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Perspectives on R&D Needs For Gas Turbine Power Generation in a Carbon Constrained World

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Outline

- Introduction to Siemens Energy
- Overview & Outlook of the World Energy Market
- Technology Drivers and Challenges for Gas Turbines
- Conclusions

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Siemens strategy is based on developing and delivering Technological Solutions in response to the Global Megatrends

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Megatrends

Urbanization

- Today: 280 million people in megacities [1]
- America's megacities: greater N.Y. (20m), greater L.A. (15m)
- 2007: First time in human history more people living in cities than in rural areas
- 2015: 350 million people in megacities worldwide

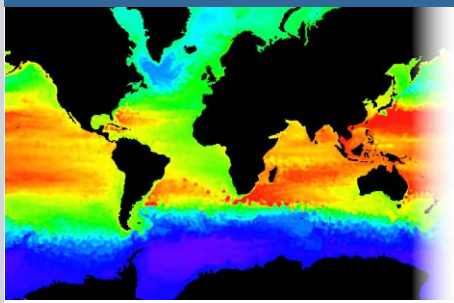
➔ **Challenge for infrastructure**

Demographic change

- Average life expectancy increasing globally from 46.6 (1950) to 72 (2025)
- The average life expectancy for an American is 77.6 years—highest ever
- Global population growth from more than 6 billion to 8 billion by 2025
- The U.S. population crossed the 300 million mark in 2006 and is growing

➔ **Challenges for infrastructure and healthcare**

Climate Change



- The past nine years have all been among the 25 warmest years on record for the United States
- Man-made CO_2 has raised the level of CO_2 significantly beyond historic levels (from 280 parts per million in pre-industrial times to 380 ppm today).
- More than a few degrees of temperature increases will lead to global problems with diseases, loss of wealth and an increase in natural disasters

➔ **Challenges for energy and the environment**

[1] A megacity is defined as having more than 10 million inhabitants.

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Energy Supply

Three global megatrends in the energy sector

Demographic dynamics

- **Population growth:** 7.5 bn in 2020 (+1.1 bn)
- **Power consumption:** +5.2% p.a. in emerging regions vs. 1.4% in developed world
- **Megacities** (>10 million): 15 new cities in 2015

Resource scarcity

- **Geopolitics:** 70% of world oil and gas supplies only in a few countries
- **Fuel diversity:** Price, availability and environmental factors accelerate shift to broader fuel mix

Environmental focus

- **Global emissions:** 40% increase in air pollution over past 20 years
- **Climate change:** Broad consensus on climate change; temperature increase of 3-4 °C in this century

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Our structure, organized to meet customer needs

Sectors		Divisions	
Industry		▪ Industry Automation ▪ Drive Technologies ▪ Building Technologies ▪ Osram ▪ Industry Solutions ▪ Mobility	
Energy		▪ **Fossil Power Generation** ▪ **Renewable Energy** ▪ **Oil & Gas** ▪ **Energy Service** ▪ **Power Transmission** ▪ **Power Distribution**	
Healthcare		▪ Imaging & IT ▪ Workflow & Solutions ▪ Diagnostics	

