Computation for Energy Efficiency and Renewable Energy

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US Department of Energy

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- Building Design
  - Tools for architects/engineers
  - Tools for setting building codes
  - Tools for financial institutions (appraisers, inspectors)
  - Tools for retrofits

- Building operations
  - Sophisticated controls (large numbers of sensors and controls)
  - Continuous learning about the building and occupant behavior
  - Forming hypothesis about impending/actual failures
  - Connection to smart grid (e.g. plan around anticipated peaks)

Validation

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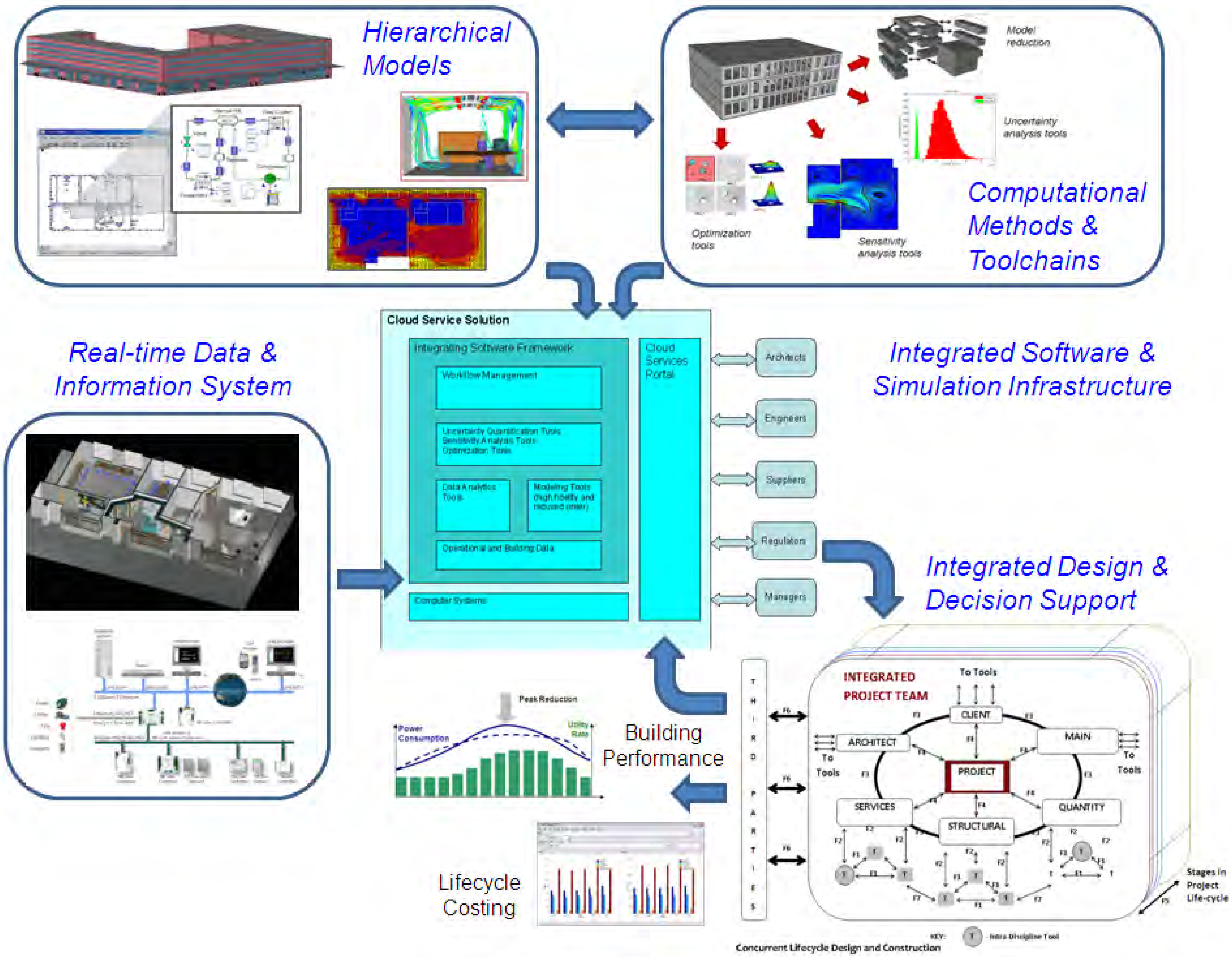
- Progress requires time and multi-directional effort
  - Statistical regression and data mining will play large roles
  - Data collection (BIM, sub-meter, sensors) is a challenge
- Usage cases: purpose of simulation & accuracy requirements
  - Is absolute accuracy necessary or is *relative* accuracy sufficient?
- Building model errors & under-specifications
  - Requires acquisition of multiple models per building
  - Inter-operability and rapid model acquisition tools will help
  - Actual mechanical efficiency is a problem on the ground
- Operation schedule assumption errors
  - Can sensing & monitoring help calibrate these?
- Simulator errors
  - Test facilities at ORNL, LBNL (2012), PSU buildings hub
  - Comparison with other detailed simulators: DeST (Tsinghua)

