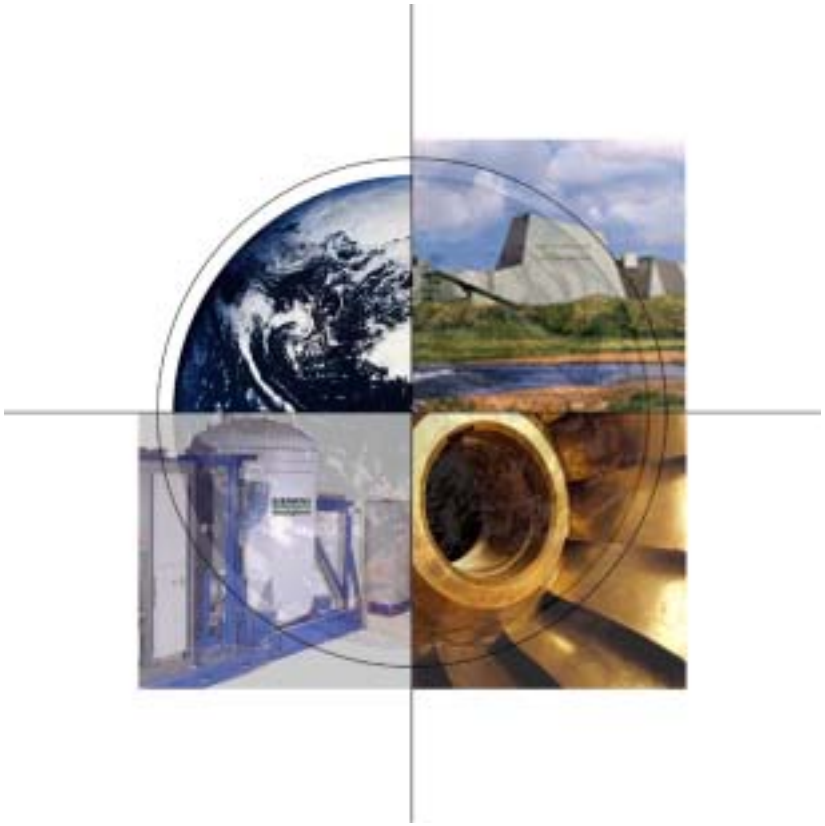
DOE's Fossil Energy Turbine Program



Turbine Road Map Stakeholder Meeting

Richard Dennis
Turbine Program Product Manager

Hyatt Regency Hotel
Pittsburgh Airport; July 29 & 30, 2003

National Energy Technology Laboratory

Mission

- **Purpose**

  Provide turbine power generation technology essential to the success of advanced fossil energy power systems in the 2008 and 2015 time frames

- **Program Areas**
  - –Turbines for syngas & hydrogen fuels in IGCC applications
  - –Turbines for fuel cell turbine hybrid systems

- **Unique Capabilities of Turbines**
  - –Fuel flexibility (market adaptability)
  - –Flexible for CO_2 control / capture
  - –Adaptable to further reductions in NOx emissions
  - –Scaleable
  - –Mature technology

DOE's Fossil Energy Turbine Program

Turbine Road Map for Syngas and Hydrogen

July 29, 2003

Turbine Program Goals
IGCC Syngas

- **Program Strategic Performance Goal (PSPG) (2008)**

By 2008 provide a commercial design for a coal-based power system at 50% efficiency and a capital cost < $1000/kW with near zero emissions

- **Vision 21 Performance Goal (2015)**

By 2015 provide a commercial design for a coal or NG fueled power system at 75% (LHV) and 60% (HHV) efficiency respectively w/ near-zero emissions w/a zero CO2 option and competitive costs

- **Turbine Program Mission Critical Issues**
  - Reduction in emissions
  - Improvements in turbine efficiency
  - Reduce capital cost
  - Designs for large gas turbines for FCT hybrid applications
  - Systems, components, integration, and controls for FCT hybrids