Comprehensive portfolio and services: from primary energy to power distribution

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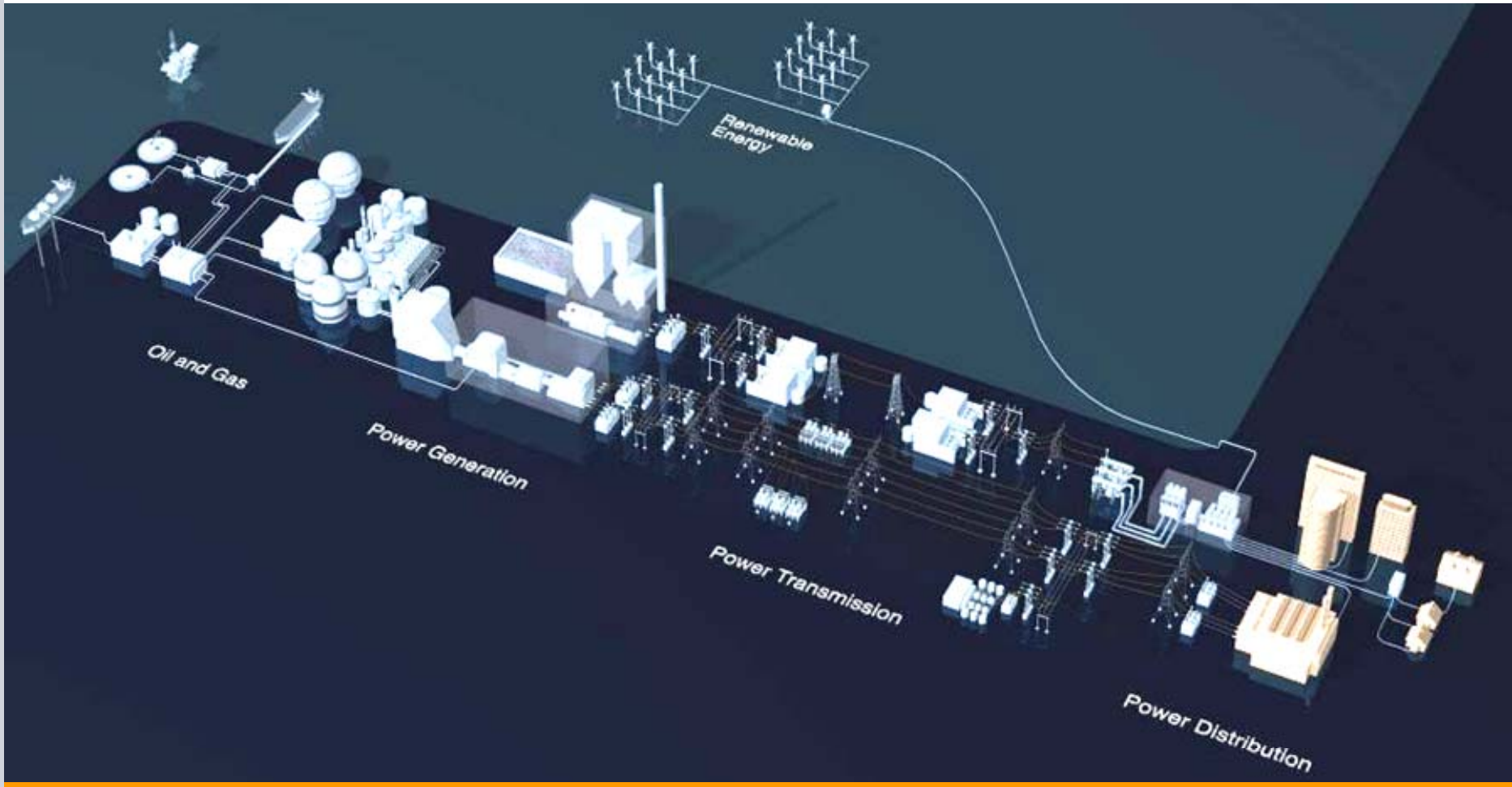

The only company that offers complete end-to-end solutions for the energy conversion process.

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World Energy Market Outlook: Demand is Growing, Supply Mix is Changing yet Fossil Fuels Will Continue to be the Mainstay

