
# Photovoltaic (PV) Inverter and BOS Development & Testing

## for the DOE Solar Energy Technologies Program Peer Review

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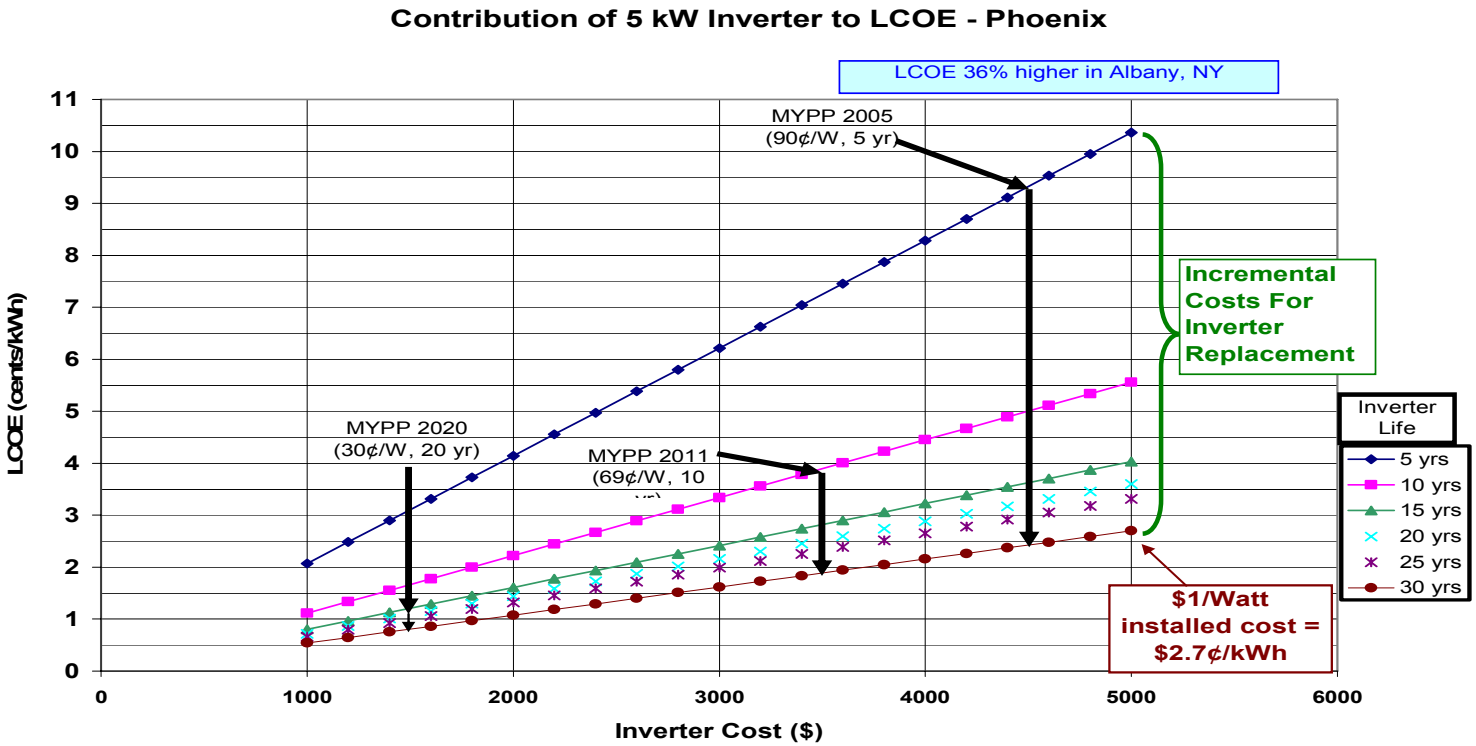
# PV Inverters and BOS RELEVANCE

