# Vision 21 Program Review
# National Research Council
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## "Systems Analysis and Integration"

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# Vision 21: Systems Analysis & Integration

- **Objectives - Systems Analysis**
  - Identify and evaluate concepts for Vision 21 plant subsystems and components
  - Select “reference” plants for detailed study
  - Identify technology gaps and R&D strategy to fill gaps

- **Objectives - Systems Integration**
  - Obtain feedback on systems integration experience from operating IGCC and fuel cell/turbine hybrid plants
  - Conduct series of systems integration workshops to identify and clarify issues

# Vision 21: Systems Analysis & Integration

- **Objectives - Systems Integration, cont'd**
  - Identify systems integration issues for reference plants (e.g., module compatibility)
  - Resolve systems integration issues; provide input to R&D strategy where necessary
  - Identify, address, and resolve issues relating to subsystem and plant dynamics and control
  - Identify, address, and resolve industrial ecology issues

# Vision 21: Systems Analysis & Integration

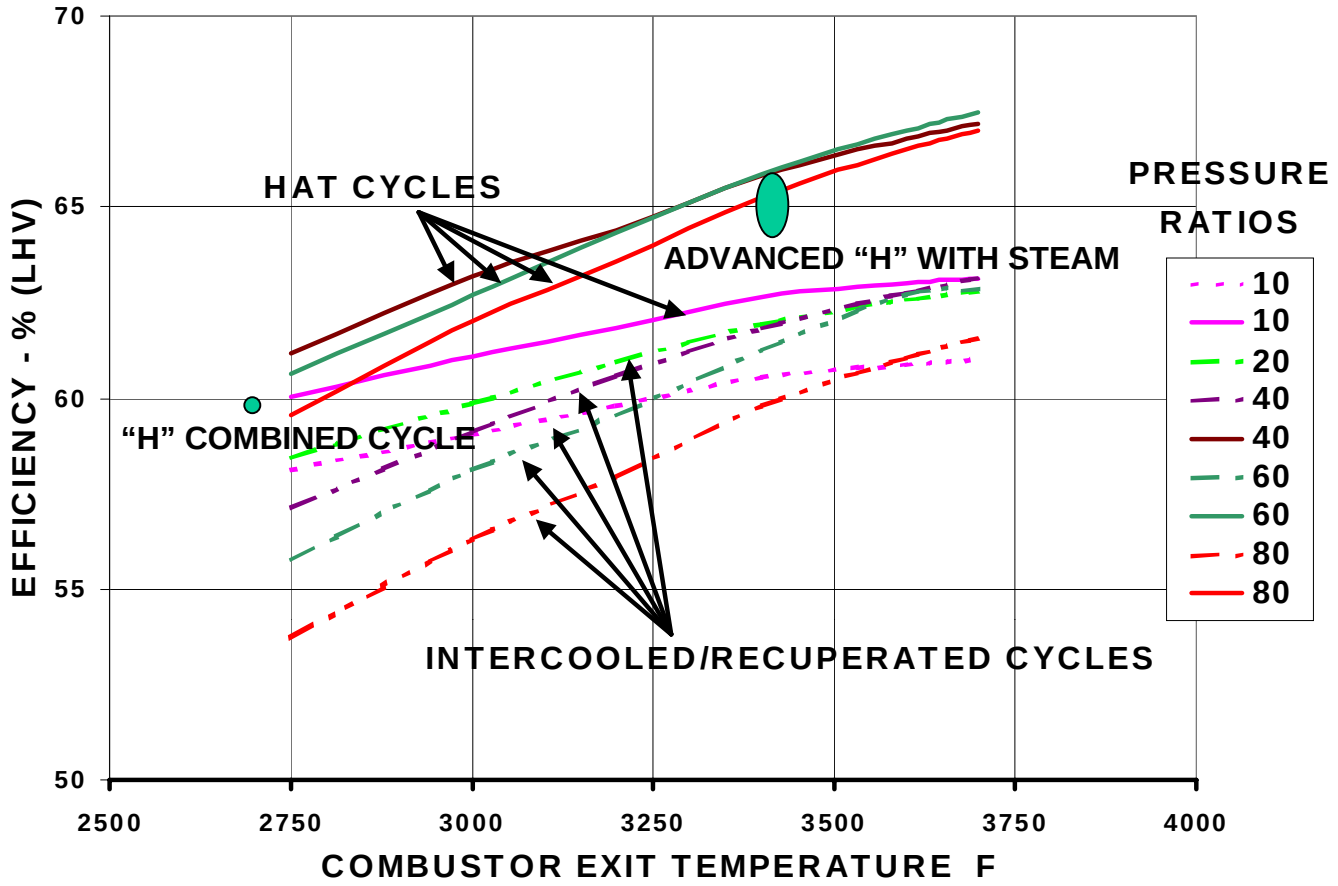
- **Milestones**
  - Identify reference plants for further study (2002)
  - Identify additional reference plants (2004)
  - Develop analyses of reference plant concepts (2005)
  - Methodology available to identify and analyze systems integration issues (2005)
  - Complete system integration analyses of reference plants (2006)
  - Complete industrial ecology assessment for reference plants (2006)
  - Technology base for Vision 21 plant modules available (2012)
  - Technology base for complete plants available (2015)