Source: Amir Roth

RD&D HIGHLIGHT 3: Integrated lifecycle building delivery

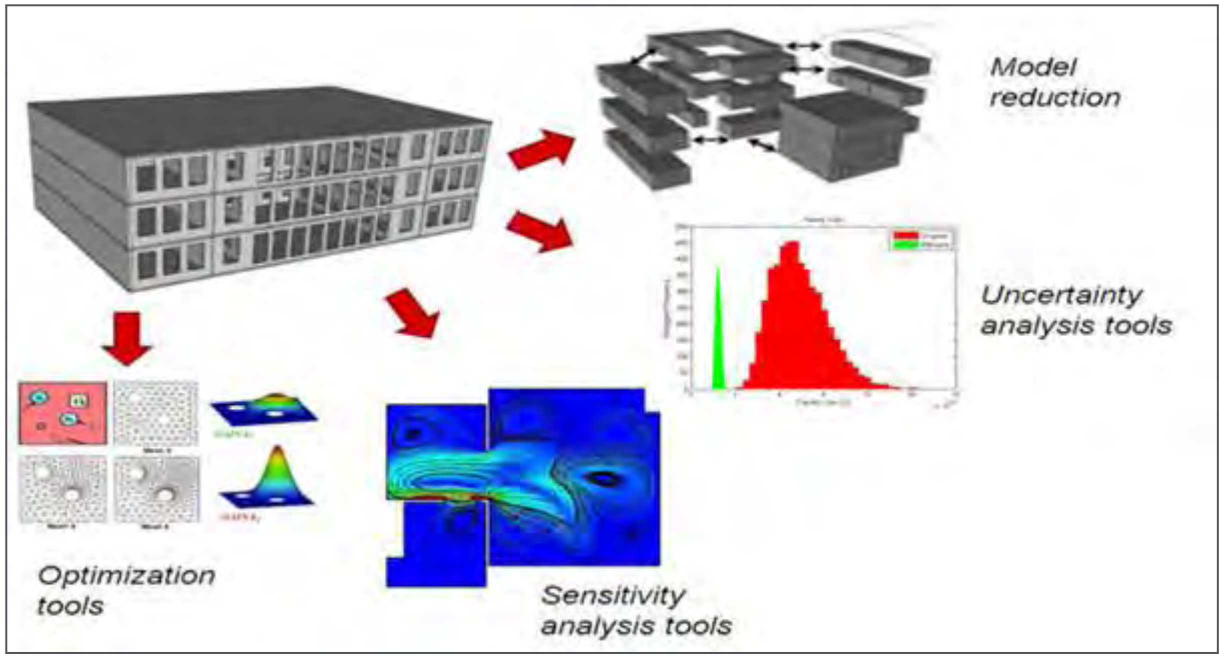
- The HUB will delivery an integrated building project delivery process that will allow interactive design and persistent data tracking.
- This will include high-level process maps to enable collaborative building design.
- This will include a change and dependency management tool, so that designers can understand the energy impacts of changes to one element of the overall design.
- This will include hierarchical models of building systems, using the open-source, object-oriented language Modelica.
- This will include tools for the optimum configuration of sensors and controls.



Computation in Buildings (HUB)

Building modeling and simulation

- The HUB will build analysis tools to simulate 3D airflow and heat transfer in buildings on the scale of single rooms, multiple floors, and full buildings, in real time. This is a prerequisite for a full-building "operating system".
- To date, most building energy simulation does not fully incorporate airflow, or treats airflow using a "multi-zone" approach that assumes full air mixing and coarse-grained, isothermal zones. [1]
- The HUB will incorporate full microscopic airflow models (CFD) into building energy simulations. The approach will use LLNL's parallel incompressible flow solver *Cgins* and multi-physics solver *Cgmp,* coupled with emerging "Fast Fluid Dynamics" techniques at Purdue, to make the simulation computationally tractable. [2,3] Will also use Open FOAM (optimized for Intel and BlueGene).
- Ultimately, the HUB will build tools to use full HPC capability for building energy simulation, using adaptive mesh approaches and numerical solvers developed by LLNL. [4]



[1] See Brown et al, "Computational Fluid Dynamics in an Equation-Based Modeling Environment", 11th International IBPSA Conference, July 2009.
[12 Henshaw and Chand, "A Composite Grid Solver for Conjugate Heat Transfer in Fluid-Structure Systems", *J. Comp. Phys.* 228 (2009). Incompressible flow is a reasonable approximation for room-temperature air below Mach ~ 0.3.
[3] Zuo et al, "Fast and Informative Flow Simulations in a Building by Using Fast Fluid Dynamics Model on Graphics Processing Unit", *Building and Environment* 45, 747 (2010).
[4] See https://computation.llnl.gov/casc/SAMRAI and https://computation.llnl.gov/casc/sundials/