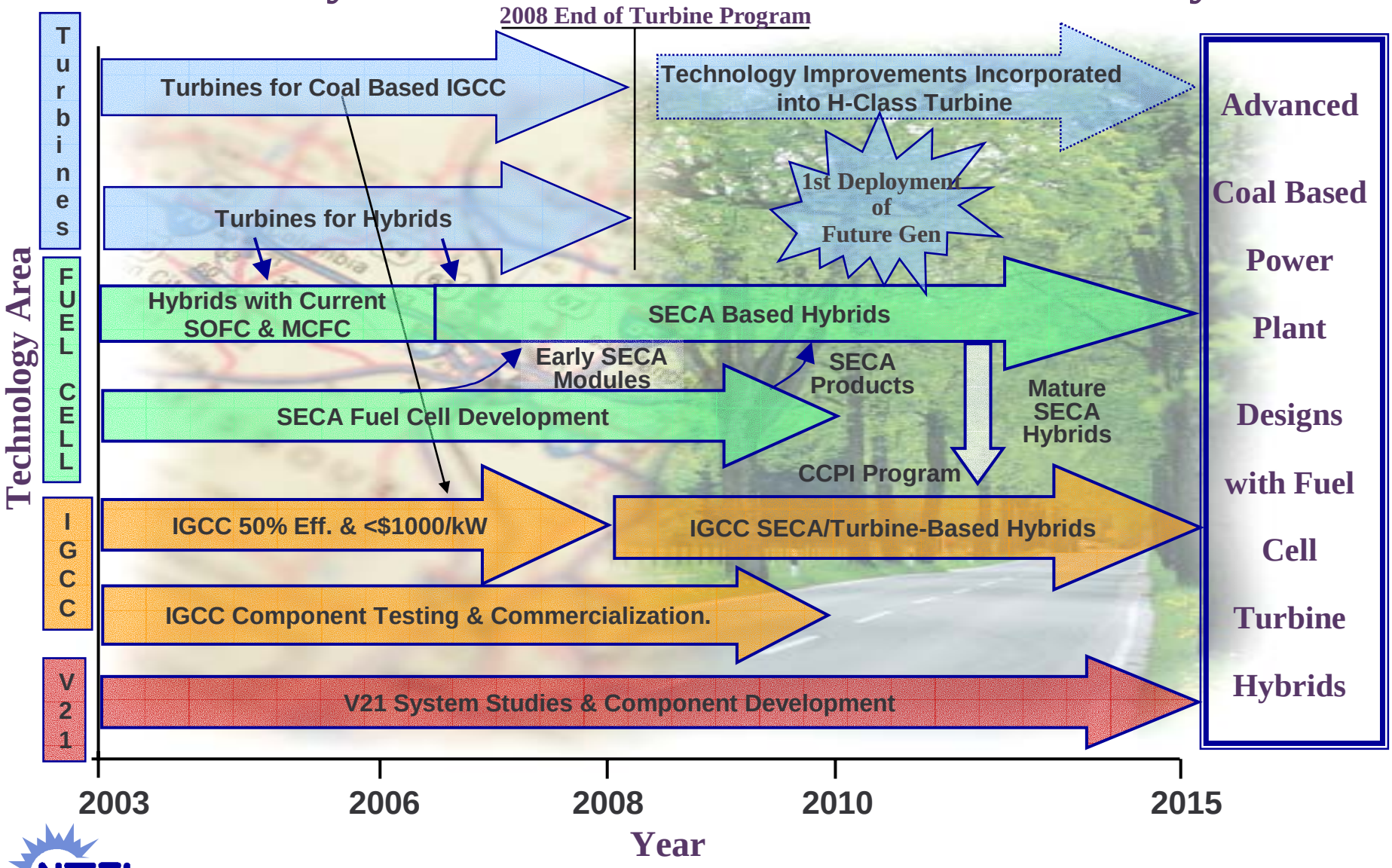
Turbines and Hydrogen

Impact on 2008 program goals

FutureGen provides an opportunity for hydrogen fired turbines

- Understanding the fundamentals of H2 combustion in coal derived syngas applications
- Assessing material issues
- Assessing 100 % hydrogen combustion (diluents & oxidants)
- Assessing turbine integration issues in a FutureGen plant configuration

