Sandia Photovoltaics Program

Managers

Charlie Hanley and Jeff Nelson

Sandia National Laboratories

Solar Program Mission

- **Work with Solar industry to develop new integrated components and systems**
  - World Class measurements and characterization capabilities and facilities
  - Enhanced understanding of performance & reliability
  - Improved, integrated overall systems
  - Increased manufacturing yield and throughput
- **Develop innovative technology solutions by partnering with internal and external R&D groups**
- **Perform comprehensive systems analysis and benchmarking of current and future systems concepts**

Maintain and enlarge Sandia's role as an "honest broker" among U.S. industry and stakeholder community for integrating, characterizing, and improving Solar systems.

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Sandia's Photovoltaic Facilities

PV Systems Evaluation and Optimization Lab




Distributed Energy Technology Lab


Sandia National Laboratories

SOLAR AMERICA INITIATIVE

Reducing Solar Costs to Grid Parity in All U.S. Markets By 2015





SAI Photovoltaic (PV) R&D activities will emphasize **technologies with the greatest potential for cost reductions** to meet SAI goals. SAI will also continue current efforts on CSP systems R&D.

To accelerate attainment of systems goals, SAI will employ **public-private partnerships to pursue component and system technologies and demonstrate manufacturing approaches** that deliver low-cost, high-reliability commercial products.

Partnership members will market and distribute PV systems developed under SAI, while SAI **technology acceptance efforts tackle non-R&D barriers to market penetration** for both PV systems and CSP technologies.

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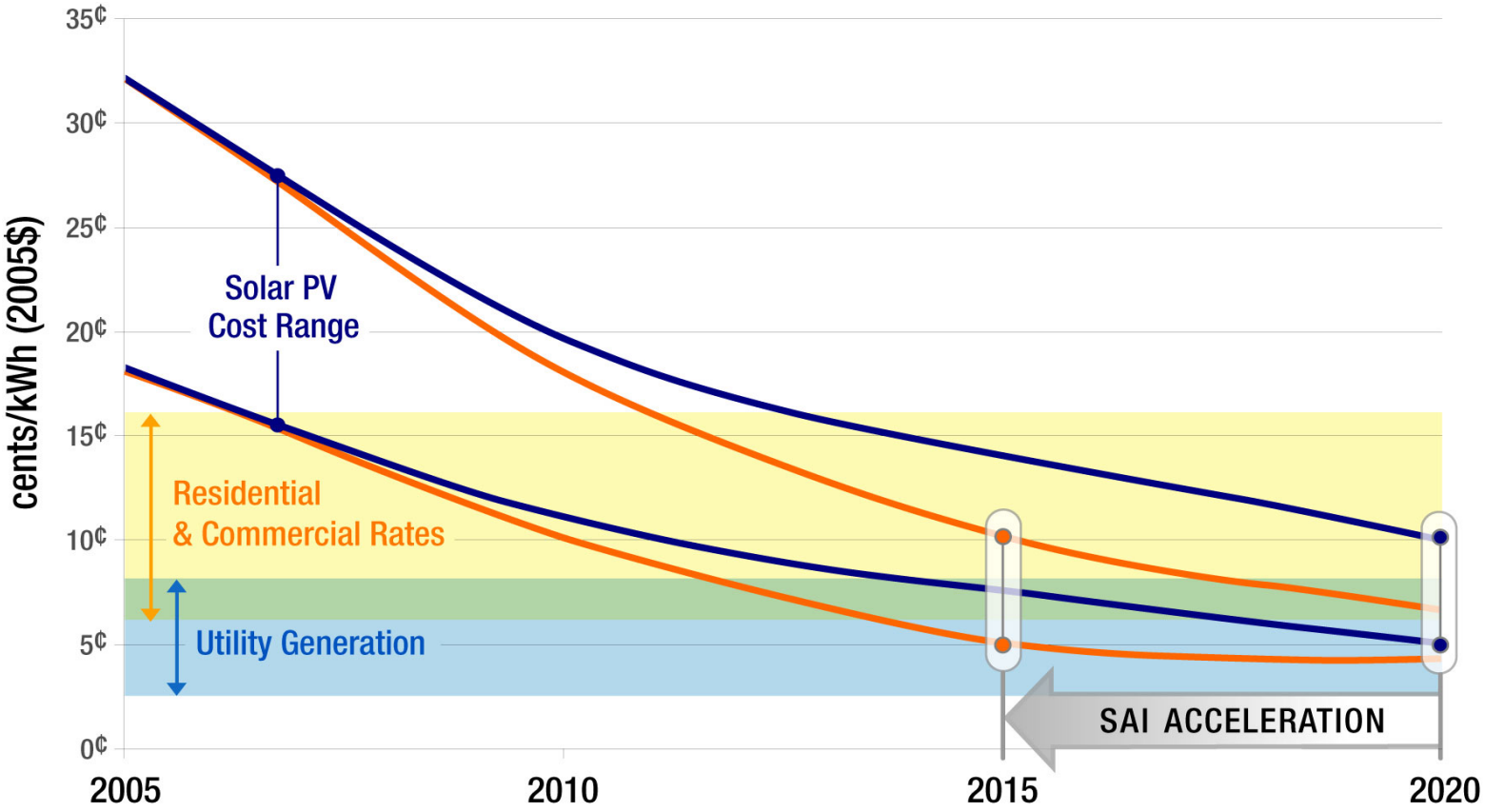
Solar America Initiative: Projected Market Impact

Projected Cost Reductions for Solar PV



Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8-16.7	23-32	13-18	8-10
Commercial	5.4-15.0	16-22	9-12	6-8
Utility	4.0-7.6	13-22	10-15	5-7

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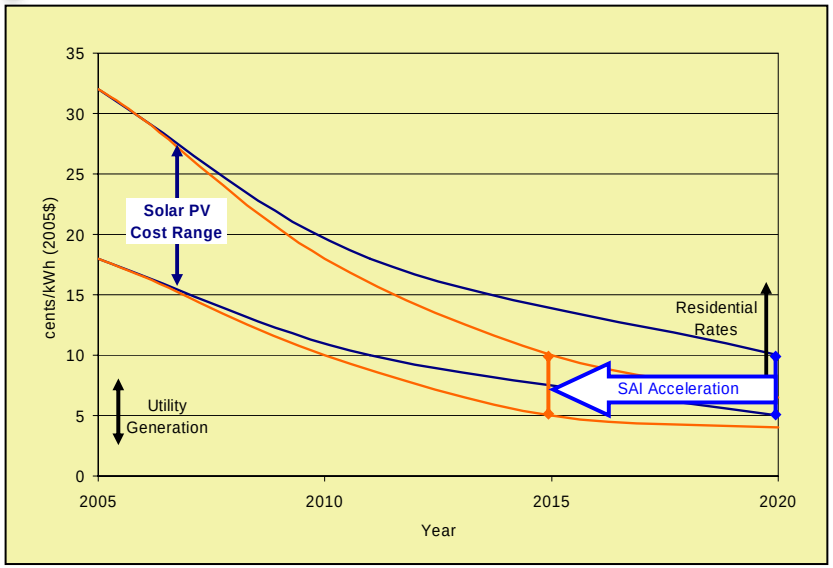
SAI and the Sandia PV Program



