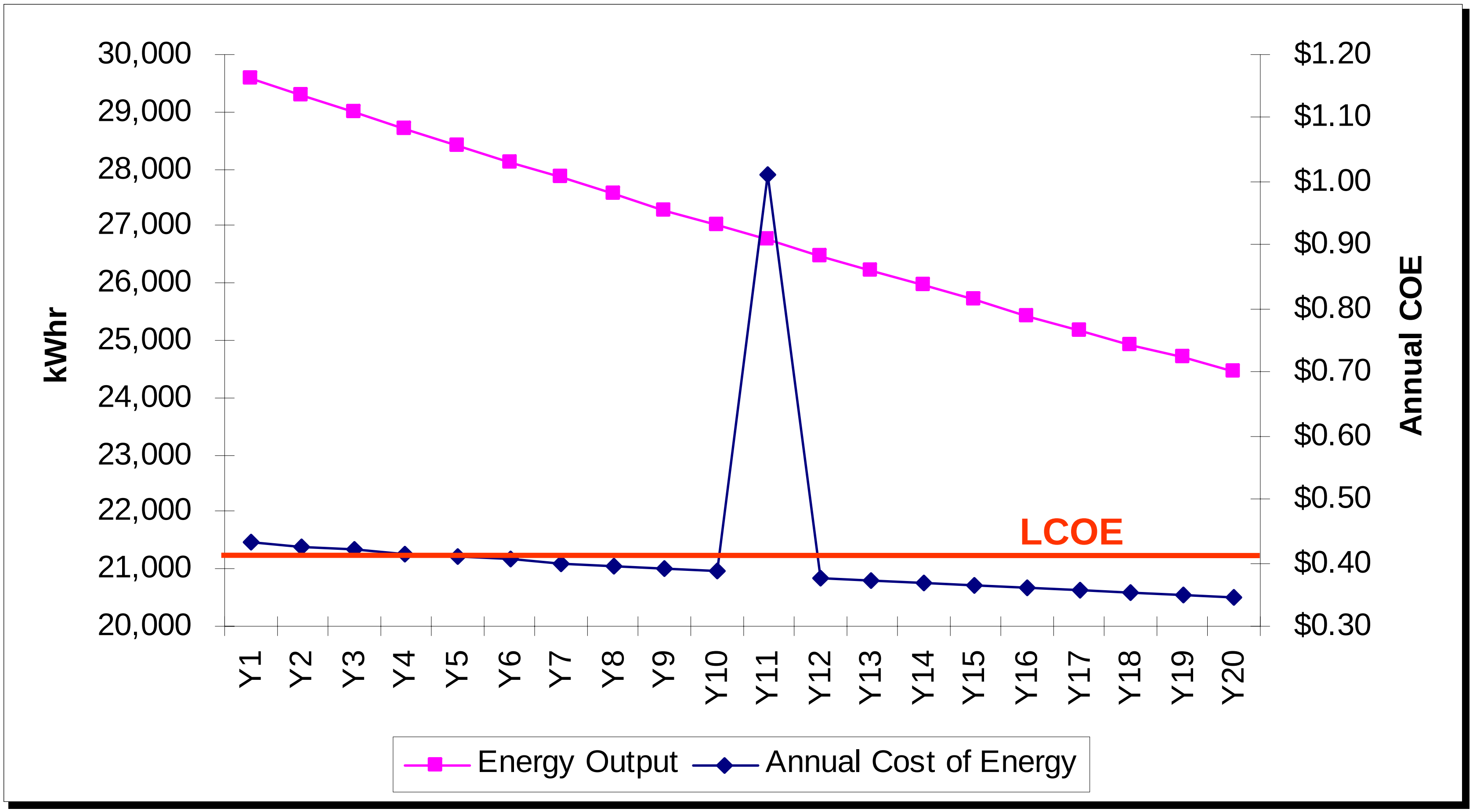
Financial Parameters

- [ ] **Annual Costs**
- [ ] **Energy Value**
- [ ] **LCOE**
- [ ] **System Cost Breakdown**
- [ ] **Module Cost Breakdown**
- [ ] **BOS Cost Breakdown**
- [ ] **System Payback**