Pathways to Advanced Coal Based Power Systems



Syngas Mission Critical Issue
Improve Efficiency

- **2 - 3 % points improvement in combined cycle (CC) efficiency**
- **State of the art**
  - H-Class CC machines (400 MW) on NG anticipated to be 60 % (LHV)
  - H-Class CC machines (400 MW) in an IGCC anticipated to be 45-49 % (LHV)
  - 2 x 7FB (563 MW) CC on NG proven at 57. 5 % (LHV)
  - 2 x W501F (550 MW) CC on NG proven at 55.8 % (LHV)
  - Delta 15 % from NGCC to IGCC, 1.5 – 2 % lower for coal LHV to HHV
  - Tampa Electric and Wabash River IGCC proven at 38 and 40 % F-class machines (HHV)
  - Destec 400 MW IGCC w/ “G-class” turbine and cold cleanup 45 % (HHV); same w/ HGCU 47.6 % (based on NETL system studies)
- **Approach to goal**

  Need to increase firing temperature (~ 200 F) in F & G class machines, maintain combustor performance while reducing NOx, incorporate ATS technology into F & G class machines, fully integrate turbine w/ gasification process, air separation unit and steam cycle.

Syngas Mission Critical Issue
Reduce Emissions

- **Reduction in NOx emissions for syngas to < 3 ppm**
- **State of the art**
  - Water or steam injection – lowest control levels 25 ppm (NG)
  - Dry Low NOX (DLN) for GE 7EA, FA and 6B gas turbines on natural gas 9 ppm at 15% O_2
    - Trapped vortex combustion may extend this limit
    - In these machines syngas has the potential for lower NOx
  - H-Class w/ DLN demonstrated 25 ppm, potential for 9 ppm
  - Catalytic combustion unproven in F-class machines potential for < 3 ppm
- **Approach to goal**

  Either extending the lean pre mix limit (TVC, H_2, others?) or catalytic combustion.

Syngas Mission Critical Issue
Reduce Capital Cost ($/kW)

- **Reduction in capital cost through increase in specific power (15 – 20 % increase in power output)**
- **State of the art**
  - Turbines designed for natural gas may have some margin when firing syngas for increasing mass throughput and result in higher power rating per frame size
  - In NG CC life cycle cost management is seen as the highest priority by gas turbine users, this issue is expected to continue in IGCC applications but may be out paced by gasifier / BOP.
  - Increasing availability by 1 % has huge financial impact on NG GT (SC & CC)
- **Approach**

  For a given frame size explore the possibility to extend or fully reach the torque and aerodynamic limitations in syngas applications to increase power output.

Turbines for Syngas to Achieve PSPG
Implementing Approach: Plan, Assess and Test

	2003	2004	2005	2006	2007	2008
Mission Critical Issue: NOx Reduction						**Target: < 3 ppm**
Syngas Turbine Analysis - DLN – lean limit extension - catalytic combustion - reheat			Down Select to Promising candidates for Laboratory & Bench Scale Testing		Component Testing → Deployment	
Turbine Development and Testing - vortex combustor - catalytic pilot and flame control			Component Testing → Deployment			
H2 Combustion -combustion approach -diluents -premixing			Down Select to Promising candidates for Laboratory & Bench Scale Testing		Component Testing → Deployment	
Mission Critical Issue: Efficiency Improvement						**Target: $\eta_{thermal}$ > 2 – 3 percentage points**
Assess Potential Efficiency Gains - Increased Turbine Inlet Temperature - ATS Tech. Transfer to F & G Class Machines - Improved Integration w/ IGCC Subsystems			Down Select to Promising candidates for Laboratory & Bench Scale Testing		Component Testing → Deployment	
Integration w/ IGCC & System Analysis -O2 Separation -Air Separation Unit(ASU) -Ion Transport Membrane (ITM)			Down Select to Promising candidates for Laboratory & Bench Scale Testing		Component Testing → Deployment	
Mission Critical Issue: Cost Reduction						**Target: Increasing specific power output (~20 %)**
Address Potential Improvements - O&M Management Techniques - RAM Control Improvements			Develop Promising candidates for Laboratory & Bench Scale Testing		Component Testing → Deployment	
Output Enhancement -torque limit enhancement -compressor pressure ratio limitations -compressor temperature limitations -firing temperature -co2 expansion issues -system analysis			Down Select to Promising candidates for Laboratory & Bench Scale Testing		Component Testing → Deployment	