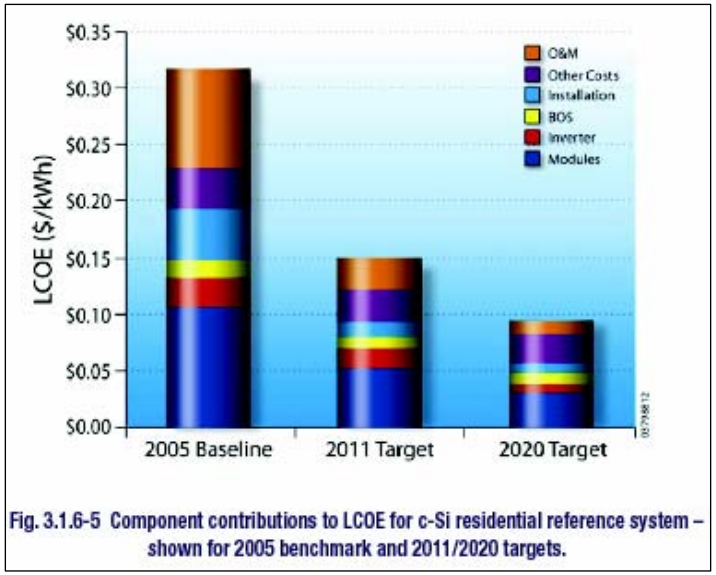


Fig. 3.1.6-5 Component contributions to LCOE for c-Si residential reference system – shown for 2005 benchmark and 2011/2020 targets.

SAI Support Areas:

- Systems Development
- Technology Evaluation
- Market Transformation
- Operations & Planning

SNL Program Leadership:

- Module Performance & Reliability
- Inverter T&E
- Systems Optimization, T&E
- Lab/Field Benchmarking & Evaluation
- Performance Models
- Systems Analysis & Modeling

Research and Development:

- Renewable Systems Interconnection (DG, microgrids)
- Advance Materials and Manufacturing Diagnostics
- Novel Device Concepts and Architectures

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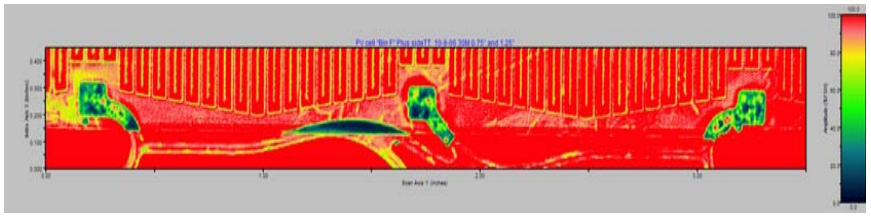
Working with Local Industry on New Commercial Technologies

PV Startup in Mesa Del Sol
Sandia Developed Technology/Staff

First Company in Science Park
Sandia Developed Technology/Staff



RD Devices → Commercial Products

Space PV → Terrestrial PV

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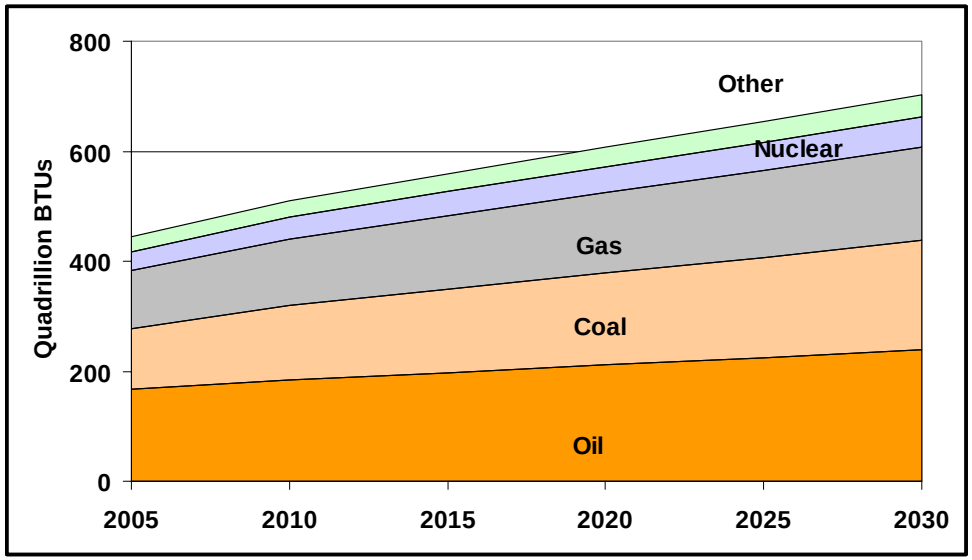
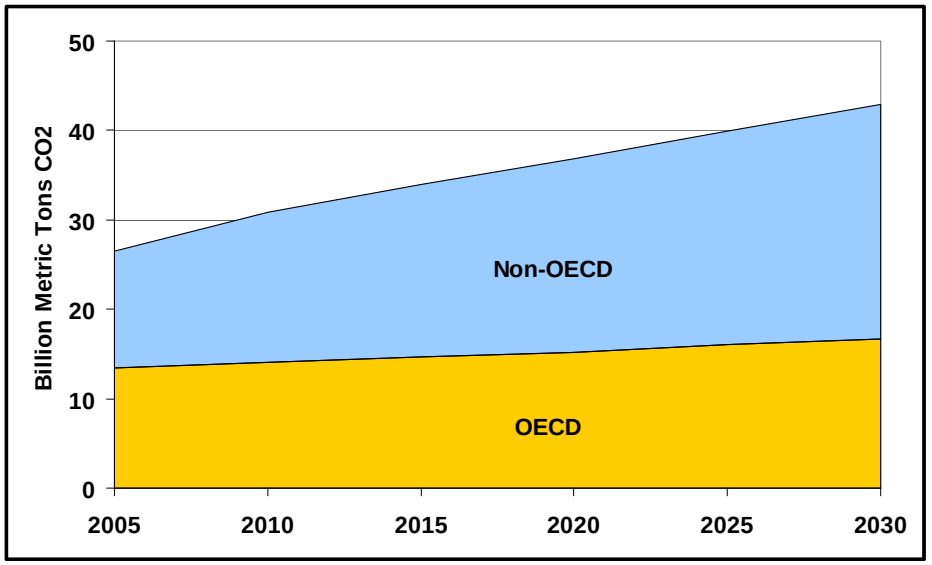
Between Now and 2030, World Energy Demand and Carbon Emissions Will Grow ~65%