## Advanced Inverter & BOS Designs & Performance Are Essential For A Successful USA PV Industry!

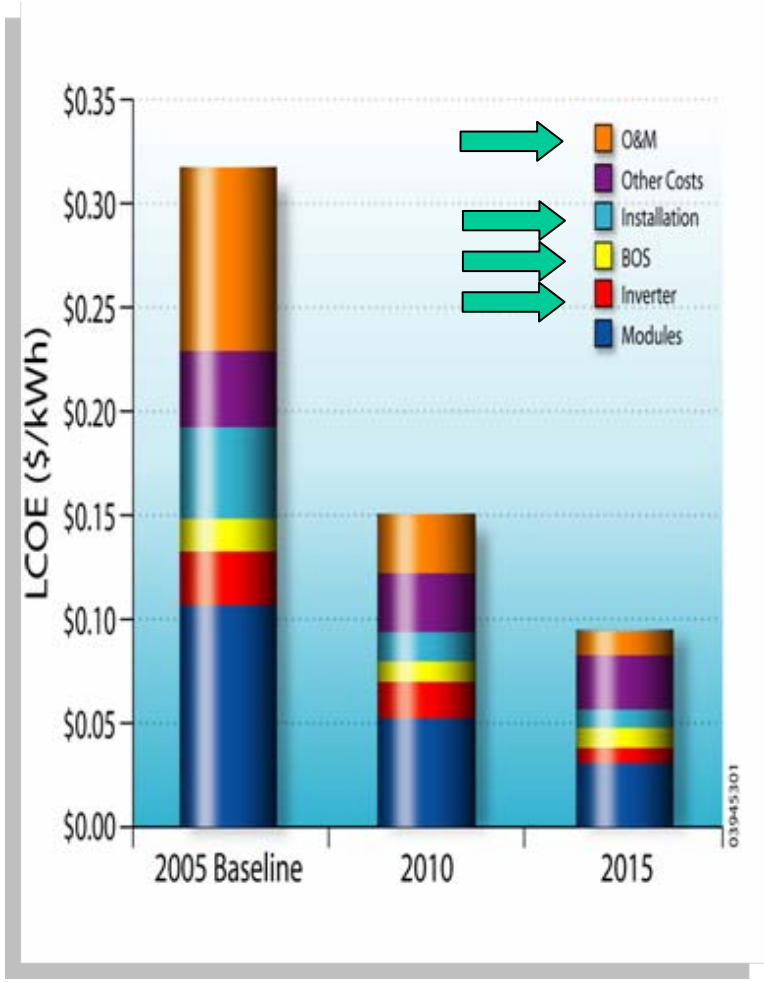



- **Advanced inverters/BOS are will improve system reliability, efficiency, LCOE**
- **The lifetime of the inverter should match that of PV modules and other BOS**
- **The goals of development and testing are consistent with the "Solar America Initiative" goals for LCOE ($.05 - $.10/kWh)**

# PV Inverters and BOS OBJECTIVES

## Improved Inverter & BOS Designs & Performance

- AOP tasks included:
  - 1) Inverter/BOS Performance Modeling and System Test Protocol Development,
  - 2) Applied R&D Industry Support
  - 3) Technology Acceptance
- Focus on power electronics/hardware advances through R&D, characterization and validations
- Feedback to industry
  - Encourages technology advances
  - Incorporation of new inverters/BOS into completely integrated systems
- Work tied to priorities derived from:
  - "DOE Workshop On a SDA to Inverter R&D"
  - "DOE High-tech Inverter" Workshop
  - SETP MYPP.



# PV Inverters and BOS TECHNICAL APPROACH

## SNL-directed Technology Development was Driven by Well-documented and Well-defined Requirements

- Coordinated with the industry/users
- Requirements based on present/potential markets and consumer/utility values
- Technology/R&D trade-off considered/prioritized via workshops and industry input
- "Testing and Evaluation" is prioritized to meet the goals of the PV program AND the industry needs.

# Inverters and BOS SUMMARY of ACTIVITIES

1. Inverter/BOS ***Hardware Development*** [(HRII) (Micro-inverter)]
2. Inverter/BOS Performance, ***Validations and Analysis***
3. Long-term Performance ***Test/Characterization*** of Inverters
4. Inverter/BOS ***Modeling and Protocol Development*** (PVSoL)
5. Applied Development with ***Support & Collaboration*** with Industry
6. Technology Acceptance Via Codes, Standards & Certification ***Development and Technical Validation***
7. Solar America Initiative Application ***Evaluations***


**PVSoL Inverters Under Long-term Tests**

# Inverters and BOS Development ACCOMPLISHMENTS

## The High-reliability Inverter Initiative (HRII)

- General Electric and Xantrex ***Completed*** HRII Phase III
- SNL ***Provided*** Technical ***Leadership*** along with Complex Prototype ***Evaluations/Analysis*** To Inverter/BOS Industry
- Micro-inverter Topology ***Feasibility*** & ***Concept Validation Completed***

