Technologies for Next Generation Turbine Systems

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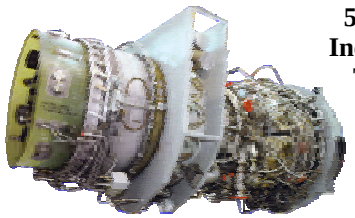
Rolls-Royce

Combined Cycle Performance at Simple Cycle Cost and Flexibility

Approach to “economically viable” NGT

High P.R. Simple Cycle



52 MW Industrial Trent

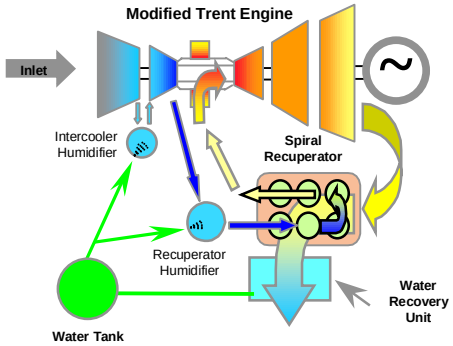
Low 40’s % eff’y. Higher PR & temp to improve - risky technologies; very difficult fuel flexible DLE.

ICR

25 MW WR-21

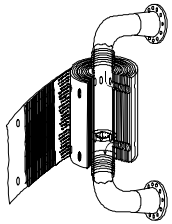
Mid 40’s % eff’y Only small additional improvements in efficiency possible.

Wet I.C. Wet Recuperated (WIWR)



Low 50’s % eff’y. Large development; high recuperator durability risk; difficult to control.

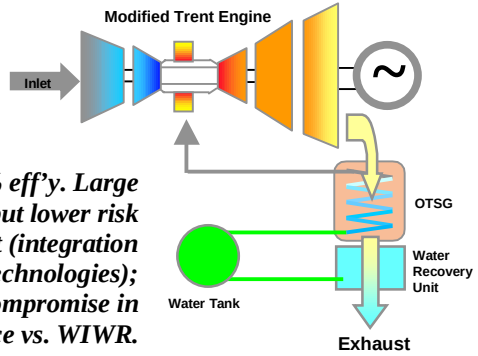
Parallel Shaft WIWR



Wet Recuperated RB211 + 501-K Power Section

Less development but compromised performance; complicated arrangement; increased unit cost.

Super Steam Injection



Low 50’s % eff’y. Large but lower risk development (integration of known technologies); slight compromise in performance vs. WIWR.

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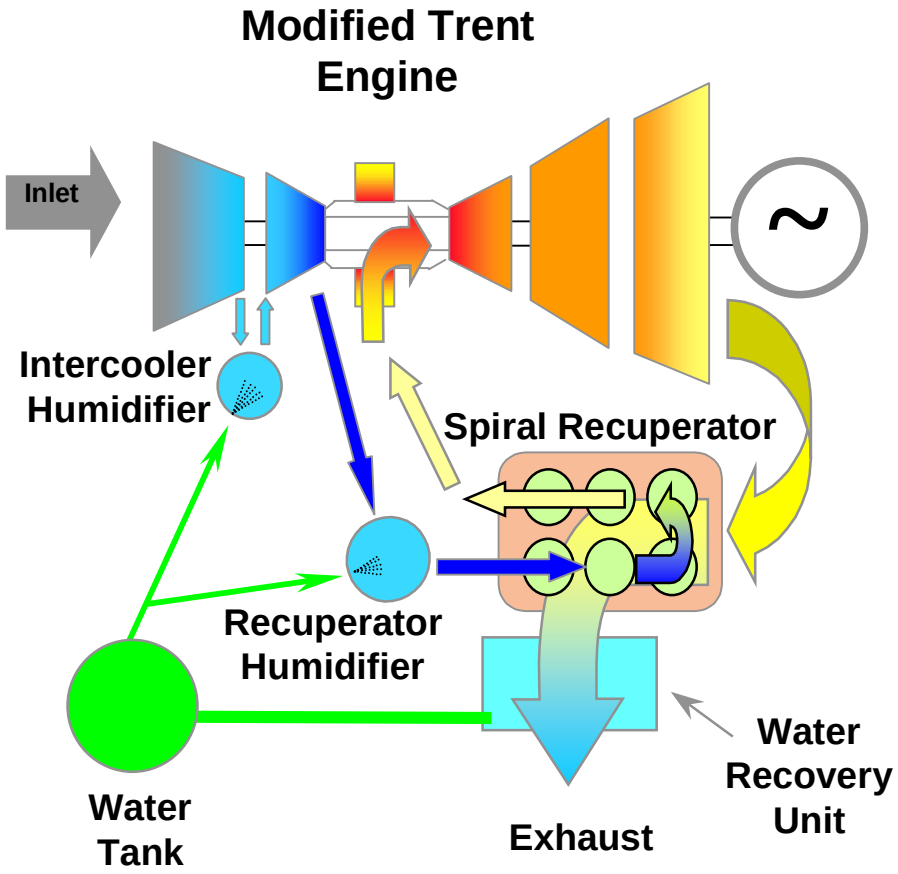
R-R NGT Concept #1 -
Wet Intercooled Wet Recuperated