- [ ] **CUSTOM GRAPH**

Generate Graph

PV Systems Analysis Model Graphing Module



Back to Graphing Module

Save Graph

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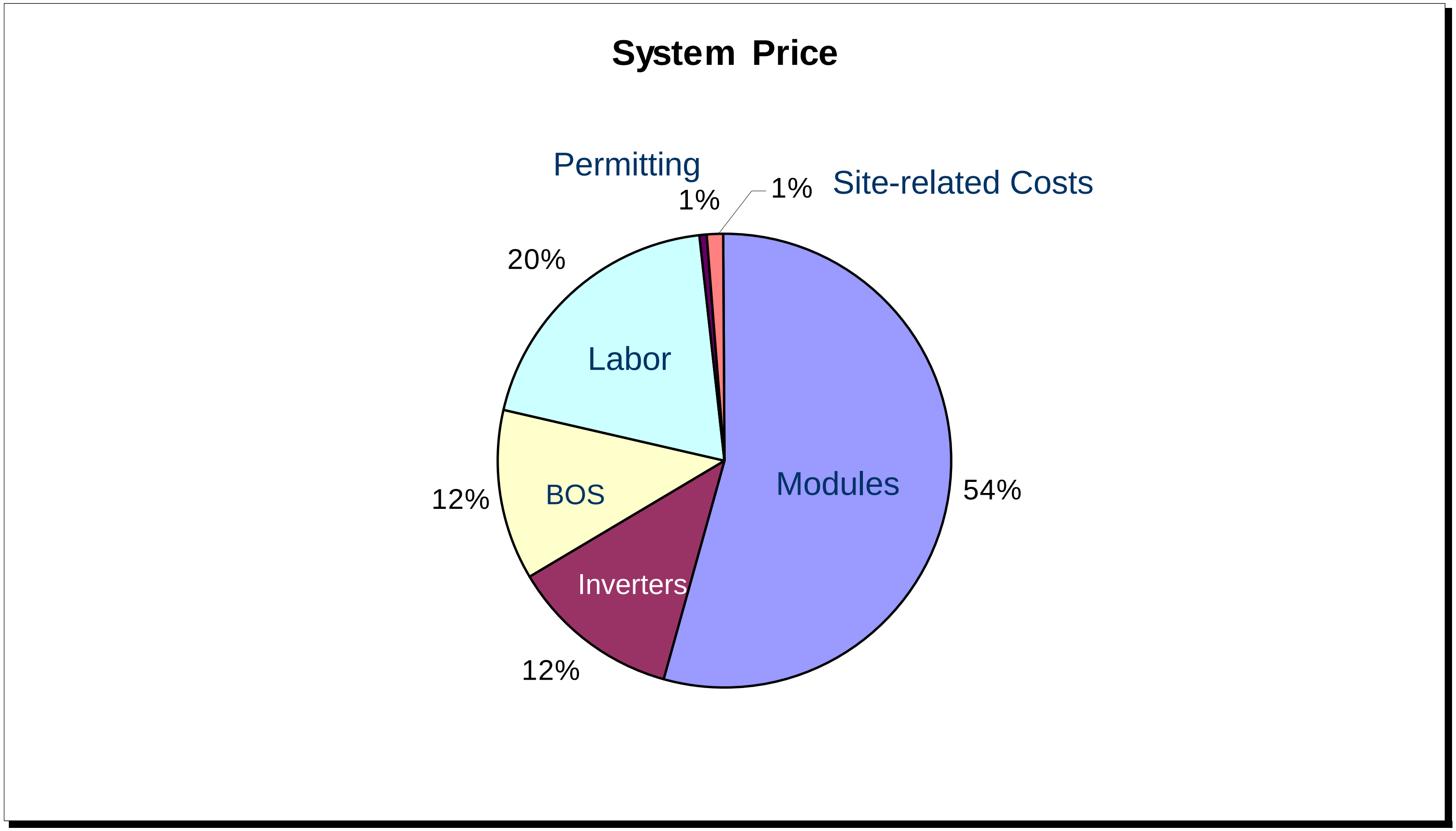
PV Systems Analysis Model Graphing Module