# General Electric

- General Electric delivered its Phase II prototype to SNL for validation.
- GE Performed Preliminary Evaluations on its Phase III Prototype
- SNL benchmark evaluations and validations resulted in
  - Design improvements
  - Changes for the upgraded prototypes that were re-evaluated before designs moved on to the Phase III

# Inverters and BOS Results of GE Effort

| Requirement | | Result |
|---|---|---|
| MTBF >10 Years |  | Calculated better than 12 years |
| Efficiency > 94% |  | Peak efficiency near 94% (93.5% final design) |
| UL 1741 Certification |  | Preliminary design analysis only (UL delays) |
| Meet FCC Part 15, Class B |  | Exceeds requirements |
| DC/AC disconnects per NEC |  | Meets contractor's system requirements |
| Heavy duty power connections |  | Beta prototype showed improvements |
| DC and AC over current protection (150% for 30 seconds) |  | Innovative smart IGBT and DSP software solutions have been implemented |
| Non-volatile memory |  | Fully functional |
| Surge protected per IEEE C62.41 |  | Conducted at manufacturer's facility only |
| Cost of < $.90/watt (at quantities of 10,000/year) |  | Met and was better than "cost target"<br>*Note: Cost was not an initiative priority* |
| TDD (total demand distortion) < 5% |  | Meets the IEEE519 requirements |
| Compliance w/ IEEE 929 (IEEE1547) |  | Meets the IEEE929 requirements (Now 1547) |
| Contract Status |  | Completed beta model & tested @ SNL.<br>Completed gamma model and tested @ GE.<br>Funding & redesign delays had negative impacts.<br>GE is designing a more competitive inverter. |

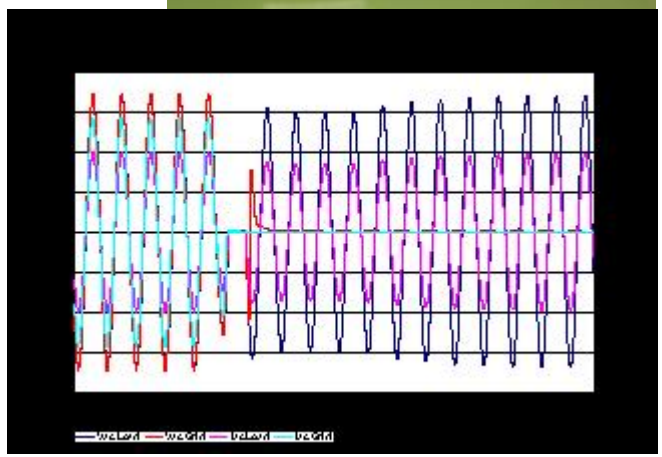
# GE HRII Advances Summary

- GE initiated, developed and continues with its total system concept of vertically integrated PV systems for the new construction market
- The design integrated internal protection (IGBT), innovative DSP controls, wide (dual input) PV operating window and active communications
- The inverter development was a pioneering project for transformerless inverters in the U.S.
- GE continues improvements in cost and efficiency with a high reliability/lower cost focus
- Results of the work (12-year MTBF) is a major step toward the SAI (LCOE) goals

# Inverters and BOS Accomplishments

## Xantrex

- Xantrex delivered its Phase II and Phase III inverter and charger prototypes to SNL.
- SNL benchmark evaluations/validations resulted in
  - Improvements in MPPT, anti-islanding, thermal layout, hardware & control methodologies
  - Changes for upgraded prototypes were re-evaluated before design moved to Phase III