Global Energy Demand



Global Carbon Dioxide Emissions



Source: USDOE EIA IEO 2006 Reference Case (updated October 2007)

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Options & Challenges

- **Continue to Buy Fossil Fuels from our "Neighbors"**

  - ***Energy Security and Economic Vulnerabilities***

- **Begin Expanding our use of Unconventional Fossil Resources**

  - ***Increased Environmental Concerns***

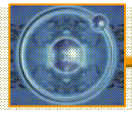
- **Expand Biofuels Efforts**

  - ***Land use; Water; Compatibility with existing infrastructure***

- **Expand Nuclear Power Efforts**

  - ***Permitting; Waste Archival***

- **Hydrogen**



  - ***R&D Advances Needed; Infrastructure***

- **Expand Renewable Energy Content of our Infrastructure**

  - ***Variability; and Geographic Diversity;Electricity & Transportation Sectors***

- **Fusion Energy**

  - ***Fundamental materials and physics advances needed***

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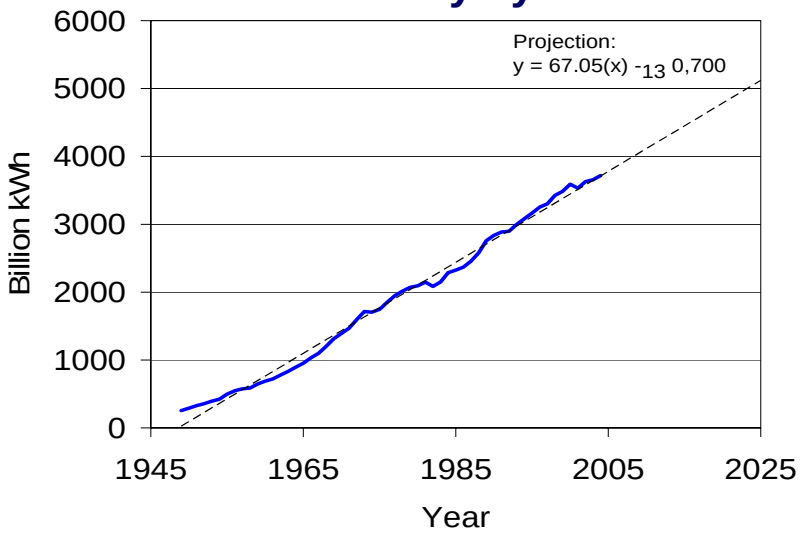
Tomorrow's Electricity Grid Will Face Many Challenges

U.S. Will Need 50% more Electricity by 2030



Aug. 13, 2003, at 9:21 p.m. EDT

Aug. 14, 2003, at 9:03 p.m. EDT

Challenges:

- **Energy Security and Economic Growth**
- ***Increasing electricity demand with minimal increased T&D capacity***
- **Increased need for low CO_2 emissions, for climate change concerns**
- **Allow incorporation of new US-based carbon-free central/distributed RE sources, many of which are variable in nature**
- **Meet increased power quality and reliability requirements dictated by load sensitivity (mobile, digital world)**
- **Robust against natural disasters and terrorist attack**
- **Enable increased electrification of $_{th}$ e transportation sector**
- **Provide superior customer value**

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Sandia's Energy Futures Group Develops Tools for the Future Electric Grid

- Demonstration of optimal energy usage at several levels:
  - Regional transmission grid
  - Distribution grid (including microgrids)
  - Within the home or building
- Distributed control architectures
- Communication protocols
- Advanced storage technologies and applications
- New hardware and equipment for power conversion, energy management, switching, monitoring, etc.

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Distributed Energy Technologies Laboratory is the centerpiece of Sandia's efforts

- Configurable testbed where new hardware integrations can be tested and optimized
- Simulation of precise daily load profiles to represent several different microgrids:
  - A single residence (with multiple loads)
  - Multiple residences
  - One or more commercial buildings
  - A mix of these situations (non-balanced loads)
- Addition of generators and motor loads to the microgrid to simulate real life situations