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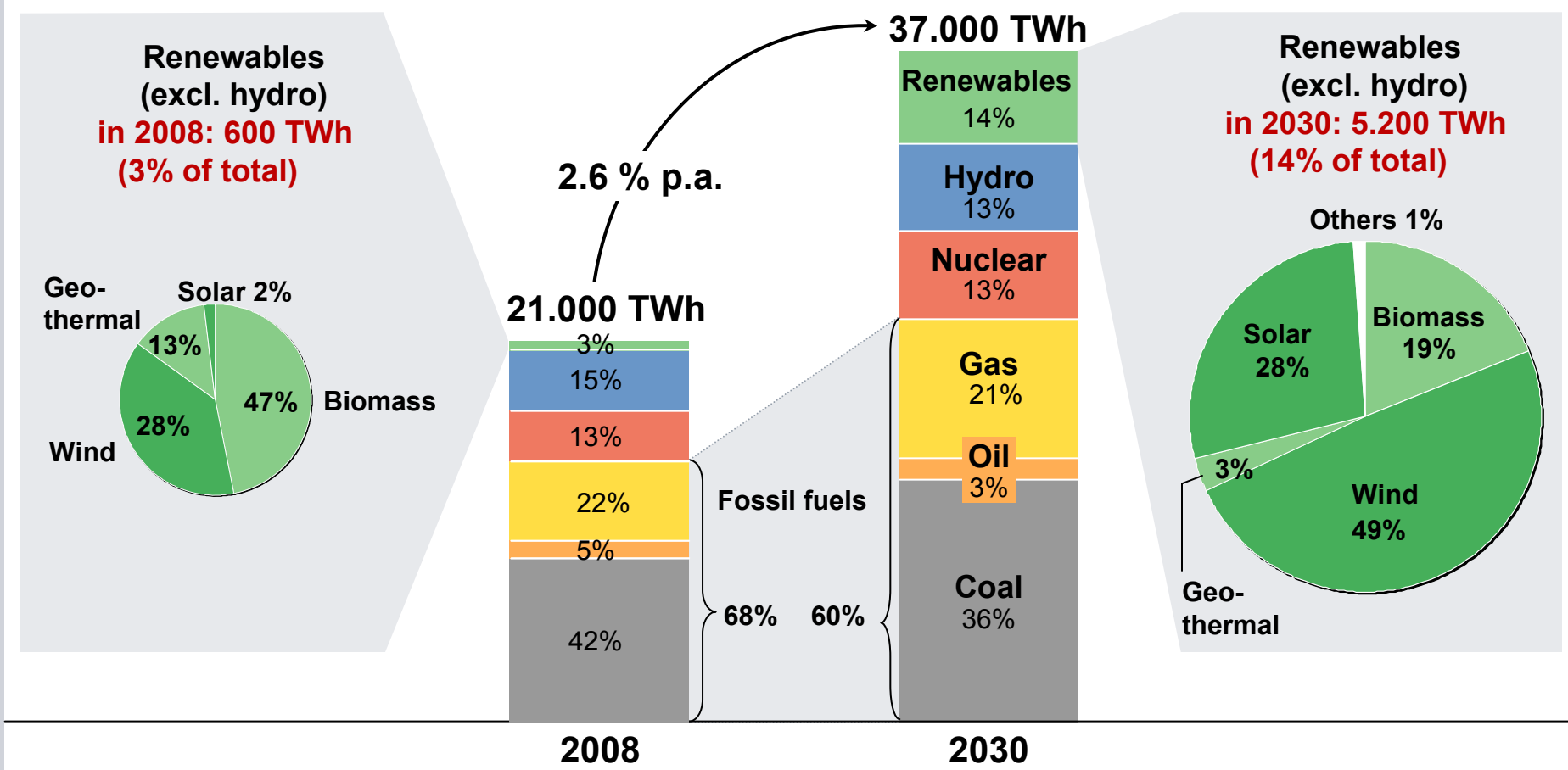
Power Generation (in 1000 TWh[1])



Quelle: Siemens Energy Sector, GS4 base case

[1] Terawatt-hours

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Growth in the Emerging Markets will continue to raise Carbon dioxide emissions with various regions relying on different fuel portfolios

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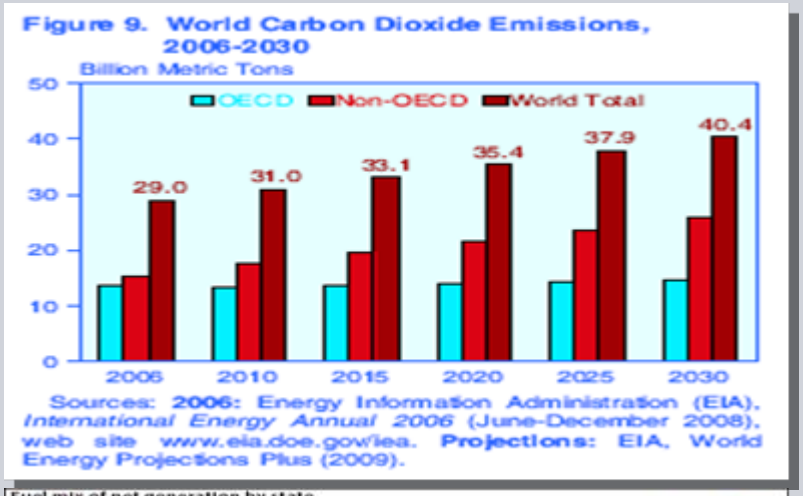
World Carbon Dioxide Emissions