# Inverters and BOS Results of Xantrex Effort

| Requirement | | Result |
|---|---|---|
| MTBF >10 Years | | Calculated @ better than 10 Years |
| Efficiency > 94% | | Peak efficiency is near 94%-(93.5 U-I) Exceeds all known S-A inverter efficiencies. |
| UL 1741 Certification | | Listed through ETL and CSA 107.1 |
| Meet FCC Part 15, Class B | | Exceeds requirements |
| DC/AC disconnects per NEC | | Meets contractor's system requirements |
| Heavy duty power connections | | Innovative XW packaging; IMS Power Ckts. |
| DC and AC over current protection (150% for 30 seconds) | | Surges to 200% with stand-alone MPPT for both S-A and U-I |
| Nonvolatile memory | | Fully functional |
| Surge protected per IEEE C62.41 | | Conducted at manufacturer's facility only |
| Cost of < $.90/watt (at quantities of 10,000/year) | | Met and was better than "cost target" *Note: Cost was not an initiative priority* |
| TDD (total demand distortion) < 5% | | Meets the IEEE519 requirements |
| Compliance w/ IEEE 929 (IEEE1547) | | Meets the IEEE929 requirements (Now 1547) |
| Contract Status | | Xantrex has completed commercial design. Final testing @ SNL in Nov 2006. Funding & redesign delays had negative impacts. |

# Xantrex HRII Advances Summary

- Initiated, developed and continues with system concept of vertically integrated PV systems for any combination of battery based SA+UI applications
- The inverter used insulated-metal substrate (IMS) for robust circuit boards, "Xanbus" communications for interface/controls and new, innovative DSP controls
- The Xantrex inverter development will be used as the product base for many new Xantrex products
- Commercialization of the XW series of products is a giant step toward fully-integrated systems

# Resulting Xantrex Commercialized HRII System Product

# Inverters and BOS T&E SNL Accomplishments

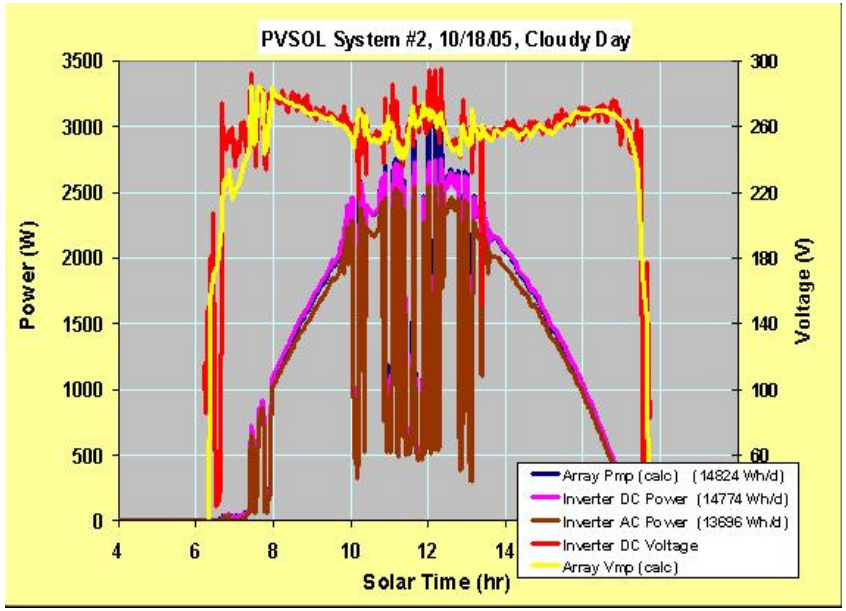
## Industry Support (Tests, Evaluations, Product Development)

- **Key Alpha and Beta Inverter Tests and Evaluations for Industry Development**
  1. Beacon Power M5
  2. Xantrex GT
  3. Solectria (2500)
  4. PVPowered (2800XV)
  5. PVPowered (30kW)(3-phase)
- **Industry Received Support and Analysis of Inverter Operations and Performance**

# Inverters and BOS T&E SNL Accomplishments

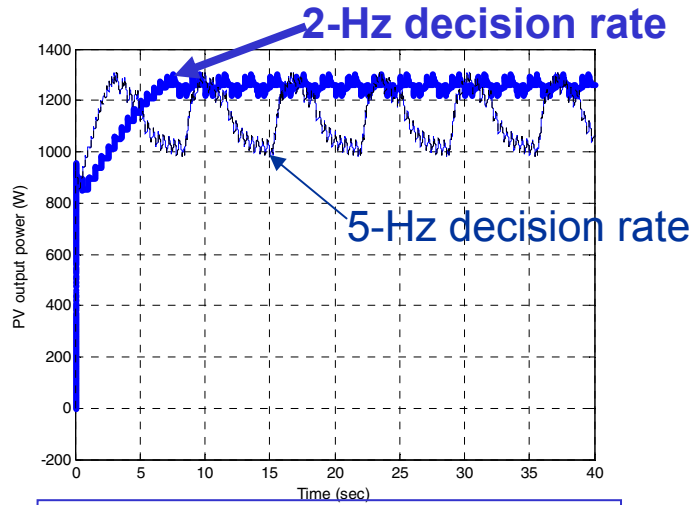
## Modeling, Long-term Tests and Protocols