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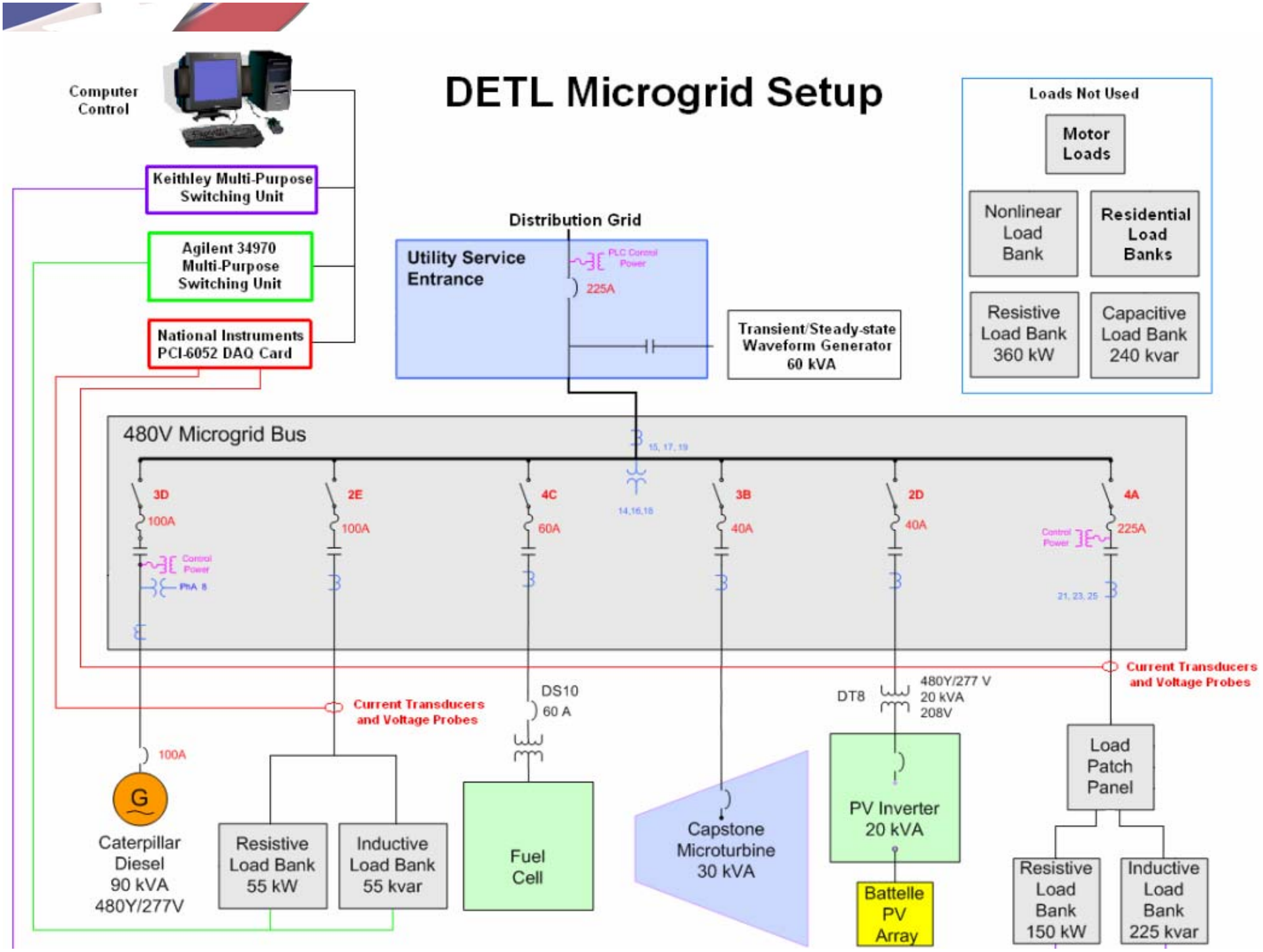
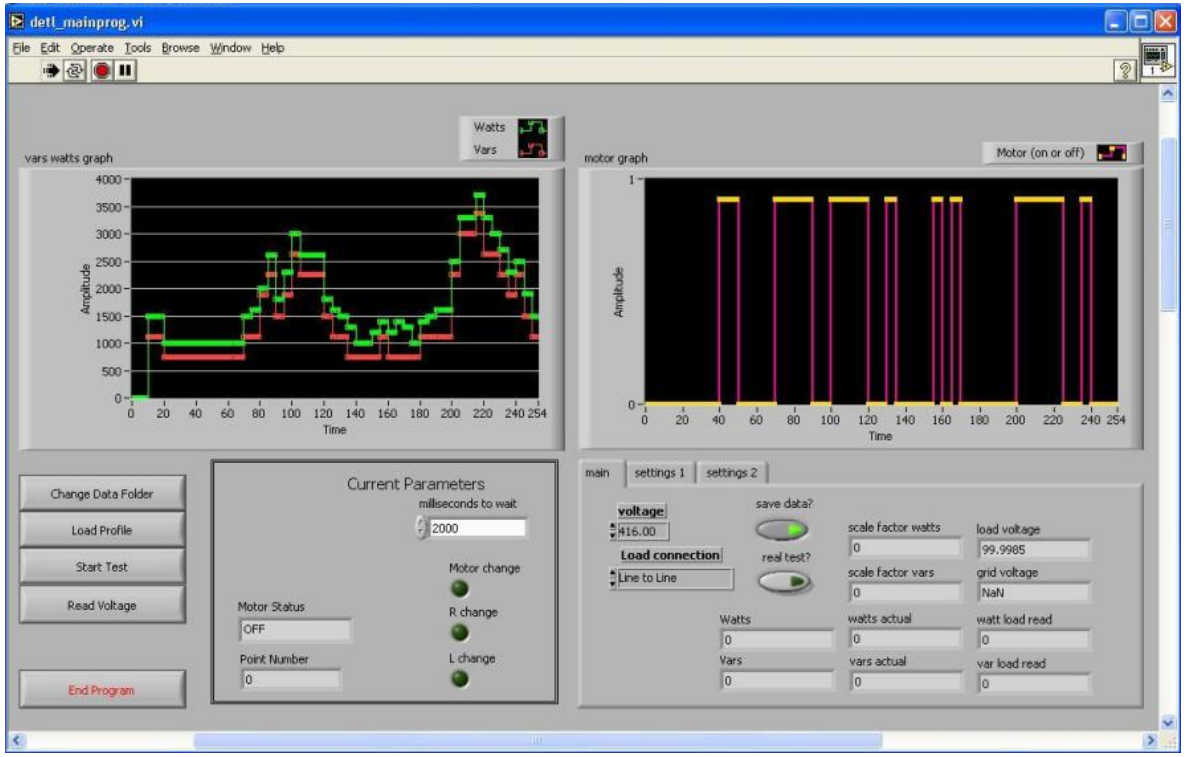

DETL Microgrid Setup
Computer Control
Keithley Multi-Purpose Switching Unit
Agilent 34970 Multi-Purpose Switching Unit
National Instruments PCI-6052 DAQ Card
Distribution Grid
Utility Service Entrance
PLC Control Power
225A
Transient/Steady-state Waveform Generator 60 kVA
Loads Not Used
Motor Loads
Nonlinear Load Bank
Residential Load Banks
Resistive Load Bank 360 kW
Capacitive Load Bank 240 kvar
480V Microgrid Bus
15, 17, 19
14,16,18
3D
100A
Control Power
PhA B
2E
100A
4C
60A
3B
40A
2D
40A
4A
Control Power
225A
21, 23, 25
Current Transducers and Voltage Probes
Current Transducers and Voltage Probes
DS10
60 A
DT8
480Y/277 V
20 kVA
208V
100A
G
Caterpillar Diesel 90 kVA 480Y/277V
Resistive Load Bank 55 kW
Inductive Load Bank 55 kvar
Fuel Cell
Capstone Microturbine 30 kVA
PV Inverter 20 kVA
Battelle PV Array
Load Patch Panel
Resistive Load Bank 150 kW
Inductive Load Bank 225 kvar

Custom Software Creates User-Specified Load Scenarios



Custom software created to control the load banks, to follow the desired profile, and record the results.