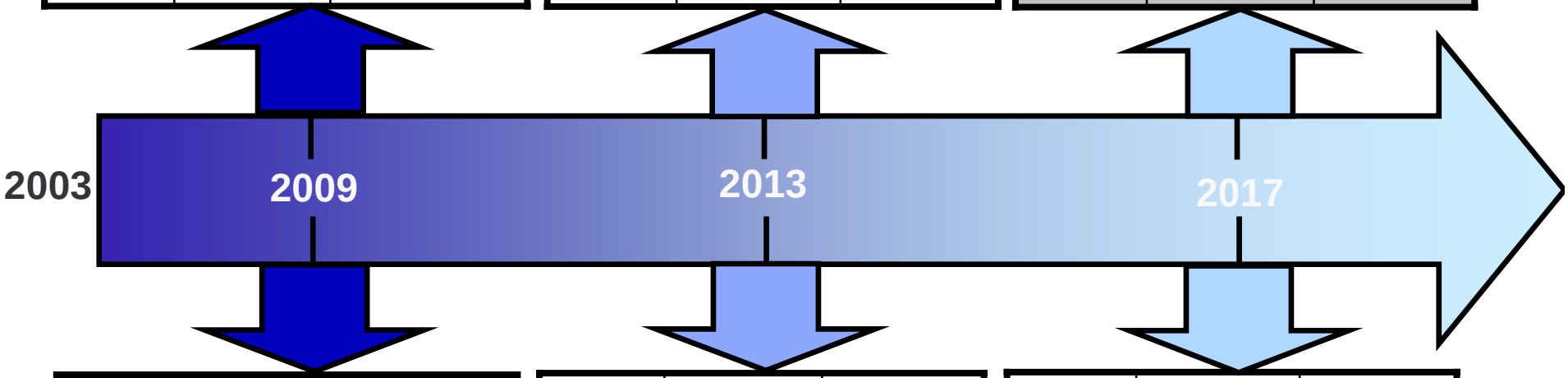
Timeline for IGCC Legislative Incentives

POWER ONLY

Heat Rate	First 5 Years	2nd Five Years
BTU/KWHR	$/KWHR	$/KWHR
8500	0.0060	0.0038
8750	0.0025	0.0010
9000	0.0010	0.0010

Heat Rate	First 5 Years	2nd 5 Years
BTU/KWHR	$/KWHR	$/KWHR
7770	0.0105	0.0090
8125	0.0085	0.0068
8500	0.0075	0.0055

Heat Rate	First 5 Years	2nd 5 Years
BTU/KWHR	$/KWHR	$/KWHR
7380	0.0140	0.0115
7720	0.0120	0.0090



Efficiency	First 5 Years	2nd 5 Years
	$/KWHR	$/KWHR
40.6%	0.0060	0.0038
40.0%	0.0025	0.0010
38.4%	0.0010	0.0010

Efficiency	First 5 Years	2nd 5 Years
	$/KWHR	$/KWHR
43.6%	0.0105	0.0090
42.0%	0.0085	0.0068
40.2%	0.0075	0.0055

Efficiency	First 5 Years	2nd 5 Years
	$/KWHR	$/KWHR
44.2%	0.0140	0.0115
43.9%	0.0120	0.0090