# Vision 21: Systems Analysis & Integration

- **Progress: National Fuel Cell Research Center**
  - Proposal selected in Round 1 of V21 solicitation, 2000: “Systems Integration Methodology.” Total value $2.0 MM, 36 month duration.
  - Objective: Identify natural gas and coal based cycle configurations that meet Vision 21 goals.
  - Approach: Screening Analysis followed by Detailed Analysis (performance and cost) of promising cycles.
  - Early finding: Gas turbines and fuel cells are required to meet Vision 21 efficiency goals.

# GAS TURBINE W/O FUEL CELL NOT SUFFICIENT

## GT-BASED CYCLE EFFICIENCIES



# Vision 21: Systems Analysis & Integration

- **Progress: National Fuel Cell Research Center**
  - **Three hybrid cycles identified for the natural gas based plants that have the potential to reach the Vision 21 efficiency and emissions goals:**
    - 1. High pressure solid oxide fuel cell (SOFC) integrated with a high-pressure ratio intercooled gas turbine/compressor
    - 2. High pressure solid oxide fuel cell (SOFC) integrated with the HAT cycle
    - 3. Atmospheric pressure molten carbonate fuel cell (MCFC) integrated with a high-pressure ratio intercooled gas turbine/compressor.

# Vision 21: Systems Analysis & Integration

- **Progress: National Fuel Cell Research Center**
  - **Two "zero emission" natural gas based plants, that is, plants recovering the carbon dioxide for carbon sequestration identified:**
    - **4.** High pressure SOFC integrated with $O_2$ breathing HAT cycle and $CO_2$ recycle
    - **5.** Advanced Rankine cycle (using gas turbine technology) using $O_2$ in rocket engine technology combustor
  - **For each plant, estimations computed for:**
    - FC kW
    - GT kW
    - Aux. kW
    - Net kW
    - Net eff.
    - kW/lb/s air
    - lb water/kWh

# Vision 21: Systems Analysis & Integration

- **Progress: National Fuel Cell Research Center**
  - Five high performance coal-based systems described and preliminary analysis begun:
    - Foster Wheeler partial gasification HIPPS with SOFC.
    - ASU/Shell/High Temperature cleanup/shift - O2 enriched GT – Consider the CES rocket combustion process moderated by CO2 recycle (while the combustion process is moderated by CO2 recycle).
    - ASU/Shell/High Temperature cleanup/shift - Advanced Rankine cycle (CES combustor) utilizing high temp H2 separation membrane.
    - ASU/Shell/High Temperature cleanup-based IGCC with SOFC.
    - ASU/Texaco-based IGHAT with SOFC.