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Residential and Commercial-Size Resistive Banks

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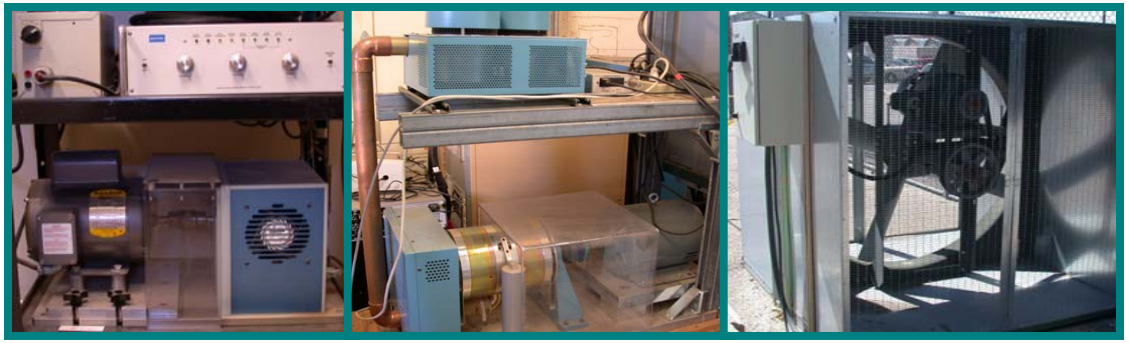
Loads for Hardware Configurations: Motor, Capacitive, Inductive, and Nonlinear



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Power Components Available

The ability to represent many real world power conditions exists, ranging from single phase to three phase microgrids

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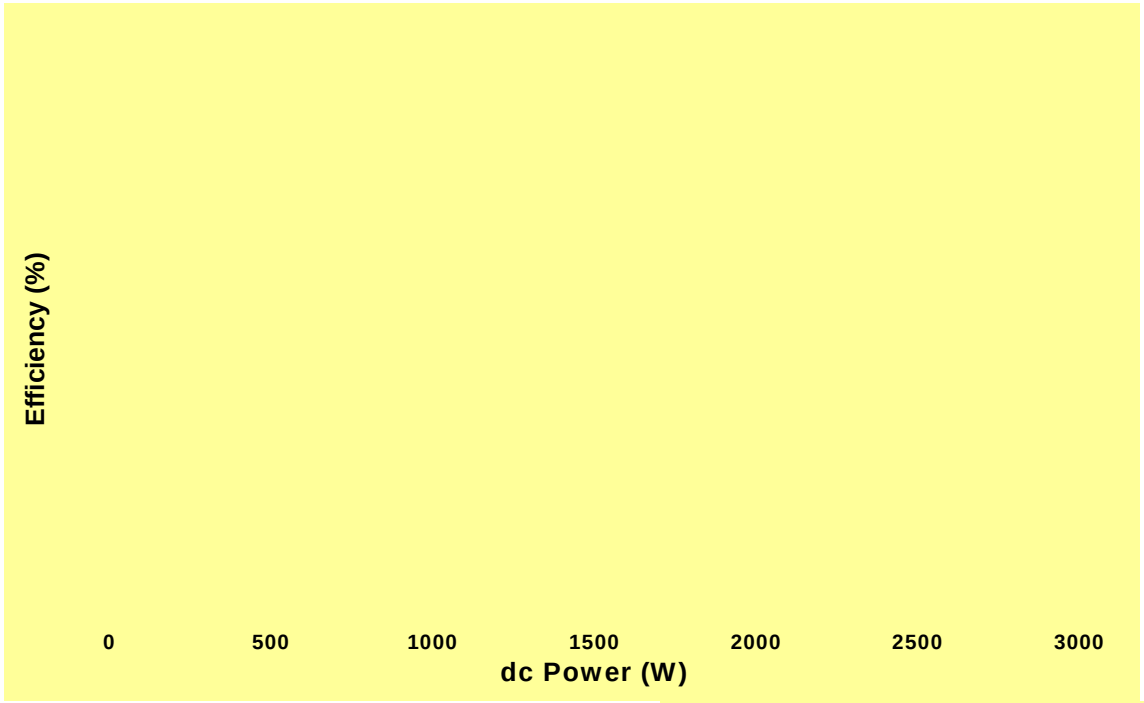
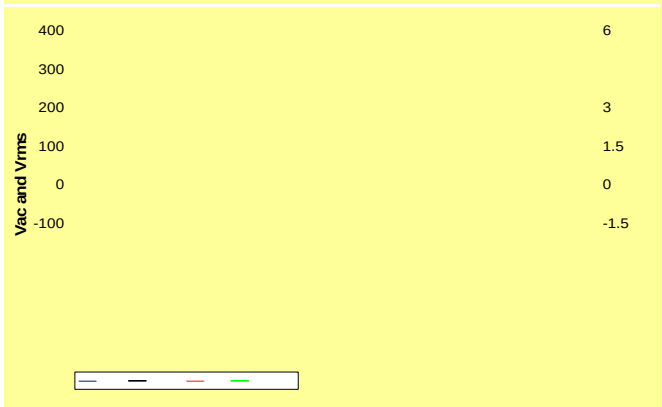
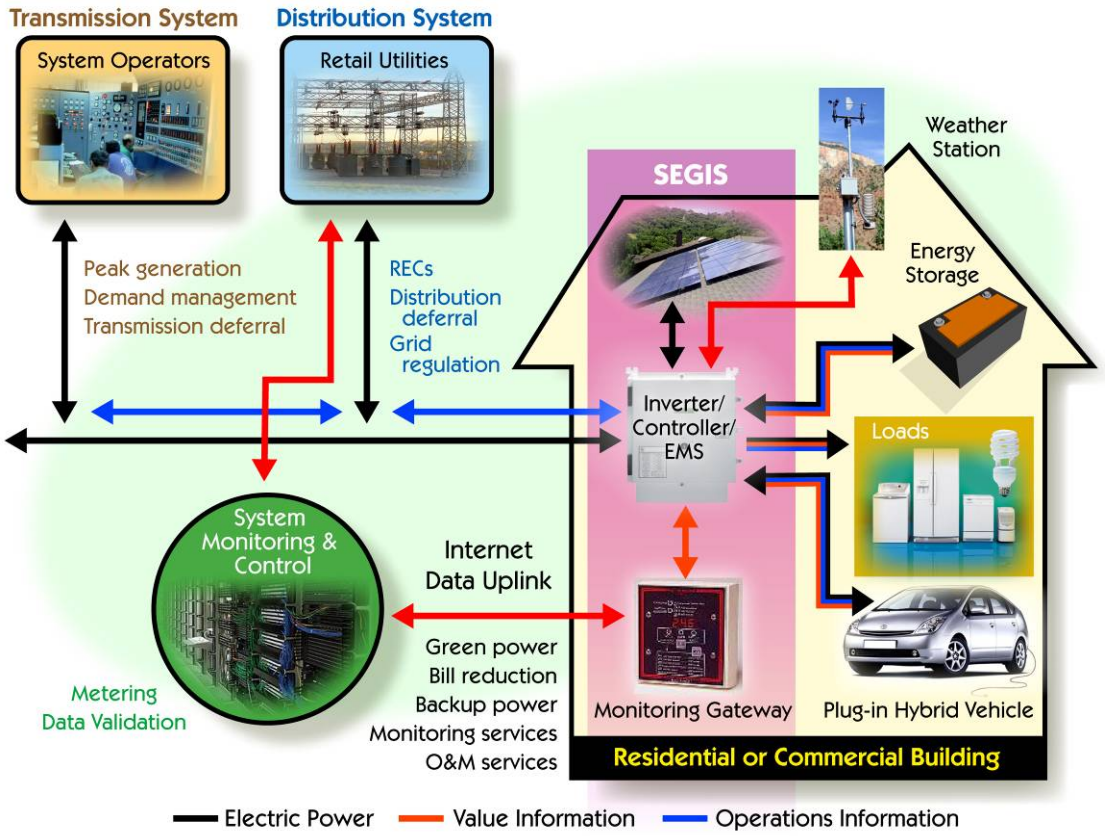