Computation in Manufacturing

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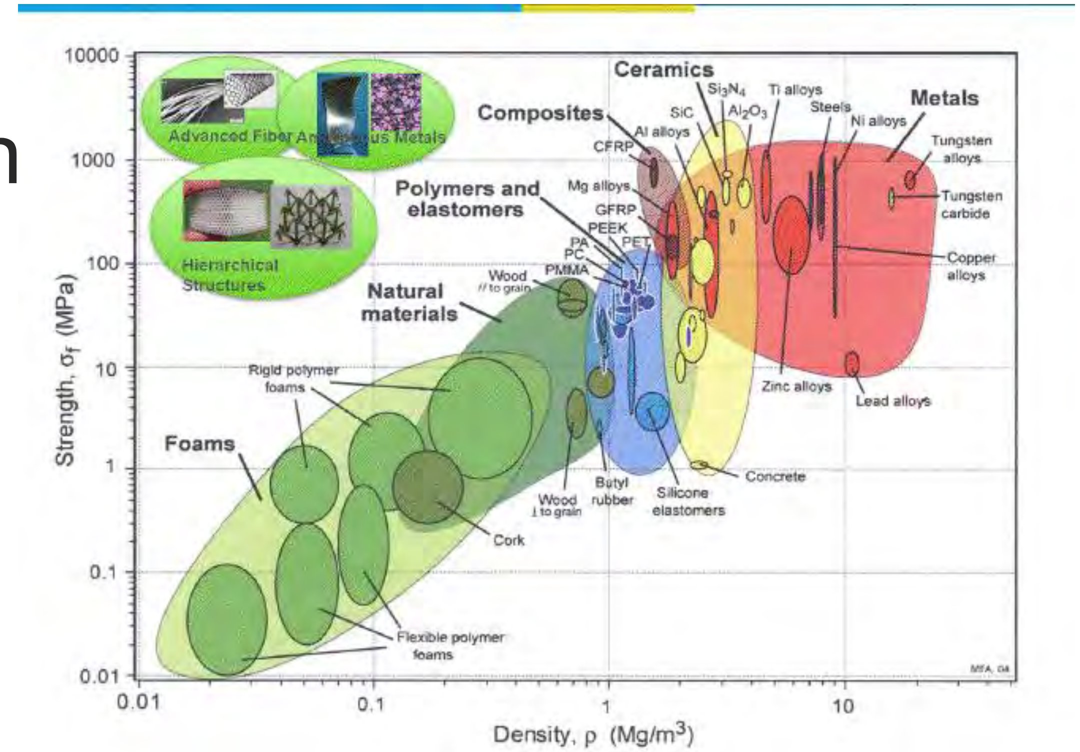
- Materials by Design
- Next generation product design (design for manufacturability)
- Next generation manufacturing processes (e.g. 3D printing)
- Continuously improving plant operations based on networks of sensors and controls



Advanced Combustion Engine R&D

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Increasing engine efficiency is one of the most cost-effective approaches to increasing fuel economy

Near-term Goals for 2015

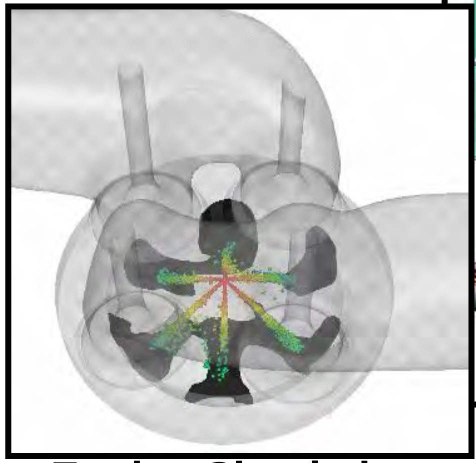
- Improve the fuel economy of light-duty vehicles by 25% to 40% for gasoline/diesel compared to baseline 2009 gasoline vehicle.
- Improve heavy truck fuel economy (engine thermal efficiency) by >20% with demonstration in commercial vehicle platforms, and 30% **by 2018**, compared to 2009 baseline.