Back to Graphing Module

Save Graph

Next Steps for PVSAM

- Convert Excel code to MatLab Code
- Compile/incorporate databases
- Evaluate/incorporate existing accessible models
- Continue interaction with industry and others

Industry perception of direct value is key to successful development/deployment

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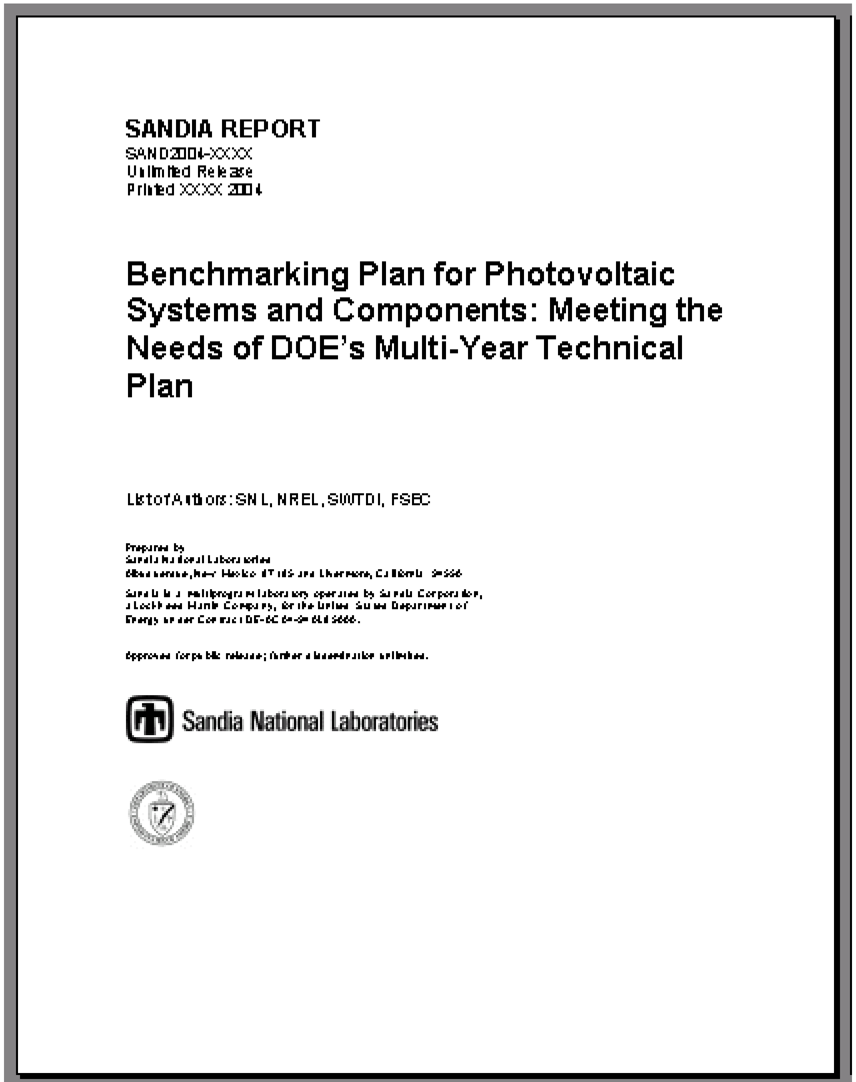
Benchmarking plan is under development



SANDIA REPORT
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Benchmarking Plan for Photovoltaic Systems and Components: Meeting the Needs of DOE's Multi-Year Technical Plan