Power:	**50-80 MWe**
Elect'l Efficiency:	**>50%**
Turnkey Price:	**$400-450/kW**
Emissions:	**<10 ppm NOx <10 ppm CO**
Start-up Time:	**<15 min**
Water System:	**Closed loop**

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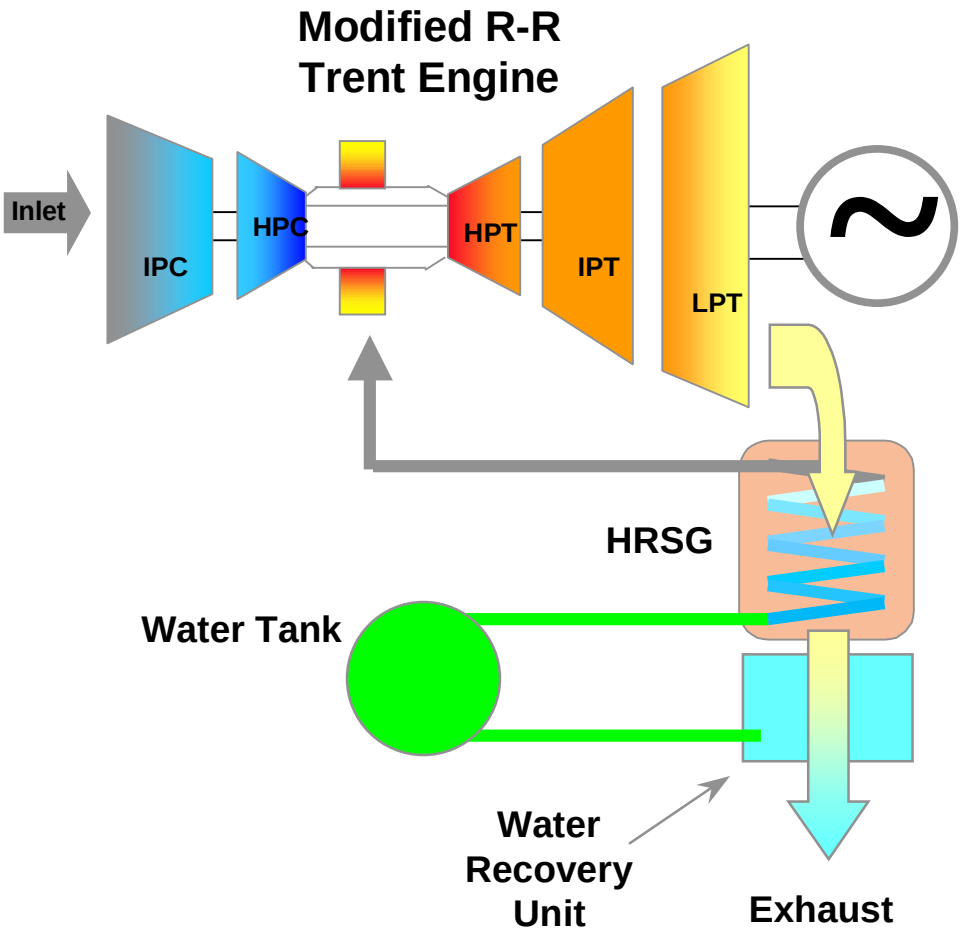
R-R NGT Concept #2 - Super Steam Injection