Efficiency (%)
0
500
1000
1500
2000
2500
3000
dc Power (W)


Vac and Vrms
400
300
200
100
0
-100
6
3
1.5
0
-1.5


500
400
200
50
40
20

DETL is Developing Next-Generation Solar Energy Grid Integrated Systems



SEGIS: Current partnership with industry – Sandia is reviewing 26 proposals for new hardware; will award 14 teams to start development

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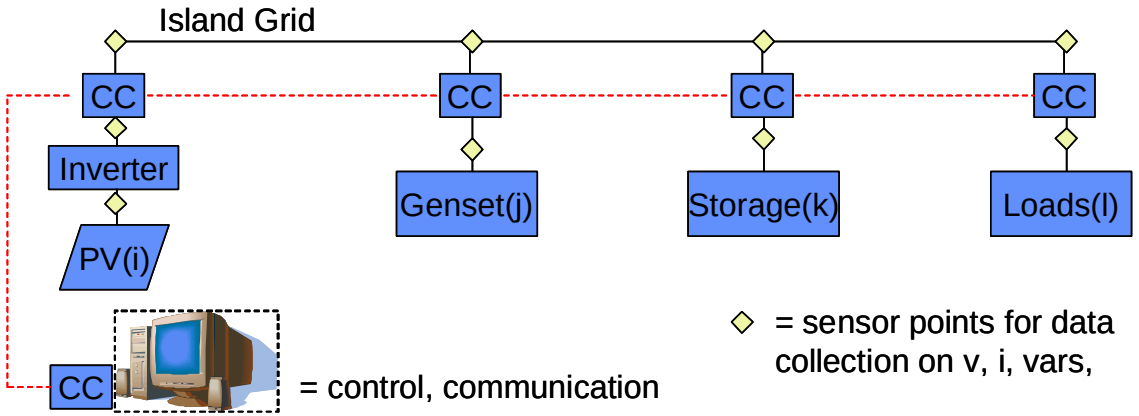
Simulating Real-World Microgrids at DETL
Example: Hawaiian Island of Lanai



Characteristics:
- **5MW grid; diesel-based**
- **1.5MW PV recently purchased**
- **2 large resorts are main loads, plus 1200 homes**

Issues being addressed:
- **Moving from diesel-based to 100% renewable grid**
- **Optimal amount/location of storage**
- **Distributed control algorithms**
- **Load management**

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Summary: Sandia's DETL is a hardware/software showcase for new energy management technologies

- **Current technology developments**
  - Inverters with storage management, voltage regulation
  - Time-of-use load controller
  - Communications with utility signals
- **Fully-integrated PV systems performance model**
  - Modifying to include other generators
- **Solar Energy Grid Integrated Systems (SEGIS)**

Many partner organizations:

- Mesa del Sol – planned community with 38,000 homes
- Utilities: Public Service Co. of New Mexico; Tucson Electric Power; others
- Military partnerships for improved reliability on bases
- Industry – manufacturers of new commercial products

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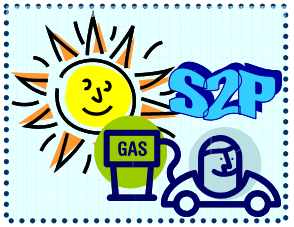
Solar Fuels: Sunshine to Petrol



Vision: **To directly, efficiently, and cost effectively produce infrastructure compatible liquid fuels employing the same resources as nature (Sunlight, CO_2 and H_2O).**

Sunlight + CO_2 + H_2O = Fuel + O_2

Sunlight + CO_2 + $2H_2O$ → CO + $2H_2$ + $(3/2)O_2$→ CH_3OH (Methanol)

Target

>10x sunlight to fuel efficiency than biomass

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Nature Has Helped Us in the Past

- Each gallon of gasoline is equivalent to tons of prehistoric biomass, processed at low temperature for millions of years (ancient stored solar energy)

- We need to speed up the process, via solar driven high temperature thermochemistry-

→ we only have 25-75 years to get this right.

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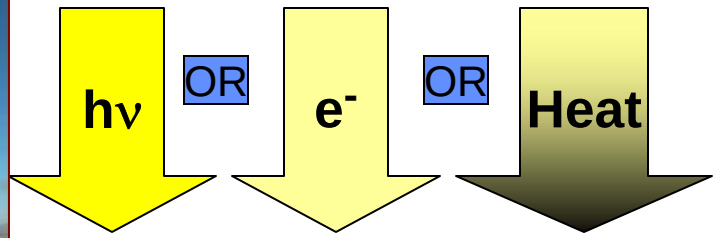
Solar Driven CO_2 to Fuel
Biofuels Without the Biology



CO_2

H_2O

Energy Input
(Reduction)

CO_2
H_2O

Fuel
O_2

Energy Recovery
(combustion)

Transportation Fuels (Gasoline, Diesel, Jet Fuel)
Natural Gas (CH_4)
Chemical Precursors