FUELS and CHEMICALS

Summary
Turbines for Syngas / Hydrogen

- **Goal**: By 2008 provide a commercial design for a coal-based power system with 50% efficiency, capital cost < $1000/kW and near zero emissions.
- **Implementing Approach**: Address mission critical issues through a plan, assess (bench-scale / exploratory testing) and test (component i.e. full size combustion can) format over 5 years.
- Use potential **customers** to drive the test program.
- Approach to address mission critical issues
  - Combustion fundamentals (syngas & hydrogen)
  - Combustion techniques (syngas & hydrogen)
  - Thermal barrier coatings
  - Increase in power output
  - Optimized integration with IGCC & BOP

Next Steps

- **Using stakeholder input**
  - Evaluate technical approaches and comments against, impact, budget and likelihood of success
- **Moving forward in developing a Turbine Road Map**
  - Assess existing and new projects against ability to address mission critical issues
  - Internal review (approach, impact, results, budget)
- **Road Map Results**
  - Plan to complete the internal process in an end of September time frame
  - Post the road map on the web

Open Discussion and Stakeholder Feedback Turbines for Syngas and Hydrogen

What is on the table for discussion:

- Stay focused on the turbine (inputs and outputs of related systems are appropriate but not the focus)
- Impact of hydrogen as a fuel
- Mission critical issues
- Priorities of mission critical issues
- Approach to mission critical issues
- Implementing approach (i.e. how will we address issues)
- What kind of program results or deliverables should be produced by 2008

DOE's Fossil Energy Turbine Program

Turbine Road Map for
Fuel Cell Turbine Hybrids

July 30, 2003

Turbine Program Goals
Fuel Cell Turbine Hybrids

- **Program Strategic Performance Goal (PSPG) (2008)**

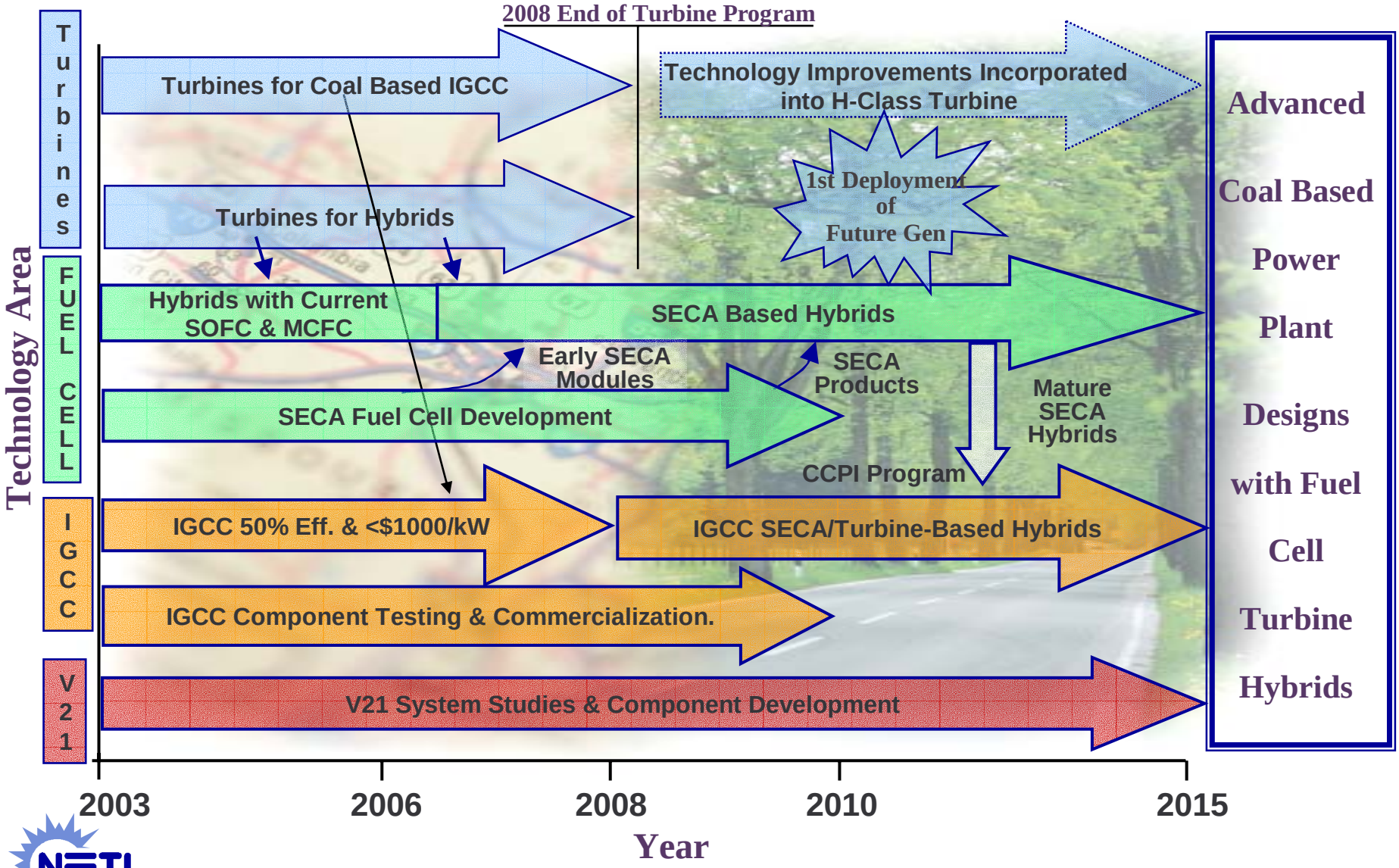
By 2008 provide a commercial design for a coal-based power system at 50% efficiency and a capital cost < $1000/kW with near zero emissions