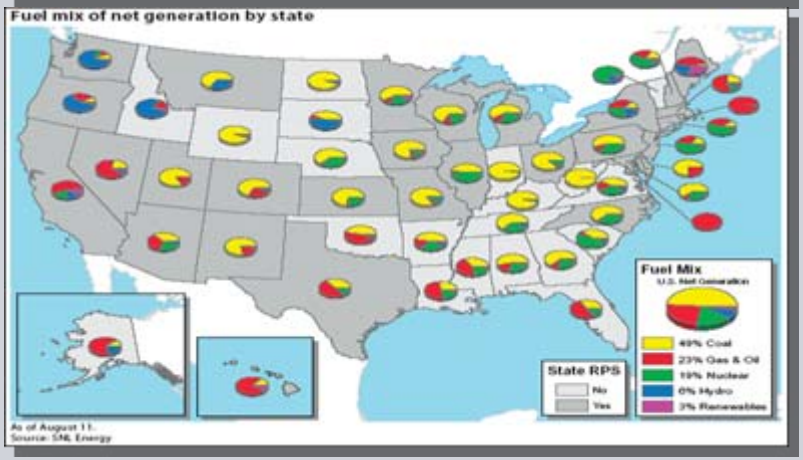
- Projected to rise from 29.0 billion metric tons in 2006 to 40.4 billion metric tons in 2030,an **increase of 39 percent** over the projection period.

- With strong economic growth and continued heavy reliance on fossil fuels expected for most of the non-OECD economies, **much of the increase in carbon dioxide emissions is projected to occur among the developing, non-OECD nations.**

- **Technology Solutions will need to be tailored** to the existing fuel mix that vary from one region to another.

**OECD: Organization for Economic Co-operation & Development*





Technology solutions need to be transferable to the Emerging/Developing markets. R&D Strategies need to flexible and aligned to the local Energy Mix.

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Environmental awareness: Increased energy use impacts climate change and endangers economical development.

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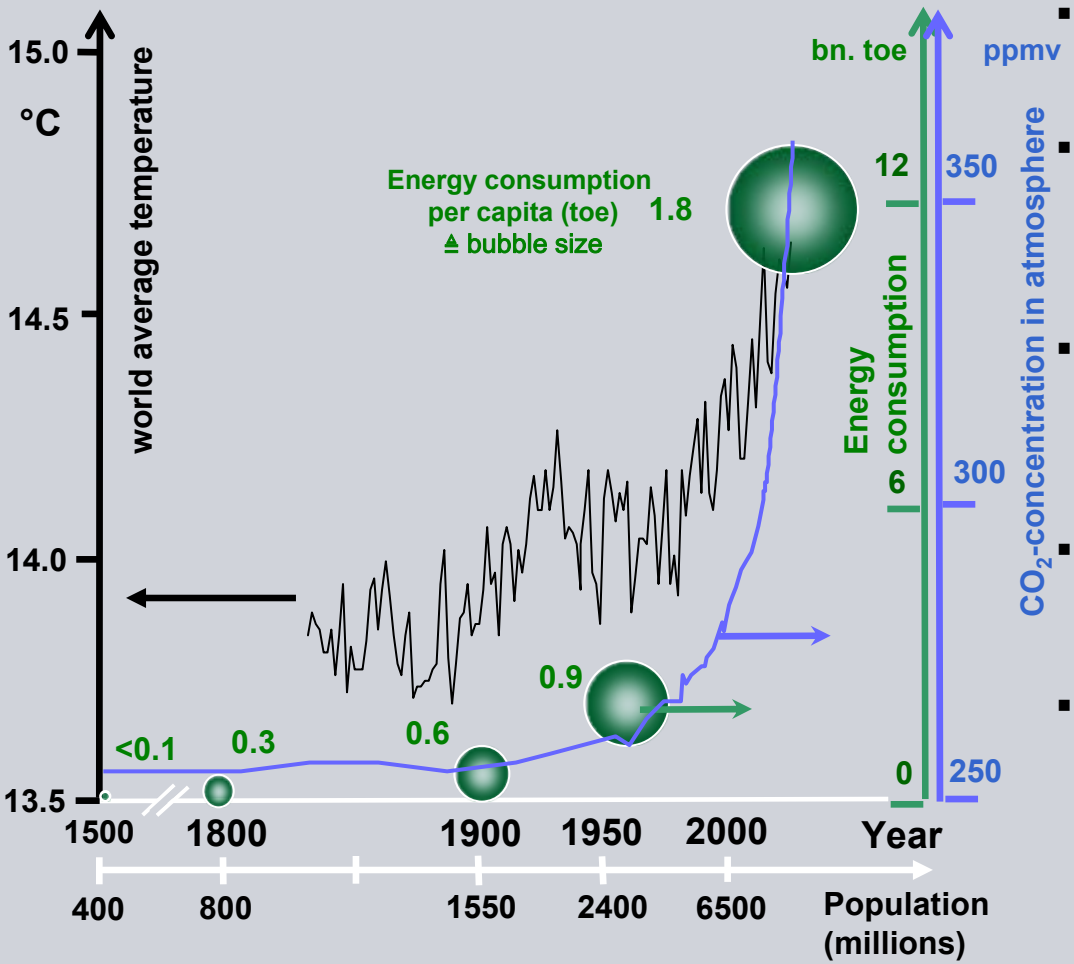
Energy consumption, CO_2 concentration and temperature increase, are they correlated?