O_2

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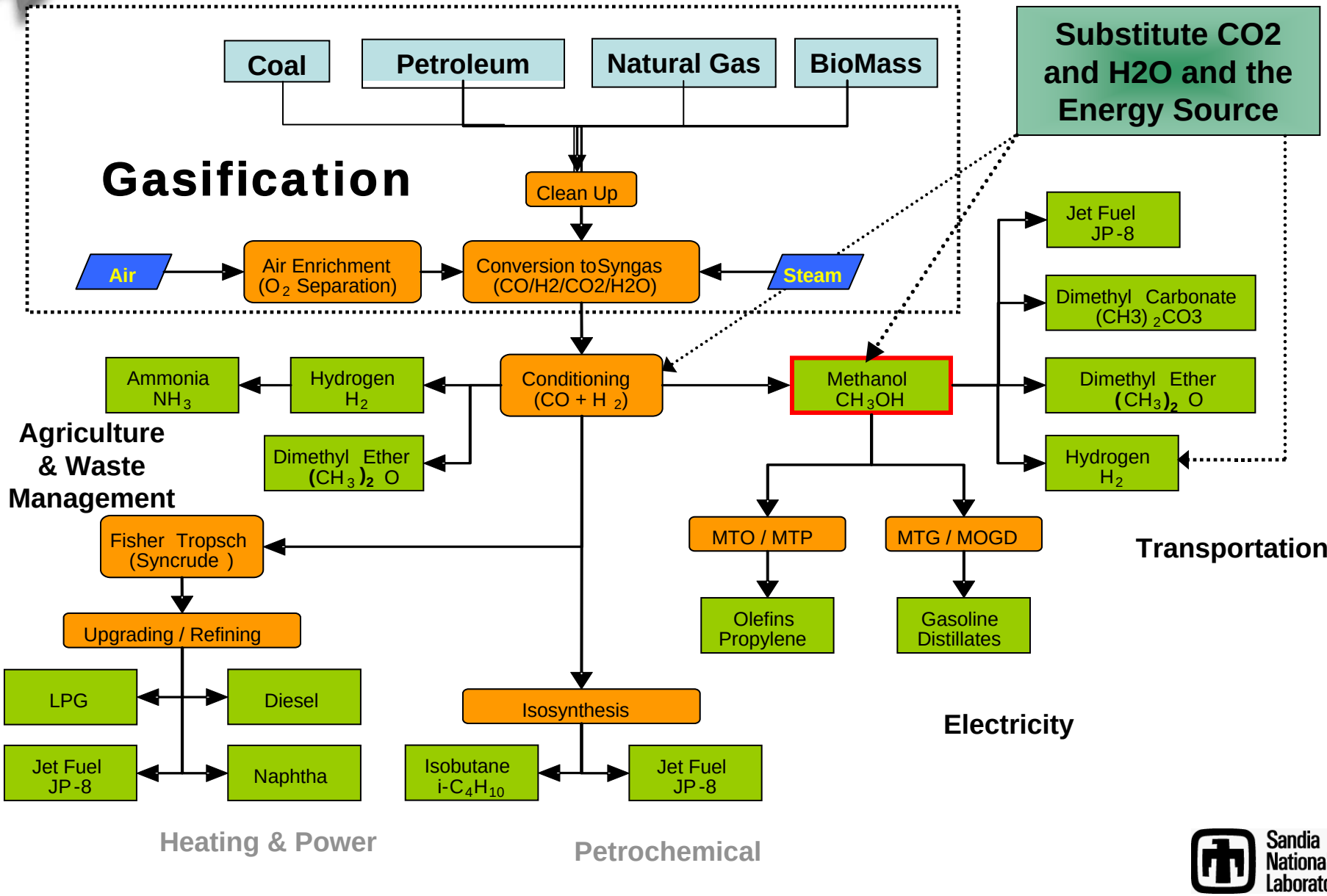
There are Known Pathways to Most Anything Desirable to Synthesize



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Thermodynamic Analysis: Efficiencies Sunlight to Fuel (Methanol)

	CO_2 from a Concentrated Source such as Flue Gas
	Thermal (%)
H_2 by PV electrolysis CO by TC	10.1
H_2 and CO by TC	17.9

Photosynthesis	~ 1-3%
Ethanol Production	< PS
Biodiesel Production	< PS

Proven/known

PV: Photovoltaics, TC: Thermochemical

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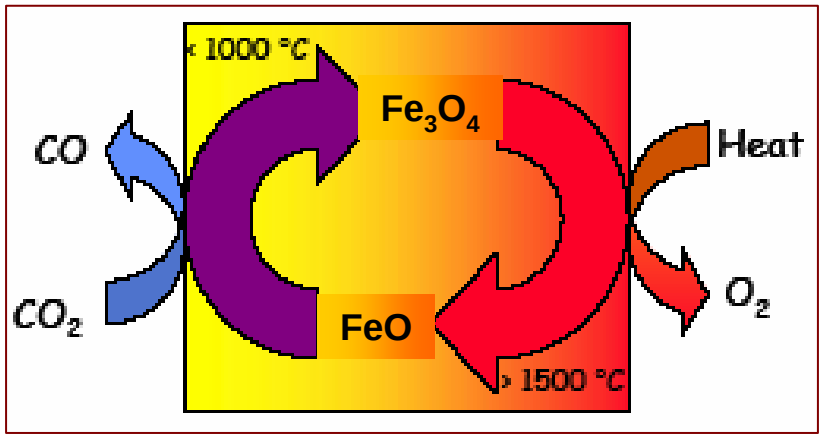
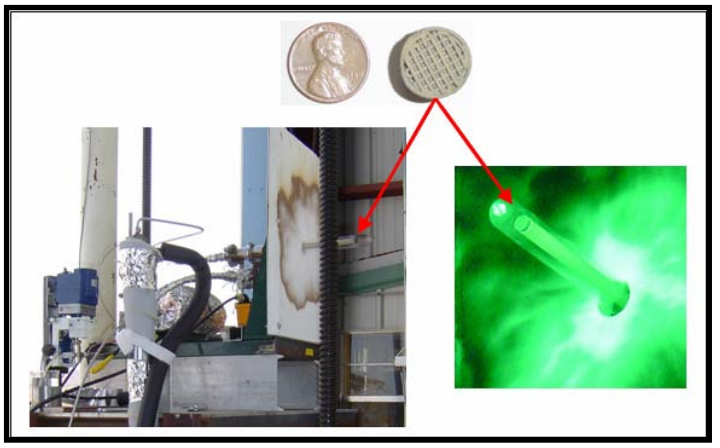
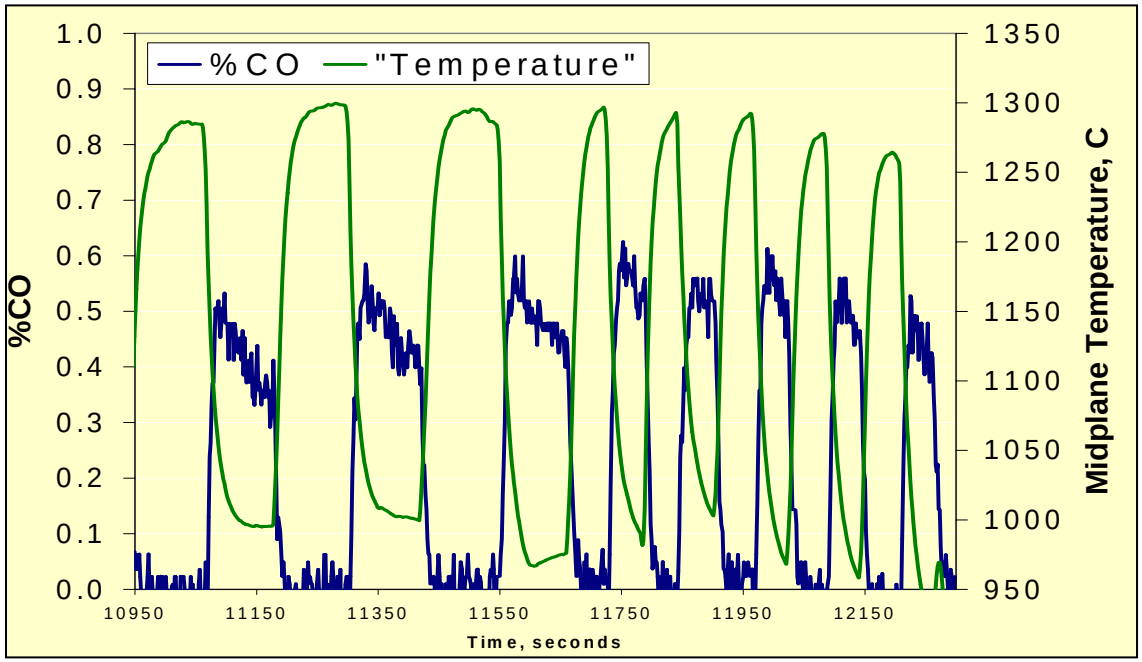
CO_2 Splitting at the NSTTF