- **Vision 21 Performance Goal (2015)**

By 2015 provide a commercial design for a coal or NG fueled power system at 75% (LHV) and 60% (HHV) efficiency respectively w/ near-zero emissions, a zero CO2 option and competitive costs

- **Turbine Program Mission Critical Issues**
  - Reduction in emissions
  - Improvements in turbine efficiency
  - Reduce the cost of electricity
  - Designs for large gas turbines for FCT hybrid applications
  - Systems, components, integration, and controls for FCT hybrids

Pathways to Advanced Coal Based Power Systems



Fuel Cell Turbine Hybrid Goals

- **Long Term Goal (2015)**

Develop deployment ready designs for nominal 300 MW fuel cell turbine hybrid technology for coal-based FutureGen plants. These plants will have the following performance targets: a capital cost of $850/kW, 60 % electrical efficiency (HHV), zero emissions of criteria pollutants with options for CO2 capture and hydrogen co-production.

- **Mid Term Goal (2010)**

To meet the long–term FutureGen goals, develop deployment ready designs for multi-MW fuel cell turbine hybrid technology for natural gas applications. These plants will have the following minimum performance requirements: utilization of a low-cost ($400/kW) high temperature fuel cell, 65 % electrical efficiency (LHV), zero emissions of criteria pollutants, and with options for CO2 capture and hydrogen co-production.

General Categories for FCT Hybrid Mission Critical Issues

1) Development of large gas turbines for FCT hybrid application (Turbine Program)
2) Systems integration and controls for FCT hybrid application (Turbine Program & Fuel Cell Program)
3) Hybrid systems and component demonstration (Turbine Program & Fuel Cell Program)
4) High temperature fuel cell performance advancement for FCT hybrid application (Fuel Cell Program)
5) Gasification systems advancement for FCT hybrid application (Gasification Program)

Hybrid Mission Critical Issues

1) Development of large gas turbines for FCT hybrid application (Turbine Program)

- Low turbine inlet temperature
- Recuperative GT design for provision of fuel cell air
- Intercooled compressor
- Oil-free bearings for large gas turbines
- Advanced combustor design for high temperature, vitiated stream

Hybrid Mission Critical Issues, Cont.