- Completed PVSoL Benchmark Characterizations (5 Inverters)
- Data Provided Input for Inverter "Performance" Model (PV SAM)
- Data Supported SNL (MATLAB/Simulink) Inverter "Development Model"

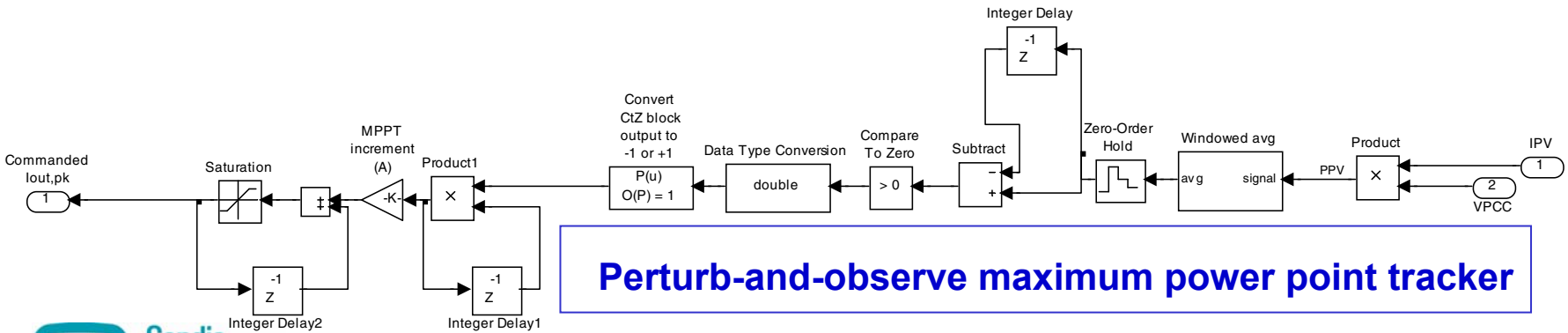



# SNL MATLAB/Simulink Inverter "Development" Model

- Models MPPT controls
- Simulates PV Array Responses
- Simulates Safety Responses
- Supports Standards Development




**Model predicts oscillation as MPPT decision rate increases**




**Perturb-and-observe maximum power point tracker**

# All CPS Milestones/Deliverables Were Met Or Significantly Advanced as They Were Folded Into The SAI

| Agreement ID | Title | AFP Recipient | Prime Awardee |
|---|---|---|---|
| 9786 | High Reliability Inverter Initiative-Base | Sandia National Laboratory (SNL) | Sandia National Laboratory |
| 9790 | Inverter Development & Manufacturing R&D | Sandia National Laboratory (SNL) | Sandia National Laboratory |

| Milestone ID | Title | Planned Complete | Actual Complete | Status |
|---|---|---|---|---|
| 23481 | Conduct High-tech Inverter, BOS and Systems Integration Project as the initial phase of the "High-tech 5-year Strategies" | 9/30/2006 | 9/22/2006 | Complete |
| 25068 | Complete prototype and component evaluations and verifications to establish and verify high-reliability inverter performance and characteristics. | 2/1/2006 | 2/1/2006 | Complete |
| 25179 | Complete High-reliability commercialized inverter designs and verifications of performance and design. | 12/29/2006 | 3/15/2007 | Complete |
| 25180 | Initiate contracts for “High-tech Inverter, BOS & Systems R&D Strategies” concepts that will seek to combine inverter R&D with new electronic technologies and integrate designs into complete systems. | 9/30/2006 | | To SAI |
| 25181 | Report on High-tech Inverter to Systems Workshop | 12/29/2006 | 12/29/2006 | Complete |
| 25249 | Send Request for Proposals for High-tech R&D | 9/30/2006 | | To SAI |
| 25250 | Review and Select winning proposals to initiate high-tech R&D strategies | 9/30/2006 | | To SAI |
| 25251 | Conduct High-tech Inverter to Systems Link Workshop | 9/28/2006 | | To SAI |
| 25252 | Complete Final Reports on High-reliability prototypes, evaluations and verifications with commercialization plans | 9/30/2006 | 2/1/2007 | On Track |