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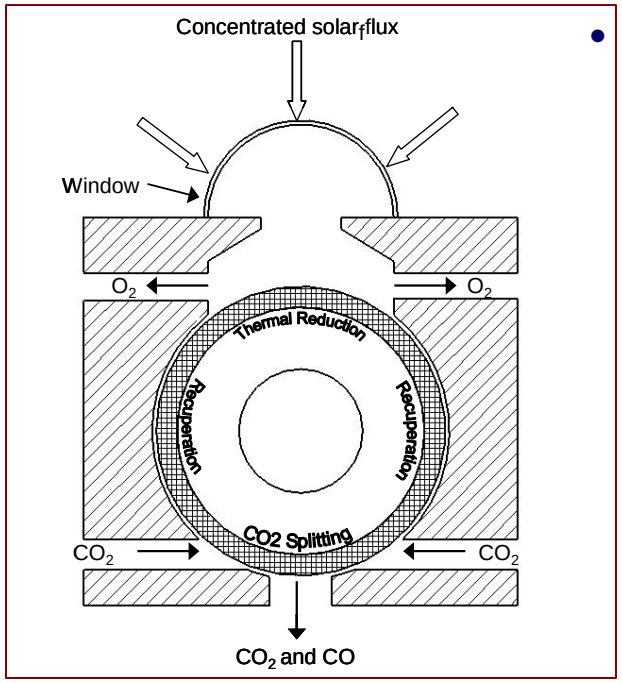
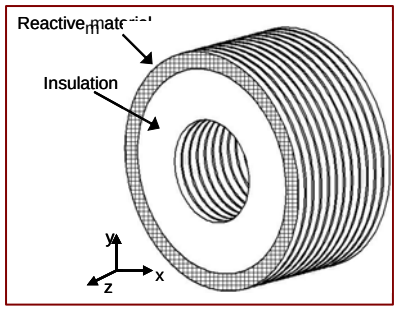
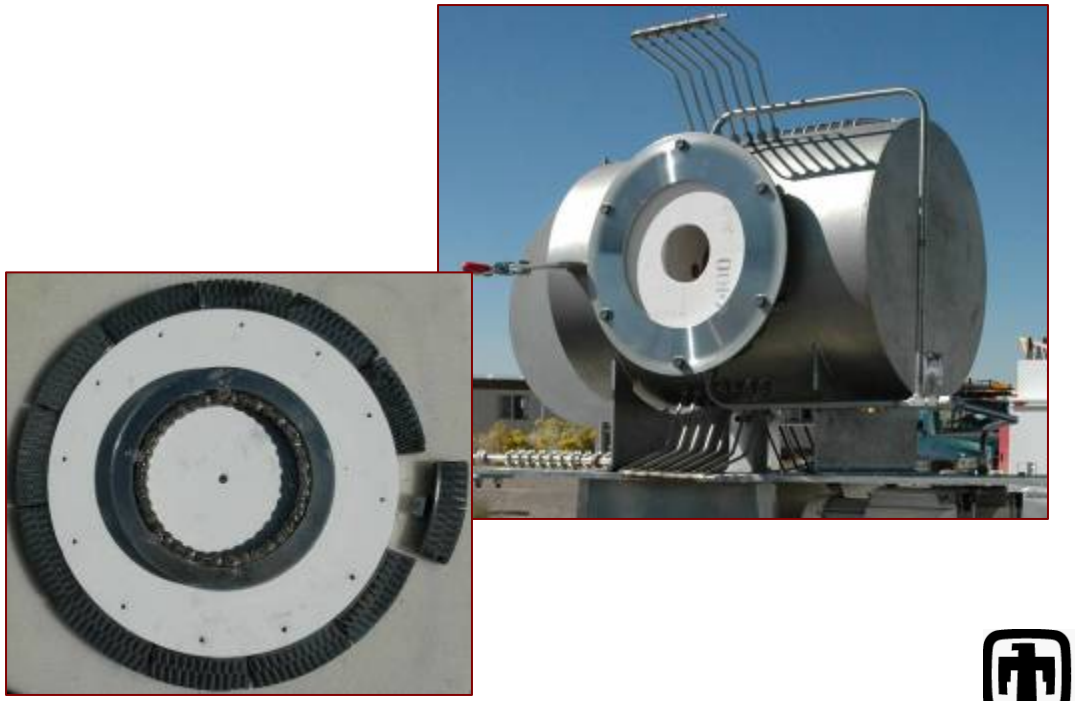
Solar Fuels Production with the CR5





- **Practical CO (or H_2) production in the CR5 requires:**
  - ***Target: ~24% sunlight to CO conversion***
  - ***Check back in a few months***



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So what might be the Impact? Does it scale to the size of the Problem?

- **What do we need?**
  1. **Land and Sunshine – How much?**
     - **Estimates indicate little impact on land usage**
       - **< 25 FT x 25 Ft per vehicle of sunny land or <27 Ft x 27 Ft of average sunshine**

       15% US penetration – 0.7M Acres (<1% of New Mexico)

       70% US penetration – 4.6M Acres (~4% of New Mexico)

  2. **CO_2 – Is there enough?**
     - **More than enough CO_2 – Coal emitted 580 MMT-Carbon in 2006**

       15% penetration – requires ~105 MMT-Carbon/Year*

       70% penetration – requires ~490 MMT-Carbon/Year*

  3. **H_2O – Is there enough?**
     - **Less than 1% of current domestic use of water**

MMT: Million Metric Tons, * Based on 2006 emissions

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NATIONAL SOLAR THERMAL TEST FACILITY

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