2) Systems integration and controls for hybrid FCT application (Turbine Program & Fuel Cell Program)

- Convergence of power island technology: coal and natural gas
- Development of novel advanced cycle concepts
- Steady state analyses of advanced cycle performance
- Dynamic simulation of hybrid FCT systems
- Control systems development
- Integration issues identification and investment in resolution
- Detailed economic and performance trade-off analyses
- Attain costs for IGFCT at $850/kW and NGFCT (natural gas) at $400/kW

Hybrid Mission Critical Issues, Cont.

3) Hybrid Systems and Component Demonstration (Turbine Program & Fuel Cell Program)

- Develop optimized SECA-based fuel cell modules for multi-MW scale systems that can be pressurized and applied to a 300 MW power island and a 50 MW co-product facility.
- Develop integrated FCT hybrid systems capable of generating electricity and hydrogen.
- Resolve component development and systems integration and control needs for FCT hybrid systems applicable to the 300 MW power island and a 50 MW co-product facility.
- Identify and resolve steady state and dynamic operational and control issues associated with large-scale hybrid systems.
- Develop turbines and FCT cycles for the 300 MW power island and a 50 MW co-product facility.

Hybrid Mission Critical Issues

4) High Temperature fuel cell performance advancement for FCT hybrid application (Fuel Cell Program)

- High power density fuel cell performance advancement
- Thermal management of low stoichiometry high temperature fuel cells (internal reforming, low temperature air)
- High pressure operation of fuel cells
- Contaminant resistant fuel cell operation
- Scale-up issues for SECA-based SOFCs
- Design of fuel cell for CO2 sequestration (separate anode and cathode exhaust streams)

Hybrid Mission Critical Issues

5) Gasification systems advancement for FCT hybrid application (Gasification Program)

- Ionic membrane air separation
- Advanced Transport Reactor (ATR) carbon conversion
- High temperature gas cleanup
- High temperature shift/membrane separation of H2
- High Temperature Air Furnace (HITAF)

Turbine Related Mission Critical Issues For FCT Hybrids

- Low turbine inlet temperature (1)*
- GT design for provision of fuel cell air (1)
- Intercooled compressor (1)
- Oil-free bearings for large gas turbines (1)
- Adv. combustor design for HT vitiated streams (1)
- Convergence of power island technology: coal and NG (2)
- Development of novel adv. cycle concepts (2)
- Steady state analyses of cycle performance (2)
- Dynamic simulation of hybrid FCT systems (2)
- Control systems development (2)

* Numbers in parenthesis refer to the general categories of mission critical issues

Turbine Related Mission Critical Issues For FCT Hybrids (continued)

- Integration issues identification and investment in resolution (2)
- Detailed economic and performance trade-off analyses (2)
- Attain costs for IGFCT at $850/kW and NGFCT (natural gas) at $400/kW (2)
- Develop integrated FCT hybrid systems capable of generating electricity and hydrogen. (3)
- Resolve component development and systems integration and control needs for FCT hybrid systems applicable to the 300 MW power island and a 50 MW co-product facility. (3)
- Identify and resolve steady state and dynamic operational and control issues associated with large-scale hybrid systems. (3)
- Develop turbine(s) and FCT cycles for the 300 MW power island and a 50 MW co-product facility. (3)

Summary
Turbines for FCT Hybrids

- **Goal**: By 2015 develop designs for 300 MW FCT hybrid technology for coal-based FutureGen plants with a capital cost of $850/kW, 60 % efficiency (HHV), zero emissions and options for CO2 capture and hydrogen co-production.
- **Implementing Approach:** Develop system concepts, analysis, designs and limited test data that address mission critical issues over the next 5 years.
- Address mission critical issues that pertain to **turbines**
- **Anticipated results at the end of 2008**: Designs for turbines and cycles for hybrid systems that have been optimized for cost and performance

Next Steps

- **Using stakeholder input**
  - Evaluate technical approaches and comments against, impact, budget and likelihood of success
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Open Discussion and Stakeholder Feedback Turbines for Fuel Cell Turbine Hybrids

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- Implementing approach (i.e. how will we address issues)
- What kind of program results or deliverables should be produced by 2008