List of Authors: SNL, NREL, SWTDI, FSEC

Prepared by
[illegible]

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- Continuous collection and analysis of data to assess status of cost, performance, reliability of technologies in SDA
  - Lab and field
  - Components and systems
- Maps into programmatic requirements of Multi-Year Technical Plan
- SWTDI, FSEC, industry – all key partners

Benchmarking plan to include several market sectors/applications

Table of Contents:

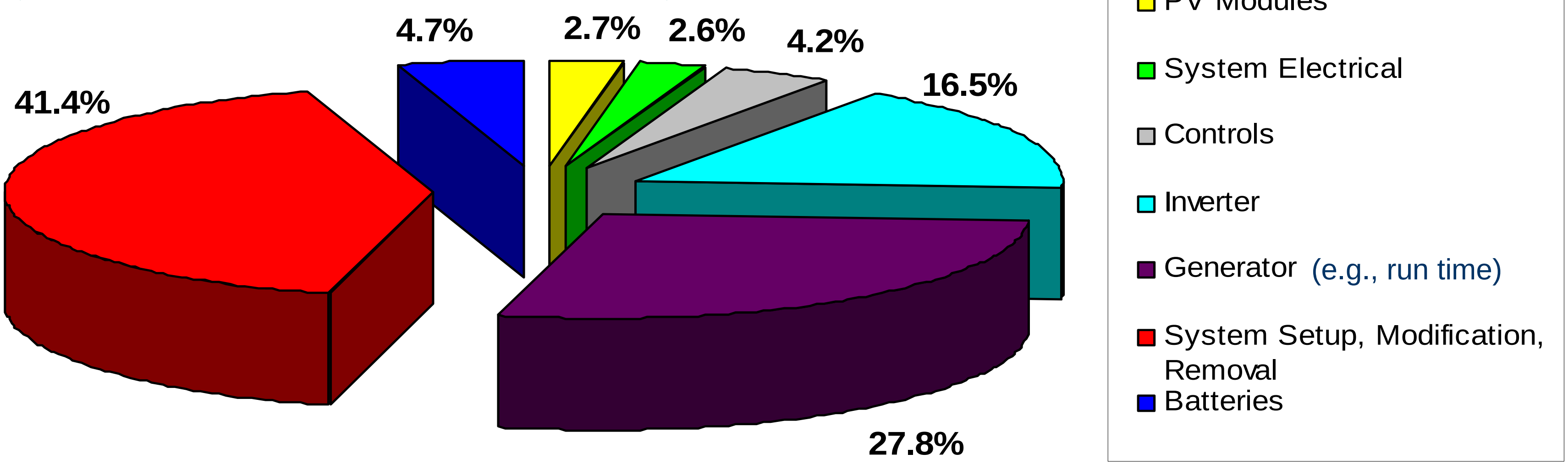
Interim Results of a Benchmarking, Reliability Exercise

Off-grid residential systems:

Installed by a Southwest utility, 1996-2002

- Generator/Inverter identified as cost drivers
- Compatibility/hardware improvements needed (coordinated with SNL power electrics group) with feedback to DOE, the utility, & manufacturers