Danger of irreversible changes

- The rapid growth of the world population corresponds with the broad 20th century industrialization.
- The availability of cheap fossil energy and increased concern for social welfare increased specific energy consumption by a factor of 2, reaching a level of 1.8 toe/capita.
- There is a good reason to assume a correlation between use of fossil energy, higher CO_2 concentrations in the atmosphere, and a corresponding temperature increase.
- Political, financial, and industrial leaders have acknowledged the danger of significant human-caused climate change.
- Technological innovation and industry response can significantly help to stabilize CO_2 concentrations to avoid possibly catastrophic results. It is estimated that this would cost less than 1% of the world GDP.

Sources: Stern report 2006, Siemens Energy GS

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Worldwide CO2 Emissions: emission reductions through use of high-efficiency state-of-the-art power plants

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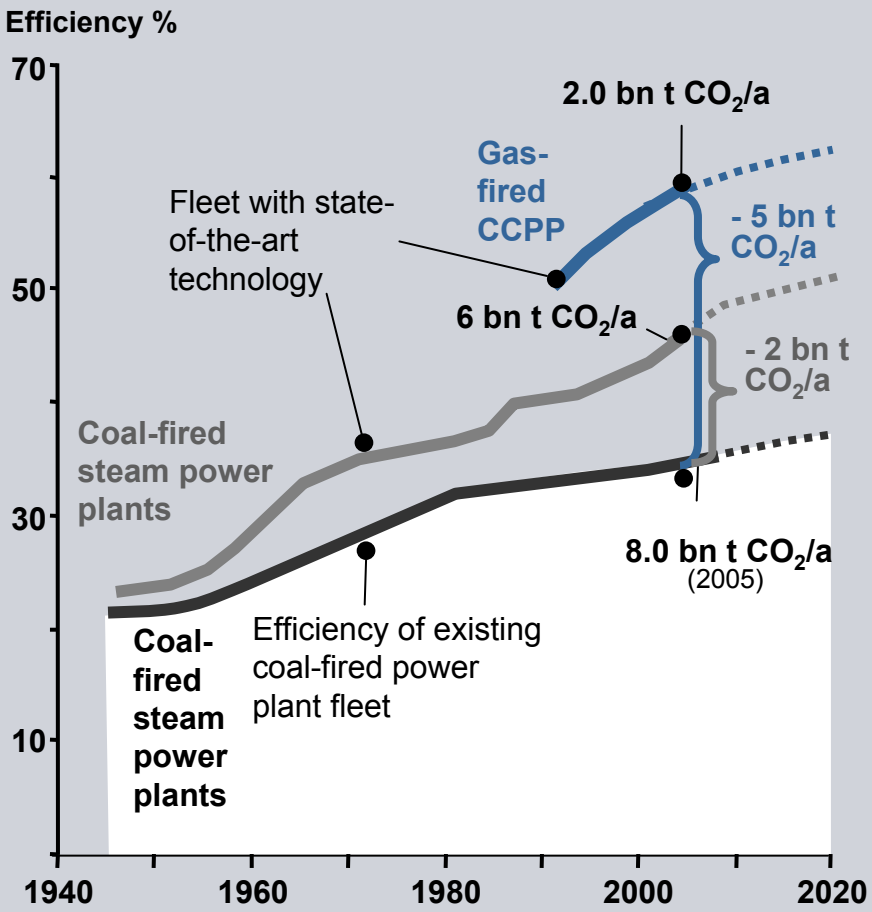
Coal fired fleet-CO_2 emissions



Source: IEA, Siemens Energy GS

CO_2 reduction potentials in power & heat

- Coal-fired power plants produce roughly 28% of the world's CO_2 emissions
- CO_2 reduction, while maintaining competitiveness, can be achieved by **replacing old coal power plants with:**
  - **<u>State-of-the-art coal power plants:</u>** **minus 2.0 billion t CO_2/yr** i.e. **minus 25%** of power generation from coal-fired steam power plants
  - **<u>Gas-fired combined cycle power plants:</u>** **minus 5.0 billion t CO_2/yr** i.e. **minus 63%** of power generation from coal-fired steam power plants