# Vision 21: Systems Analysis & Integration

- **Progress: NETL**
  - Prepared analysis for internal use on numerous novel power processes, e.g.,
    - SOFC/PEM hybrid
    - Clean Energy Systems (steam/CO2 turbine)
    - Ramgen (supersonic ramjet turbine)
  - Employ NEMS to estimate extent of advanced technology deployment for scenarios involving the President's "3P" and Greenhouse Gas Efficiency initiatives
  - Participating in ASME Performance Test Code 47 project aiming to develop a protocol for IGCC plant evaluation and acceptance.

# Vision 21: Systems Analysis & Integration

- **Progress: NETL**
  - Prepared report on Sierra Pacific IGCC project in CCT program. Contains useful lessons for project management of highly integrated power systems.
  - Prepared a methodology for life cycle analysis of power cycles with respect to generation of criteria pollutants and GHGs.
  - Published analysis of Matiant cycle power system (CO2 working fluid; complete CO2 capture) with ITM for air separation.

# Vision 21: Systems Analysis & Integration

- **Progress: Fuel Cell Energy Inc.**
  - Designed, built, and operating hybrid MCFC/Air turbine power system at 250kW scale. Operation time over 4500 h with efficiency of 52% (LHV).
  - Projected net efficiency with natural gas feed 71% (LHV) with 85% of power provided by fuel cell.
  - Longer term expect to achieve 80% efficiency (LHV).
  - Brayton cycle is unfired, indirectly heated with fuel cell waste heat. Reduces process integration constraints compared to direct fired hybrid.

# Vision 21: Systems Analysis & Integration

- **Progress: Siemens Westinghouse Power Corp**
  - Designed, built, and operating hybrid SOFC/Combustion turbine hybrid at 200 kW scale (Southern Cal. Edison). Operation time over 1300 h.
  - Demonstrated efficiency with natural gas 52% (LHV).
  - Scaled up version (19.0 MWe) has estimated efficiency 67.3% (LHV). 79% of power from fuel cell.
  - Process improvements and addition of low pressure steam turbine estimated to yield efficiency of 71% (LHV).
  - NOx emissions 0.006 kg/MWh (1 ppm). Compares to 10-25 ppm for NGCC.
  - Total capital requirement $1431/kW.

# Vision 21: Systems Analysis & Integration

- **Critical Barriers**
  - Data describing capabilities of advanced modules for power systems are unavailable to system design/system integration analysts.
  - Value of carbon emission avoidance still unclear. Deters private sector investment in power technologies providing high efficiency and/or carbon capture.

# Vision 21: Systems Analysis & Integration

- **Response to NRC Vision 21 Report**
  - (Most Findings and Recommendations pertained to Computational Modeling/Simulation activities.)
  - NRC Observation: “Because emphasis of the Vision 21 Program is on the development of hardware *components*, computer-based capabilities for system simulation, integration, and analysis will be essential to the development and deployment of Vision 21 facilities.”
  - DOE Response: Initiated project with National Fuel Cell Research Center (University of California/Irvine), KraftWorks Corp., and Spencer Management: “Systems Integration Methodology.”

# Vision 21: Systems Analysis & Integration

- **Strategies for Deployment of Fossil Energy Systems Employing High Systems Integration**
  - Fund development of system components/modules that facilitate achieving high thermal efficiency through tight systems integration, e.g.,
    - High temperature heat exchangers
    - Hydrogen separation membranes
    - Oxygen separation membranes
  - Publicize progress made in cost-shared projects with industry that are achieving Vision 21 efficiency and emissions goals.
  - Host Vision 21 conferences and workshops; participate in other conferences describing high performance systems.

# Vision 21: Systems Analysis & Integration

- **Plans for Future Efforts**
  - Conduct workshops for industrial ecology for fossil power systems, FY03.
  - Conduct training at NETL in industrial ecology, FY02 or FY03.
  - Receive identification of technology pinch areas in Tasks 3 and 4 of National Fuel Cell Research Center project and act upon recommendations in future Vision 21 solicitations.
  - Improve NETL abilities for process evaluation as additional data on advanced technology modules become available.