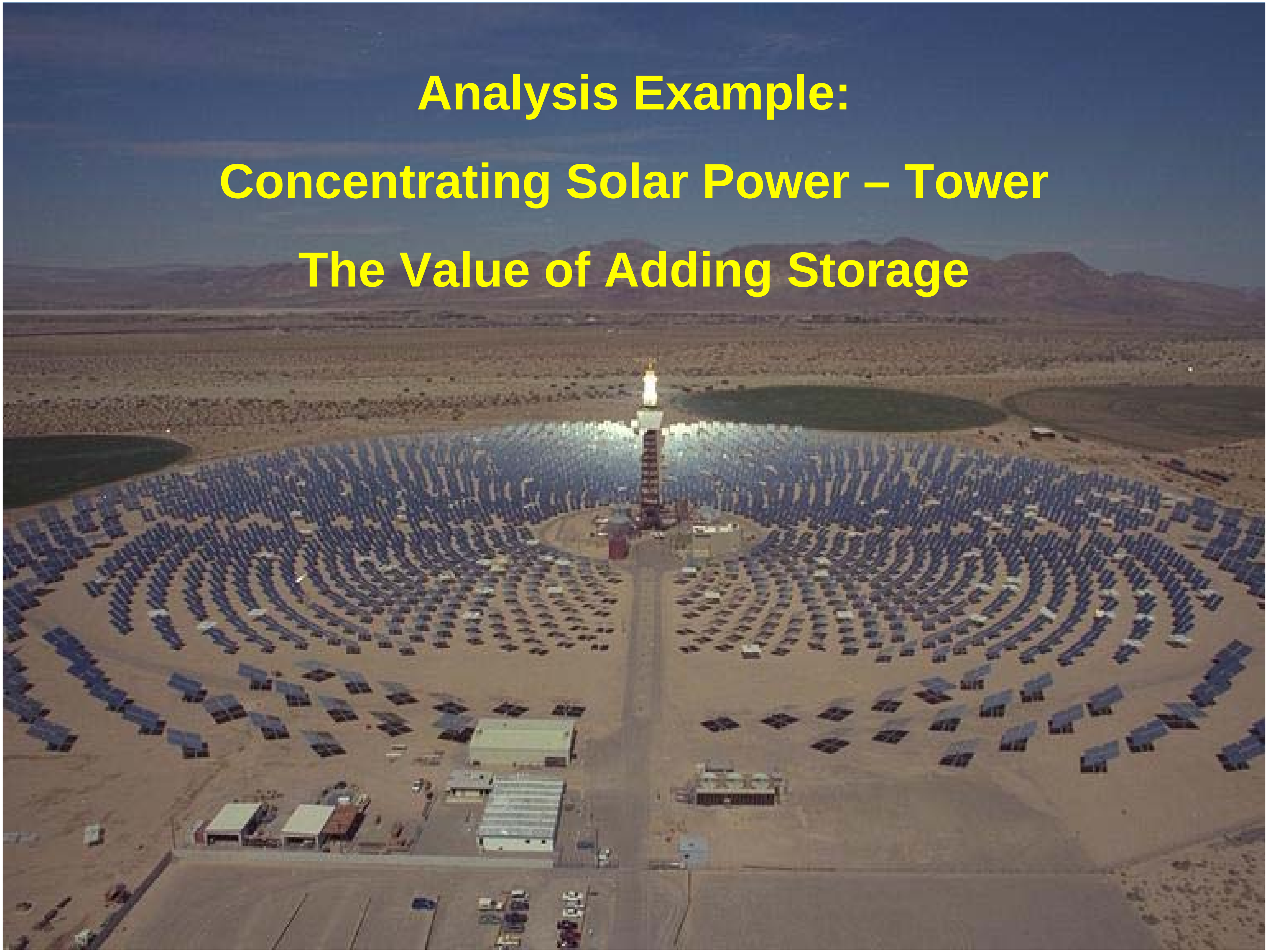
Unscheduled Maintenance Cost by Component (% of Total Unscheduled O&M)



Analysis Example:

Concentrating Solar Power – Tower

The Value of Adding Storage



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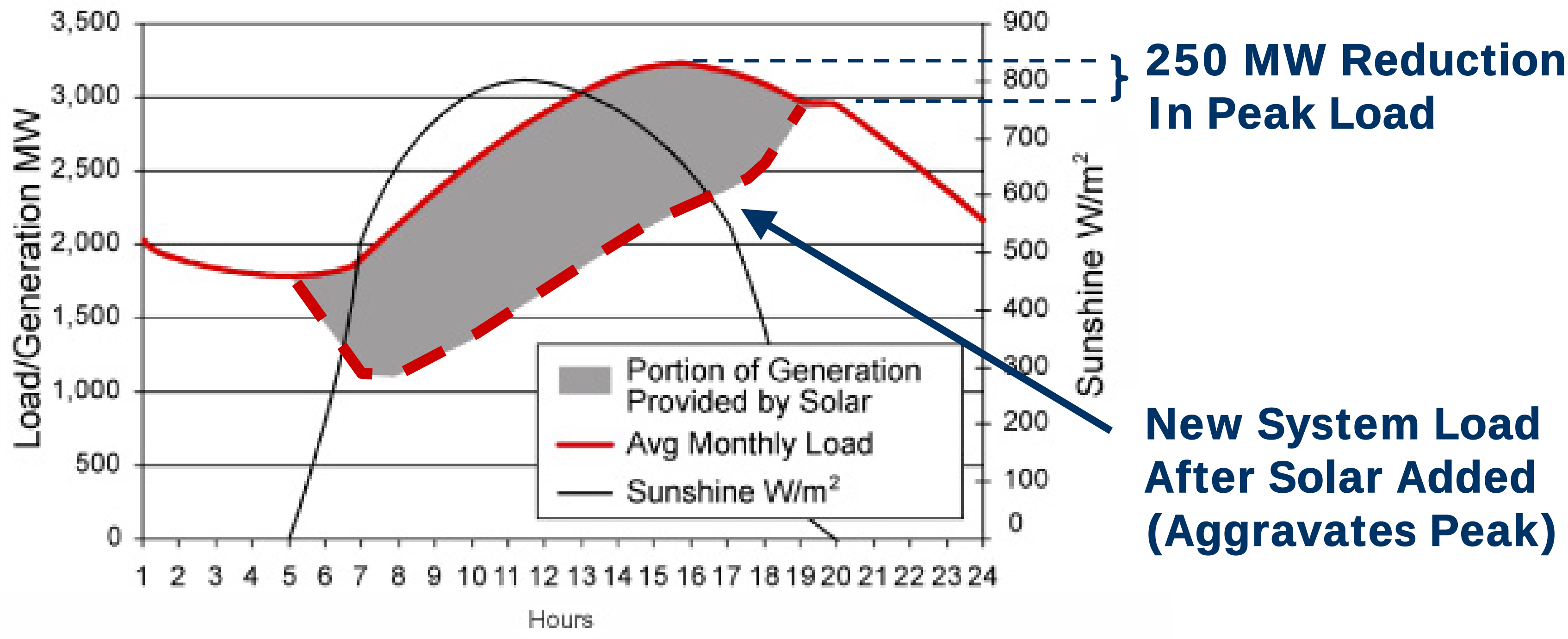
Analysis Example: Solar Plants w/o Storage