Benefits all Vehicle Classes, HEV and PHEV

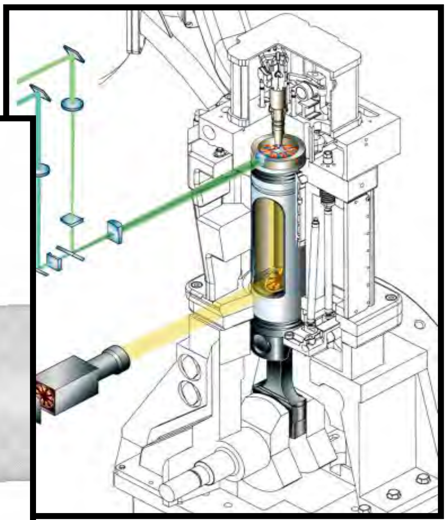
Goals Beyond 2015

Potential to **double fuel economy** for light-duty vehicles

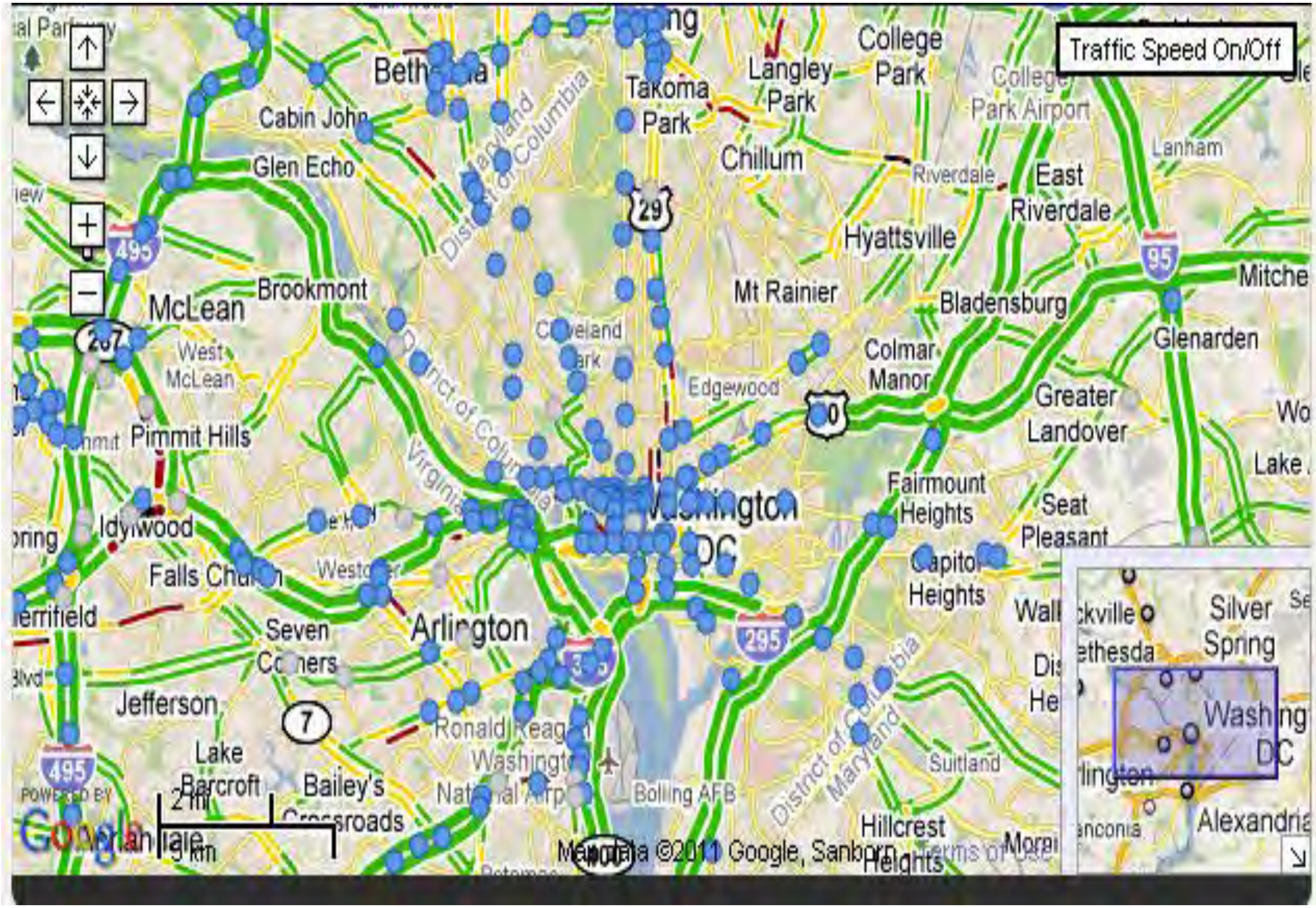
- Improve low-load engine efficiency with low-temperature combustion
    - Demonstrated up to 100 percent improvement over current gasoline engine
- Develop free-piston and compound-cycle engines



Engine Simulation



Optical Engines



Traffic Speed On/Off
College Park
Langley Park
Takoma Park
Chillum
College Park Airport
Lanham
Riverdale
East Riverdale
Hyattsville
Cabin John
Glen Echo
Brookmont
McLean
West McLean
Pimmit Hills
Mt Rainier
Bladensburg
Mitche
Glenarden
Colmar Manor
Edgewood
Greater Landover
Cleveland Park
Fairmount Heights
Seat Pleasant
Capitol Heights
Idylwood
Falls Church
Seven Corners
Arlington
Jefferson
Lake Barcroft
Bailey's Crossroads
Ronald Reagan Washington National Airport
Bolling AFB
Suitland
Hillcrest Heights
District of Columbia
Maryland
Virginia
Silver Spring
Alexandria
Map data ©2011 Google, Sanborn
POWERED BY Google
2 mi
5 km

Computation in Wind (SNL)

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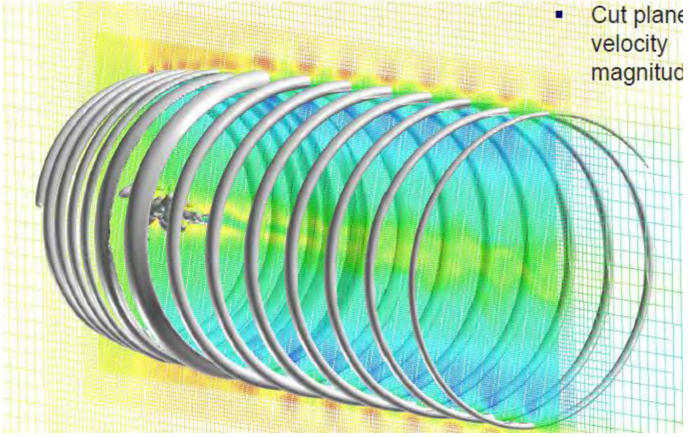
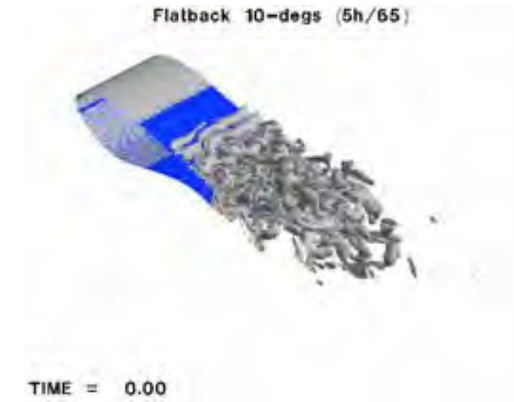
- Wind Turbine Rotor Aerodynamic Simulations
  - Collaboration with UC-Davis applying NASA Overflow code to full rotor Computational Fluid Dynamic simulations
  - Enables innovative design of wind turbine rotors for improved energy capture
- Wind Turbine Rotor Noise Prediction
  - Investigations of aerodynamic noise of innovative blade shapes using Sandia and Penn State U. CFD tools
  - Enables prediction and reduction of wind turbine noise through blade design innovations
- Wind Turbine Probabilistic Design Methods
  - Office of Science "Advancing Uncertainty Quantification (UQ) in Modeling, Simulation, and Analysis of Complex Systems" Project
  - Collaboration between SNL's Wind Energy, Optimization & UQ , and Computational Mechanics Depts.; Stanford U. and Purdue U.
  - Combination of mathematical methods, high-fidelity fluid/structure modeling, and wind application expertise to advance the state-of-the-art in probabilistic design methods for wind turbines