# All CPS Milestones/Deliverables Were Met Or Significantly Advanced as They Were Folded Into The SAI

**Agreement: PV System Performance Testing, Modeling, and Aging (Agreement ID: 13574)**

| Milestone ID | Title | Plan Complete | Actual Complete | Status |
|---|---|---|---|---|
| 25413 | Complete and document baseline performance of five commercial inverter types used in initial phase of long-term inverter performance evaluation at SNL, FSEC, and SWTDI. | 1/1/2006 | 11/1/2006 | Complete |
| 25414 | Joint report with FSEC and SWTDI describing new inverter aging and performance characterization capabilities and procedures. | 6/1/2006 | | Individual Reports |
| 25415 | Continued effort to develop and improve a general performance model for inverters including characteristics associated with dc/ac efficiency, MPPT effectiveness, start up, shut down, power limiting, thermal derate, and power factor. | 9/30/2006 | | On Track & to SAI |

**Agreement: Codes, Standards, and Certification (Agreement ID: 13493)**

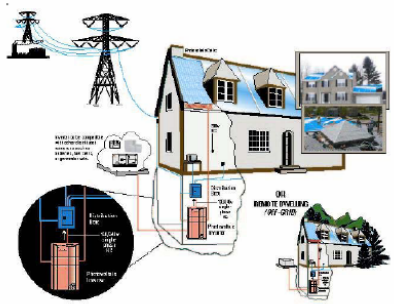
| Milestone ID | Title | Plan Complete | Actual Complete | Status |
|---|---|---|---|---|
| 25041 | Support Practitioner Certification through incremental funding for NABCEP. | 8/1/2006 | Ongoing | Complete |
| 25042 | Provide Proposed National Electrical Code Changes per the SNL Industry Forum to the National Fire Protection Association | 11/4/2005 | 12/6/06 | Complete |
| 25253 | Submit Revised Inverter Performance Certification Protocol for IEEE or IEC Standard Consideration | 9/30/2006 | | On Track & to SAI |
| 25254 | Initiate PV Module Performance Certification Forum | 12/1/2005 | On Going | To SAI |

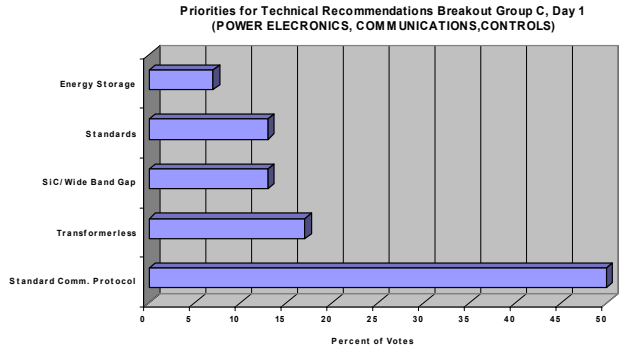
# Inverters and BOS Budget History

| SNL Project Areas | FY06 $K | FY07 $K |
|---|---|---|
| Inverter/BOS Development, Manufacturing R&D, & Testing | 380* | 1000* |
| System Performance Optimization, Modeling, and Benchmarking | 835 | 850 |
| Module, Array, and System Manufacturing, Reliability, Test and Evaluation | 300 | 1500 |

**Relates to information provided in this presentation*

# Inverters/BOS/Systems & Energy Management - Future Directions






- TPPs will likely produce EVOLUTIONARY and short-term inverter advances.
- However "REVOLUTIONARY (leap-frog) Changes" are needed.
- "Advanced Integrated Inverter & Energy Management Technology Initiative" will:
  - Fill critical inverter/integration gaps
  - Provide complementary, long-term inverter/system development utilizing new (high-tech) technology advances and like-technology synergisms
  - Complement critical technical issues (TIOs) such as building integration, surge protection, thermal management, communications, magnetics, advanced semiconductors, packaging, materials compatibility, and safety.
- DOE Headquarters and SNL developed a 5-year initiative (1st Workshop at SETP Program Review 4/17-19/07)
- The 5-year plan will include workshops to solicit inputs. Technical workshop (May 10-11, 2007, Albuquerque, NM) will contribute to needs/priorities.


THANK YOU!