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Water System:	**Closed loop**

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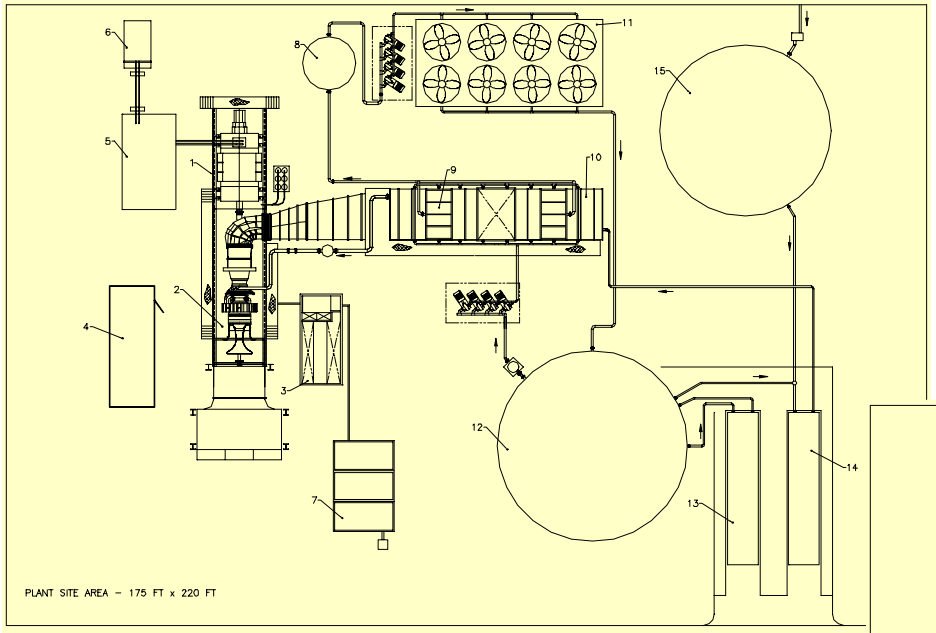
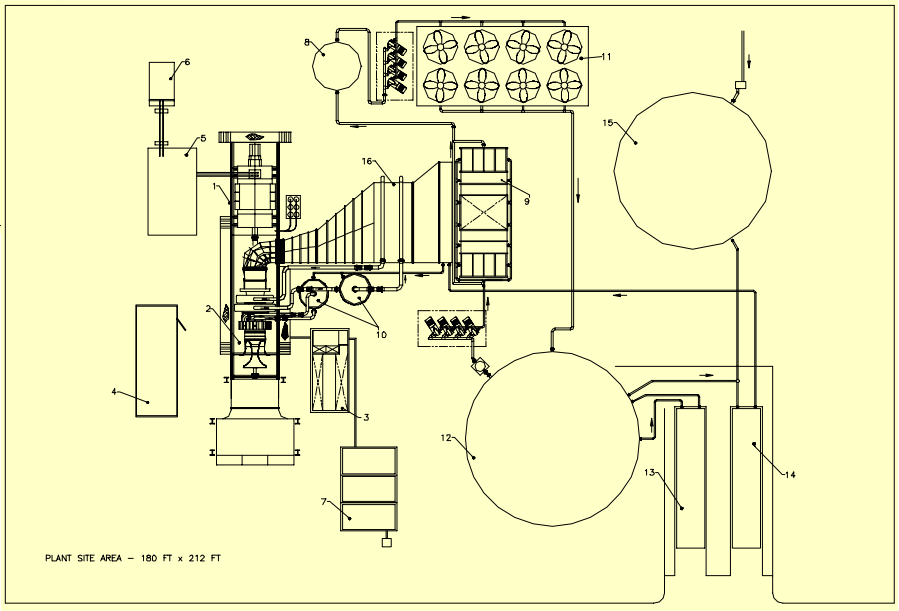
Similar Plant Layouts