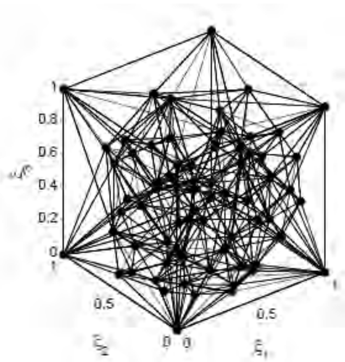
Simulation of a 5 MW Wind Turbine Wake



Flow and Noise Simulation of an Innovative Wind Turbine Blade Section



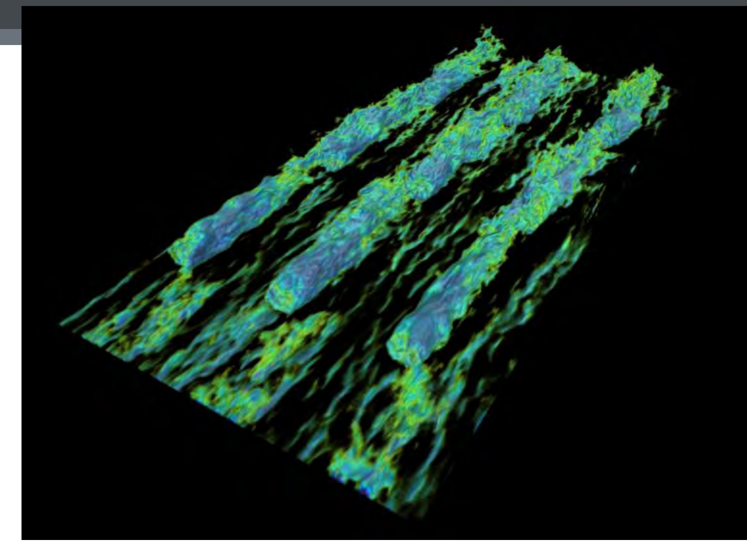
Sampling uncertain wind turbine design parameters.

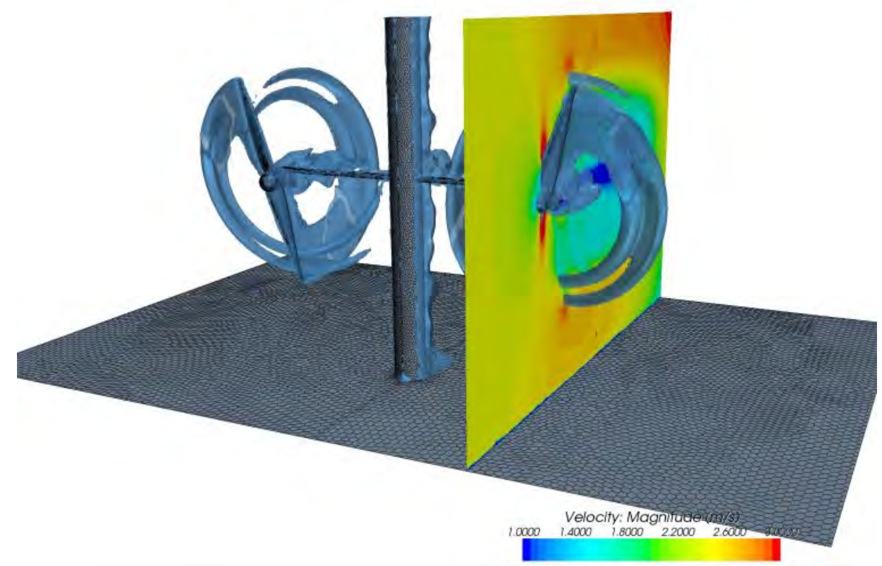


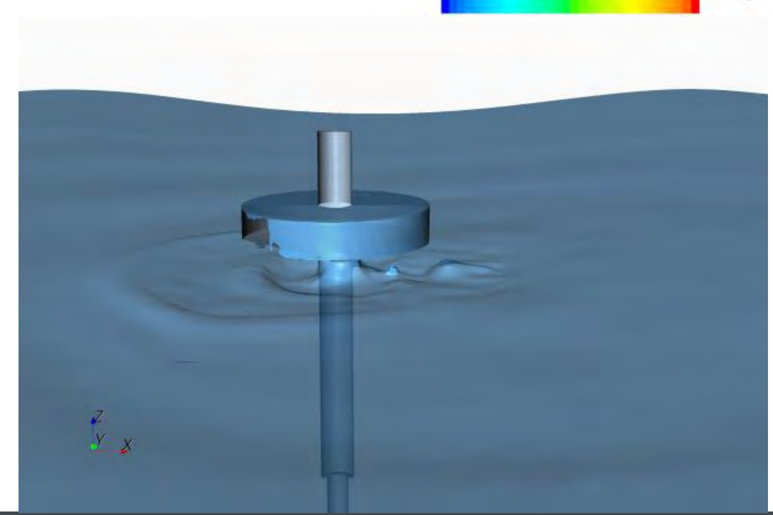
Computation for the Wind & Water Program (NREL)