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A balanced Energy Mix is needed

Obama presses Senate to forge bipartisan climate change bill October 23, 2009 (Speech at MIT)
By Kathleen Hart

Noting that Sen. John Kerry, D-Mass., is working on climate change legislation and actively reaching out to Republicans in the Senate, Obama said: "This should not be a partisan issue. … Everybody in America should have a stake in legislation that can transform our energy system into one that's far more efficient, far cleaner, and provide energy independence for America — **making the best use of resources we have in abundance, everything from figuring out how to use the fossil fuels that inevitably we are going to be using for several decades,** things like coal and oil and natural gas; **figuring out how we use those as cleanly and efficiently as possible**; creating safe nuclear power; sustainably grown biofuels; and then the energy that we can harness from wind and the waves and the sun."

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Product Focused, Multi-Disciplinary R&D that takes a Systems Engineering view….

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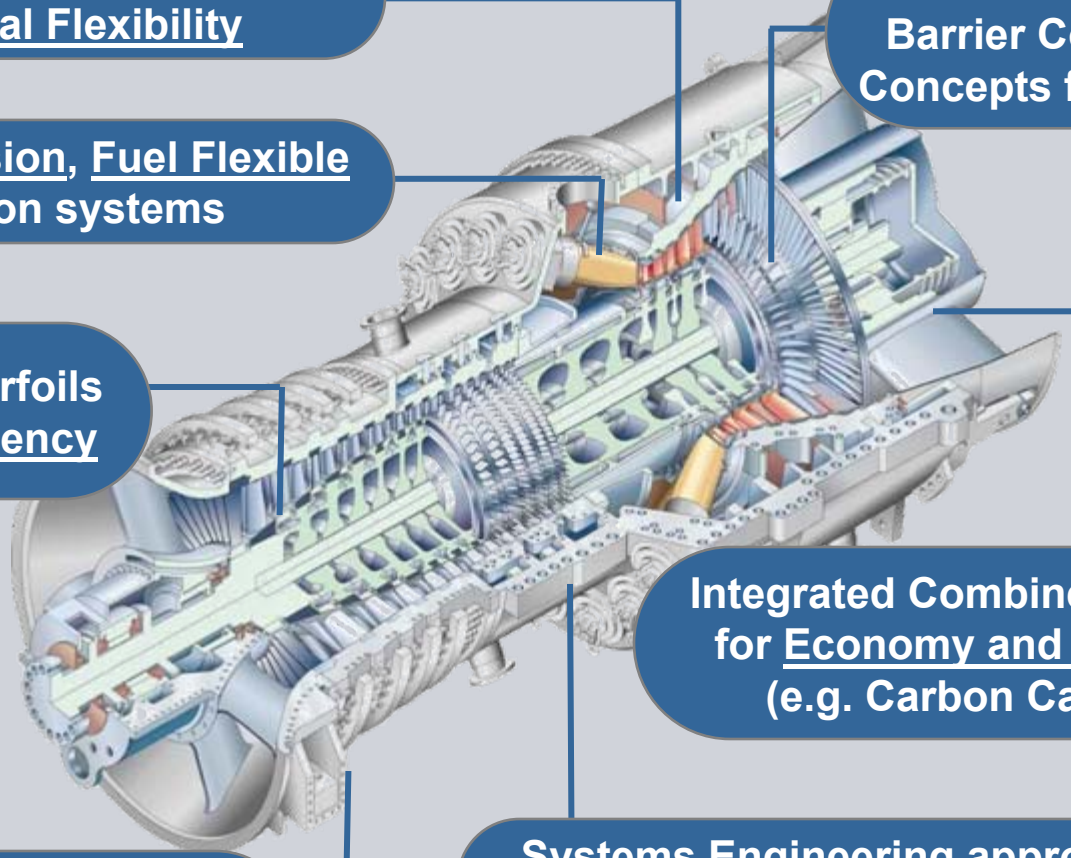

High cycling capability for Operational Flexibility

Ultra Low Emission, Fuel Flexible Combustion systems

Advanced 3D Airfoils for Higher Efficiency

Condition Based Monitoring, NDE & Lifing Methodologies / Tools

Advanced Materials, Thermal Barrier Coating and Cooling Concepts for Higher Efficiency