1 Generator Skid
2 Gas Turbine Skid
3 GTG Auxiliary Module
4 Control Room
5 High Voltage Module
6 Utility Tie
7 Gas Compressor
8 Water Recovery Tank



9 Water Recovery Sys
10 Once Thru Steam Generator
11 Fin Fan Cooler
12 Demin water storage
13 Polishing Unit
14 Demin Unit
15 Make up water

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R-R's NGT - Comparison to Current Products

	Simple Cycle			Wet Cycle			Combined Cycle			
	GE LM6000 PD (DLE)	R-R Trent DLE	GE Fr6FA	GE LM6000 Sprint	R-R NGT#1-SI (Super Stm Inj)	R-R NGT#2-WIWR (Wet IntrCool / Wet Recup)	GE LM6000 C.C.	R-R Trent C.C.	GE Fr6FA C.C.	GE Fr7EA C.C.
Power (MW)	43.1	51.2	70.1	47.3	50-80	50-80	56.4	66	107.4	130.2
Efficiency (%)	41.4%	41.6%	34.2%	41.4%	>50%	>50%	52.5%	54.3%	53.2%	50.2%
Turbogenerator Price ($/kW)	$366	$303	$285	$298						
Turnkey Price ($/kW)	~ $560	~$500	~$480	~$430 (no water recov)	$400-450 (incl water recov)	$400-450 (incl water recov)	$658	$650	$730	$514
Flexibility	High	High	High	High	High -	High -	Med/Lo	Med/Lo	Low	Low

Source: Gas Turbine World Handbook

R-R's NGT Solution:

- **~ 25% improvement in efficiency of simple cycle machines**
- **~ 30% improvement in capital cost ($/kW) of combined cycle plants**
- **Maintains operational flexibility of simple cycle machines**