- **Modeling Horizontal-Axis Tidal Current Turbines**
  - Develop analysis methods to predict the performance of tidal current turbines
  - Determine hydrodynamic loads on the turbine
  - 2,000 CPU-hours required for a single simulation

- **Simulating the performance of wave energy conversion systems**
  - Study the interactions between waves and floating bodies
  - Optimization of power-take-off system
  - 5,000 CPU-hours required for a single simulation

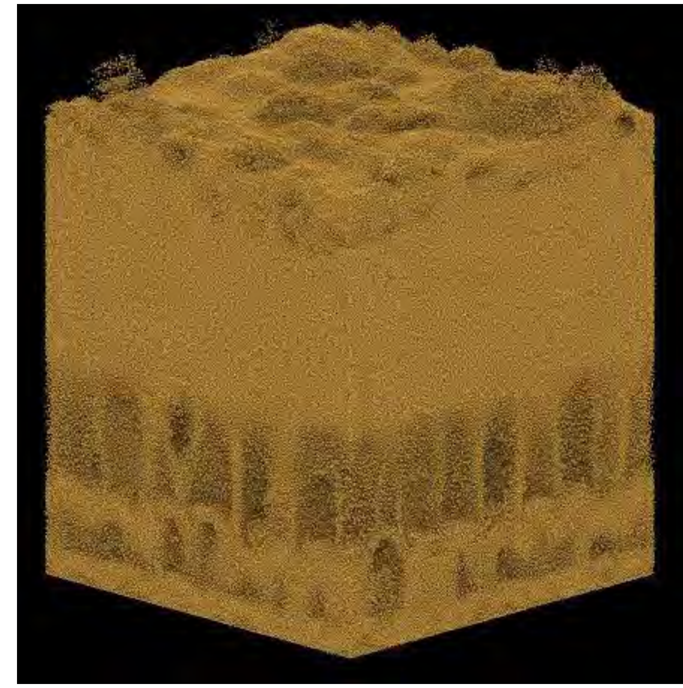




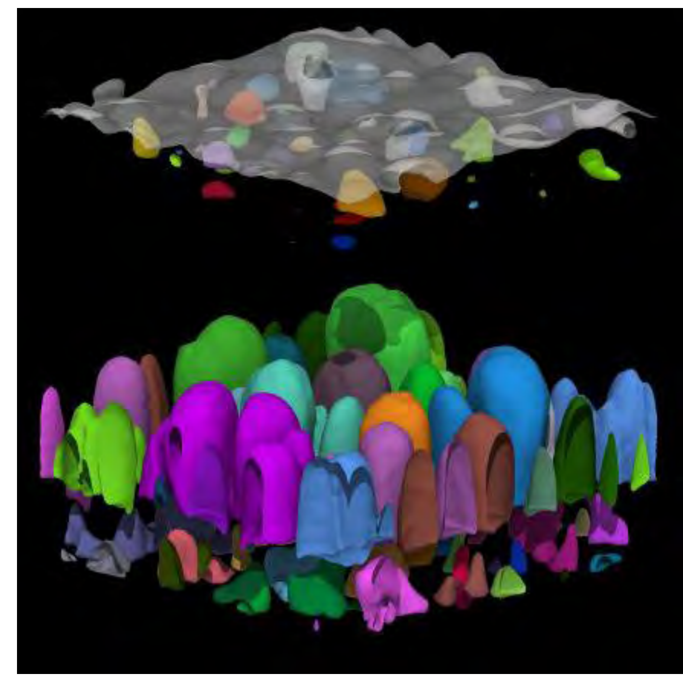


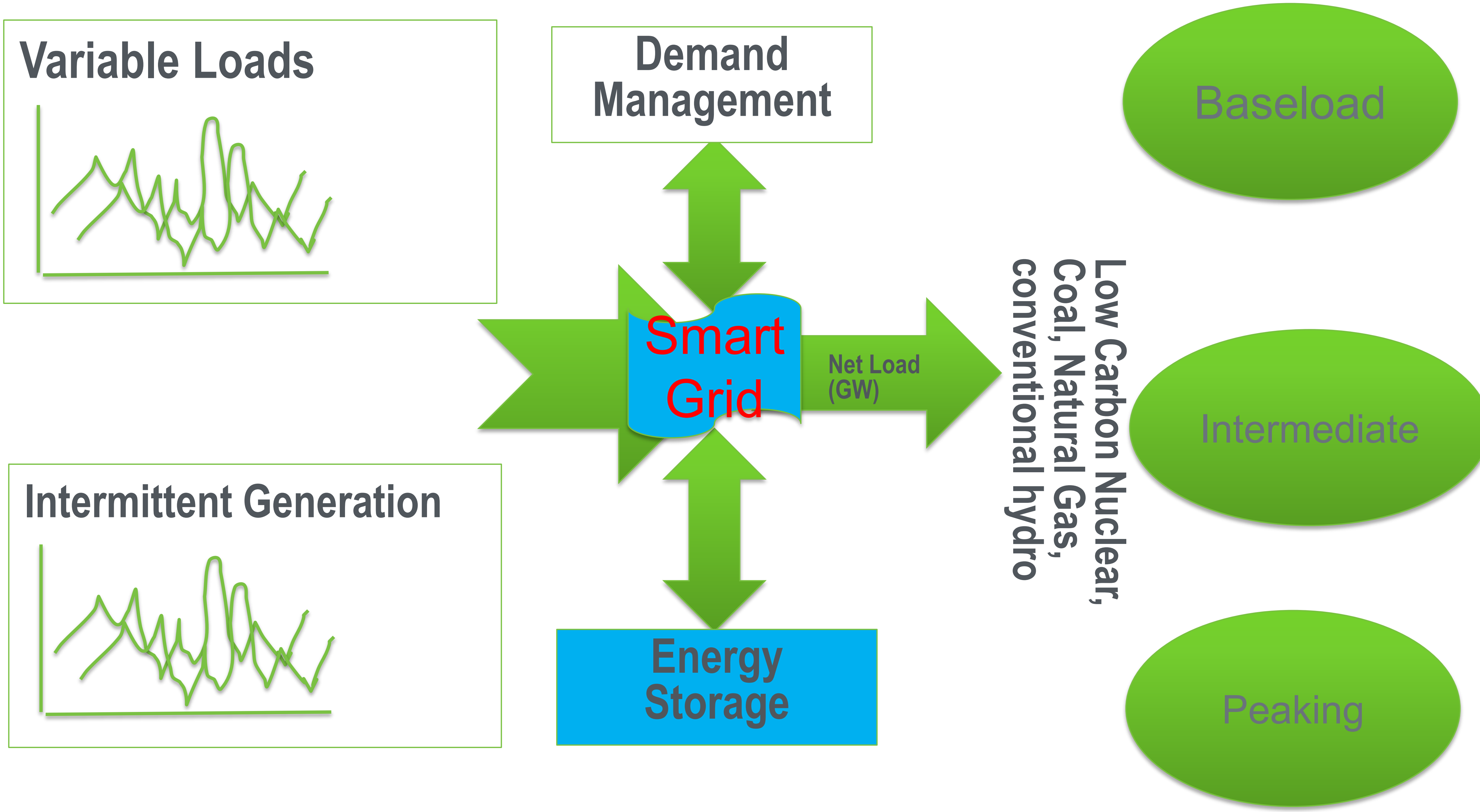
Computation for Biomass and Solar

- **Large molecular dynamic simulations study deconstructing cellulose**
  - Gain **molecular-level understanding of biomass recalcitrance.**
  - ID promising routes for plant engineering of bioenergy crops.