1250 MW Central Receiver Solar Plant No Thermal Storage



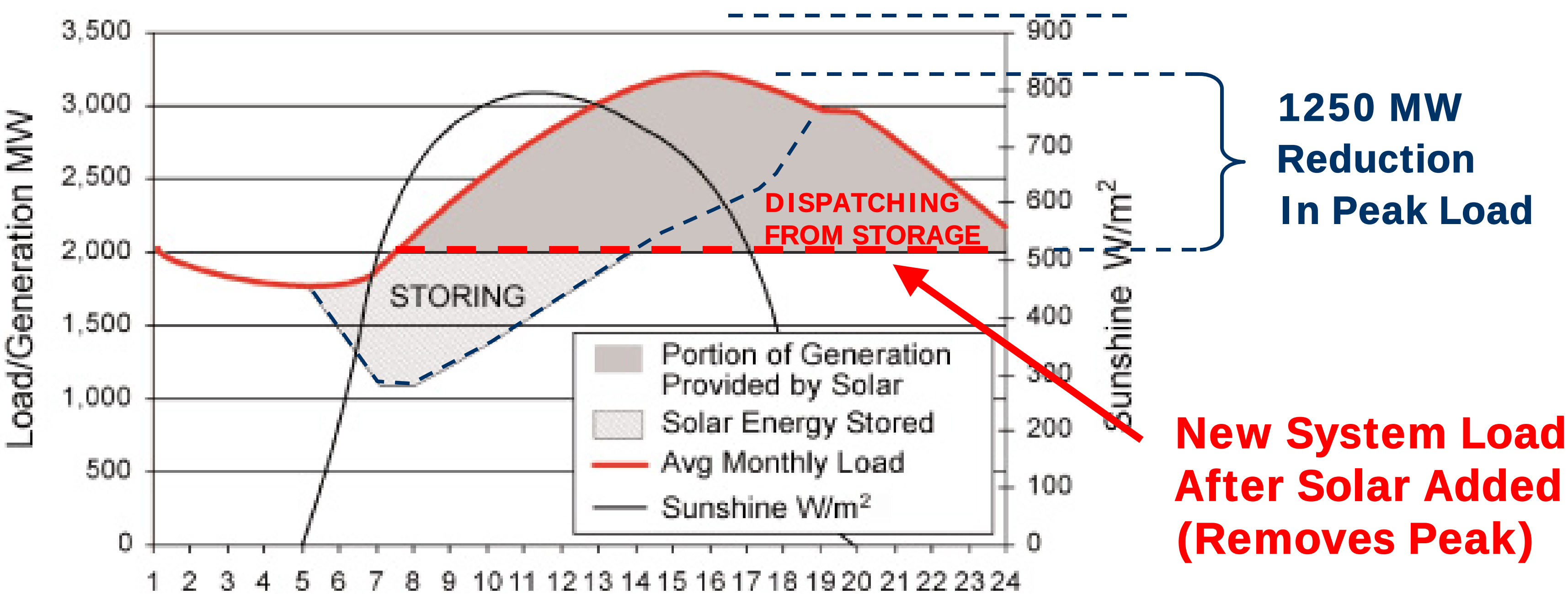
Nevada Power

Source: Platts Research and Consulting

Solar Plants w/ Storage

1250 MW Solar Plant
With Thermal Energy Storage

Exhibit 27: Generation of 1,250 MW of Solar with 3.5 Hours of Storage During Nevada Power's Summer Peak Month (August)



Source: RDI Consulting

Source: Platts Research and Consulting

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Summary for CSP with Storage

- Storage can lower levelized cost
  - Storage is proven for towers, planned for troughs
  - Increases capacity factor from ~25% up to ~70% (site dependent)
  - Increases efficiency (part-load, startup/shutdown, clouds)
  - Additional storage less costly than turbine, BOP
  - Annual O&M ($M) incr. but unit O&M ($/kWh) decr.
- Storage increases value & potential market share for utility-scale CSP technologies
- Similar analysis for PV?

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The role of storage in solar and systems driven approach

- ***Energy security:*** For any kind of energy security,storage is a requirement
- At present, storage is not strong in PV Systems Analysis Model
  - Early focus on demo of grid-tied, non-storage systems
  - Beta version next June will include MYTP configurations (incl. grid-tied residential with storage)
  - Future plug-ins for storage will be developed for other market segments
- Grid-tied systems of the future will benefit from storage
  - Energy security, reliability for homeowners and commercial users
  - Peak shaving, grid stabilization for utilities
    - City of Fairbanks, AK: 40 MW-hr battery bank
  - ***Microgrids –*** the distributed utility of the future

The role of storage in solar and systems driven approach

- Technical development is needed to make storage more economically and technically viable:
  - Integration of grid-tied PV and UPS systems
  - Control algorithms
  - Installation practices
  - Maintenance

  of batteries
- Must give consideration to the market sectors in SDA and prioritize inclusion of storage in modeling, analysis, and benchmarking:
  - Utility-scale
  - Buildings
  - Distributed
  - Off-grid