Integrated Combined cycle process for Economy and Low Emissions (e.g. Carbon Capture & Seq)

Systems Engineering approach for Optimizing overall Life Cycle Cost

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Siemens preferred solutions for CO_2 capture

IGCC / Pre-combustion carbon capture

- Gasification technology with multi-fuel capability for new power plants
- Technology “ready for implementation”
- Alternative route for chemical / fuel production, hydrogen economy
- Mastering higher technological and contractual complexity with “Siemens phased project execution offer”

Post-Combustion carbon capture

- Scalable market introduction, Demo-plants with slipstreams, minimize upgrade risk in process trains
- Enhancement potential for solvents, scrubbing process and for integration into the power plants
- Worldwide development activities with different solvents and related processes under way
- For retrofit and new coal-fired power plants

Siemens Fuel Gasifier

Siemens IGCC in Puertollano (E)

Siemens scrubbing process test lab

Post-Combustion carbon capture plant design

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Meeting DOE Goal of 2ppm Emissions Requires Development of these Key Technologies

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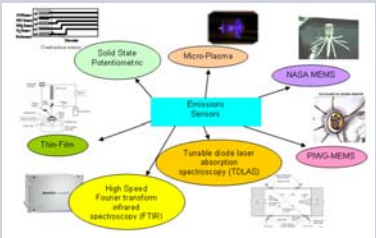
Advanced High Temperature Combustor

+

Poly-functional Emissions Reduction System

+



Advanced Emissions Sensors

=

2ppm Nox Emissions

- ✓ High Plant Efficiency
- ✓ Low CO_2 emissions
- ✓ Low Plant Nox Emissions
- ✓ Robust to fuel and ambient variation.
- ✓ Best fit with advanced high temperature engine.

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Combustion Systems Development Challenges & Needs (*partial list*)

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Challenges

- Flame Speed / Stability
- Flashback
- Combustion Dynamics / Acoustics

} e.g. H2

- Fuel Flexibility (Always need back-up fuel)
- Low Emissions at Increased Temperature
- Large variation in fuel properties depending on feedstock.

Needs

- Turbulent Flame Speed Data
- Kinetics Modeling
- Better predictive tools that can replace expensive high pressure testing
- Understanding impact of exhaust gas recirculation (EGR) on combustion phenomenon (emissions and stability)
- Rapid prototyping approaches to allow rapid manufacture and testing of combustor hardware designs in relevant fuel environment

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Turbine (Aero / Heat-Transfer) Challenges & Needs (*partial list*)

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Challenges

- Reduced cooling at elevated temperatures
- Increasing mass flow with low BTU fuels
- High moisture content with H2 fuel

Needs

- Improved aerodynamic and heat transfer predictions; Advanced 3D CFD Modeling
- Airfoil / end-wall geometry optimization for aero and heat transfer
- Improved internal cooling schemes and manufacturing methods
- Advanced blade trailing edge cooling concepts
- Novel external (film) cooling concepts; manufacturing techniques for post TBC coated surfaces
- Unsteady effects on aero, heat transfer and film cooling
- Increased diffuser performance
- Advanced sealing and secondary air systems technologies
- Rapid design iterations; Rapid Prototyping

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Materials & Coatings Development Challenges & Needs (*partial list*)

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Challenges

- High temperature low conductivity TBC
- Materials issues with Syngas and high hydrogen fuels
- Corrosion & oxidation capability

Needs

- High temperature capable TBC systems
- Understanding specific mechanisms of degradation process for top coats, bond coats and base materials
- Understanding of material erosion and deposition under realistic turbine conditions
- Improved corrosion resistant TBC for high moisture content and deposits such as Na_2SO_4 and $CaSO_4$
- Low cost and effective manufacturing process for application of coating architectures
- Ability to predict remaining TBC life based on operation history
- Sensor / NDE techniques to provide in situ TBC quality

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The Pathway Forward
Summary

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- **We have a Carbon constrained world where Greenhouse gas emissions** have to be reduced. Governments of the world are committed to this common goal.
- **Diversity of supply** will be necessary to meet the ever growing world energy demand. **Renewable technologies** wind and solar are improving their relative competitiveness, but they are intermittent and need back up.
- **Emissions restriction** will increase and therefore the need for "cleaner" Gas turbines with broad **operational and fuel flexibility** will be needed.
- As Natural Gas continues to be a premium fuel, G**as turbine efficiency is critical** to the cost of electricity and to the dispatch ability of the plant.
- Given the **differences in Energy/Fuel Portfolios** around the globe, the R&D/Technology **solutions need to be flexible & transferable**

Multi-disciplinary, **product focused** R&D is needed that not only targets performance attributes but also ensures the **lowest Life Cycle Cost** of the system.