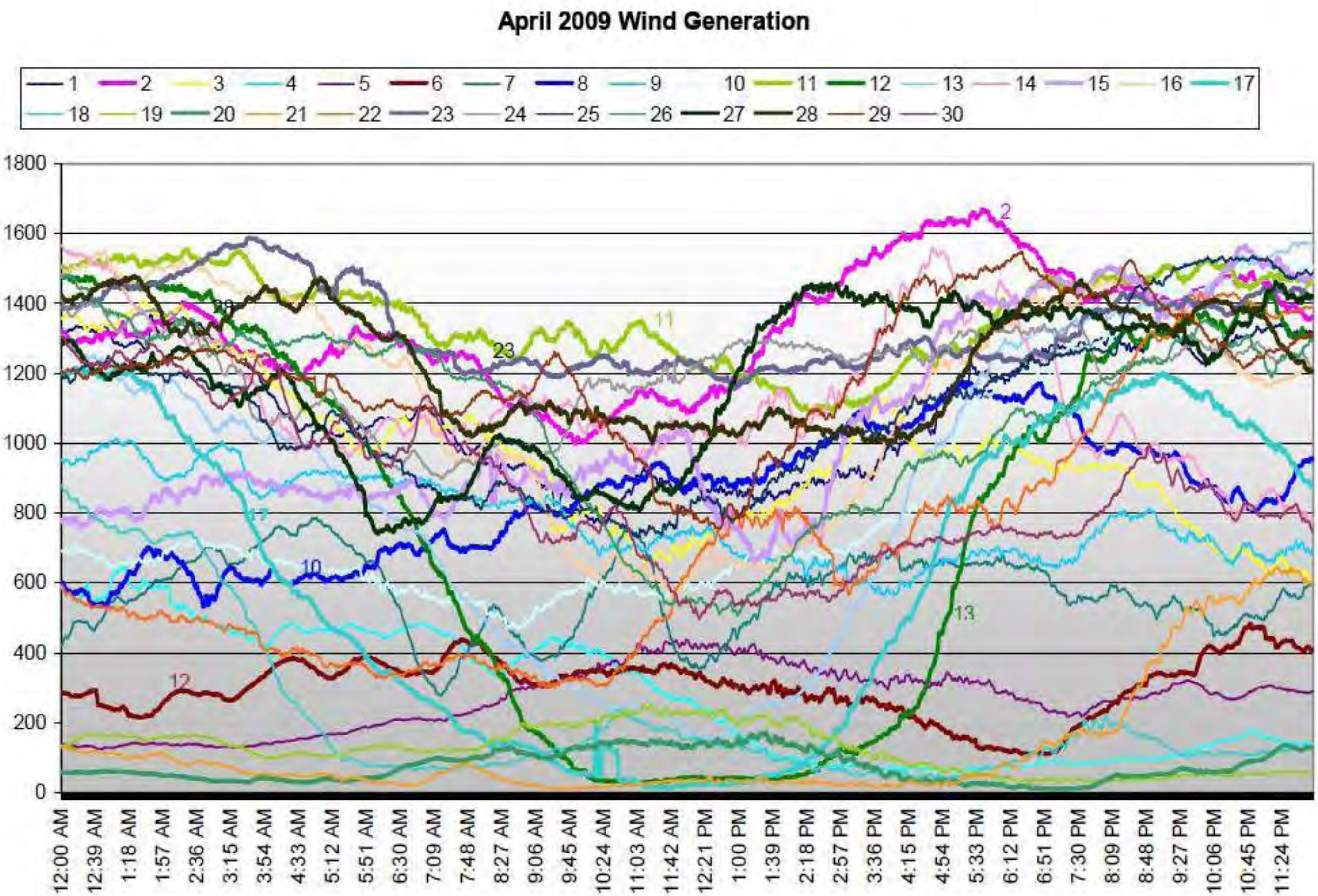


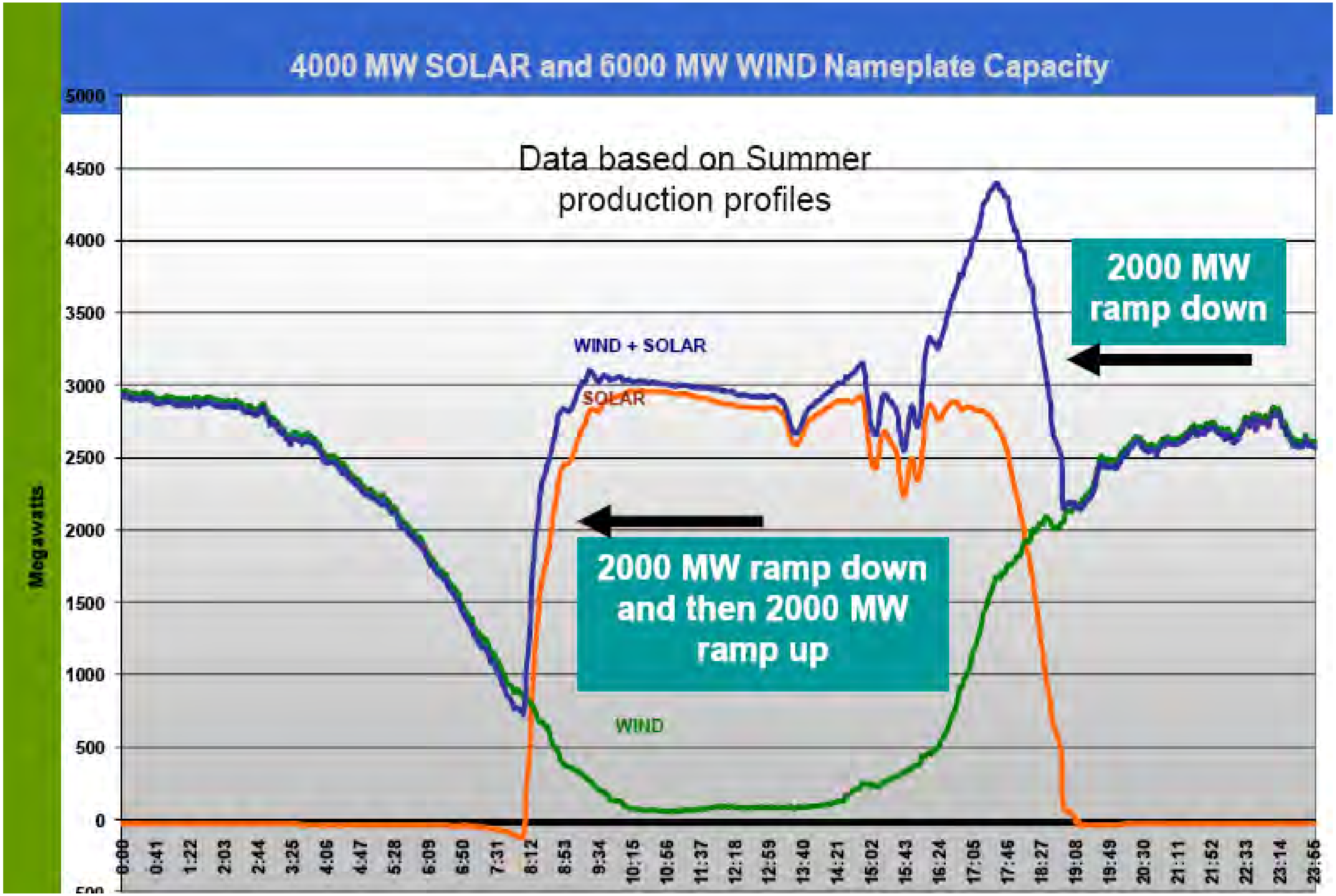
- **Renewable Fuels: fluidized bed reactor design**
  - Cost of producing renewable fuels via biomass gasification sensitive to amount of tars produced during gasification step in fluidized bed reactor.
  - Large simulations, involving 35 million particles, have led to new insights into gas residence time distributions, bubble formation, and mixing properties.
  - Numerical results and visualization guide optimization of fluidized bed reactor designs to reduce cost of renewable fuel production.




Variable Loads
Demand Management
Baseload
Smart Grid
Net Load (GW)
Low Carbon Nuclear, Coal, Natural Gas, conventional hydro
Intermediate
Intermittent Generation
Energy Storage
Peaking

California ISO April 2009 Wind Generation in 30 s





4000 MW SOLAR and 6000 MW WIND Nameplate Capacity
Data based on Summer production profiles
WIND + SOLAR
SOLAR
WIND
2000 MW ramp down
2000 MW ramp down and then 2000 MW ramp up
Megawatts
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
0:00
0:41
1:22
2:03
2:44
3:25
4:06
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23:55

Computation for Education and Training

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