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The Pathway Forward

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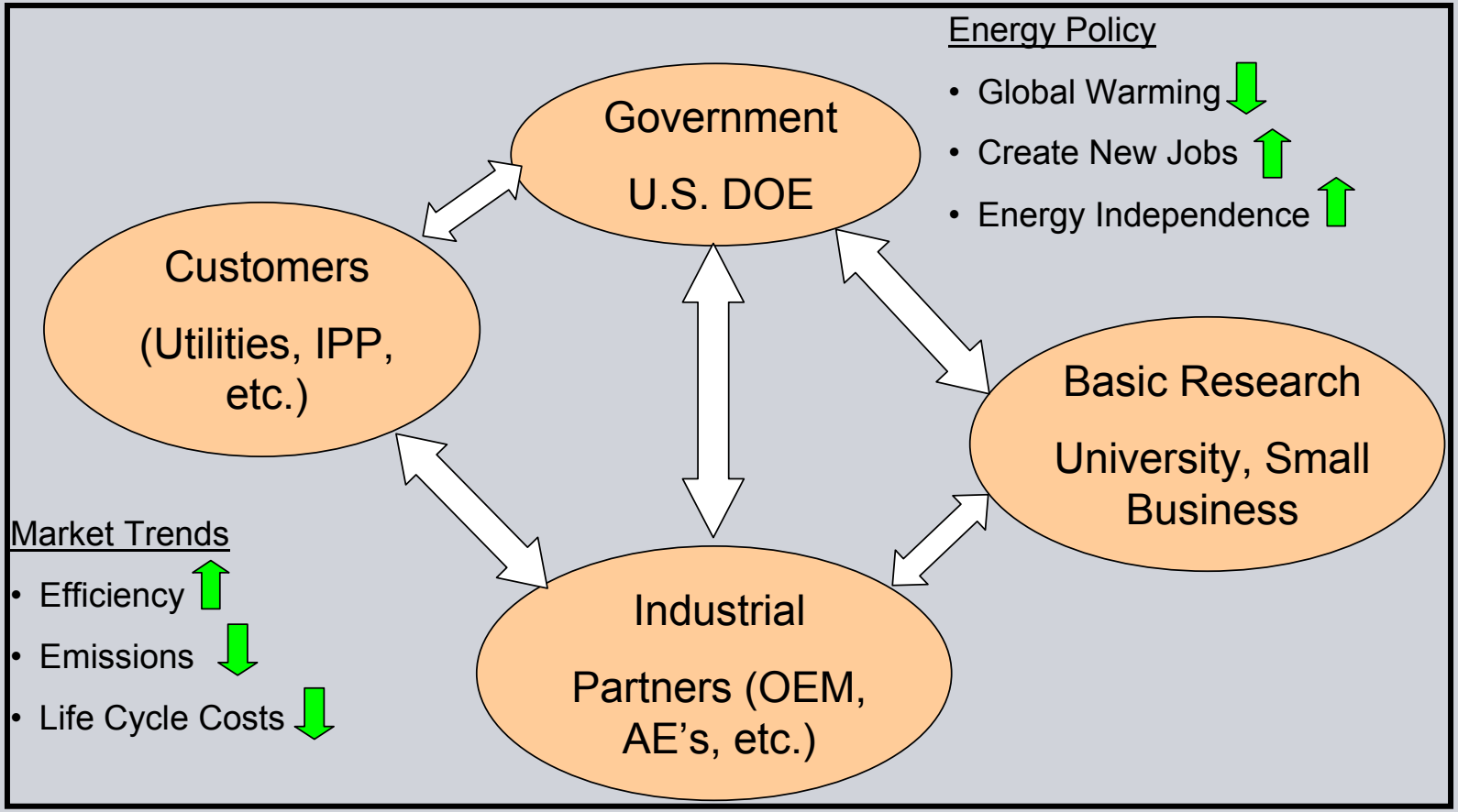
Leverage relationships



Key Success Factor will be our ability to leverage our relationships in order to be "pulling" synergistically in the same direction

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Thank you….

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