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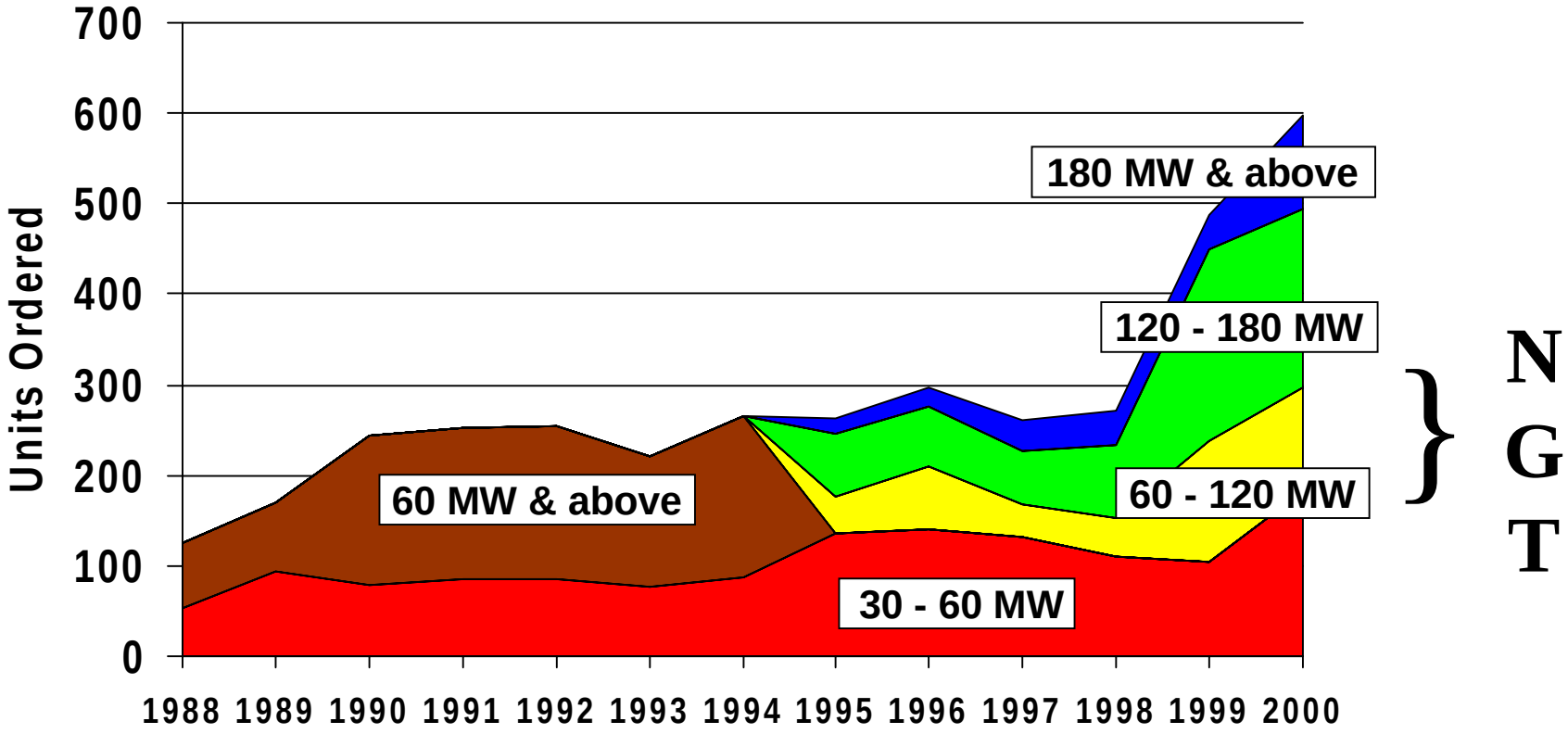
R-R's NGT Concept Meets The DOE Goals

Determine the feasibility of developing flexible gas turbine systems with a greater than 30 MW power rating. Compared to 1999 state-of-the-art systems, the proposed systems shall include:

	R-R's NGT
– 15% or higher improvement in net system efficiency;	√
– improvement in turndown ratios;	√
– 15% or higher reduction in COE;	√
– improved service life;	**Achievable**
– reduction of emissions (carbon and NOx);	**Achievable**
– 15% or higher reduction in operations & maintenance costs;	**Achievable**
– 15% or higher reduction in and capital costs;	√
– increased flexibility (min. 400 starts/year);	√
– improvement in RAM; and	**Achievable**
– capability to use multiple fuels.	**Achievable**

The Market Opportunity Appears to Exist



Source: Diesel & Gas Turbine Worldwide Annual Power Gen Survey

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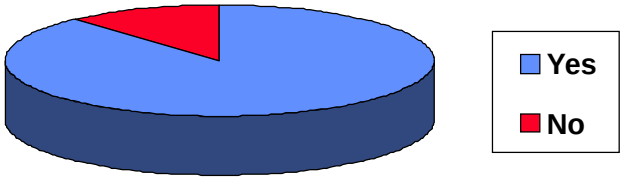
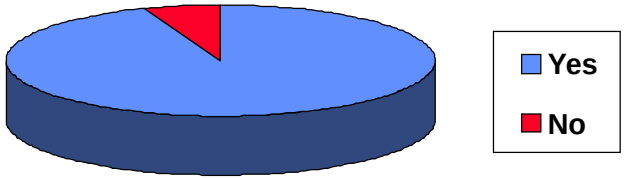
Customer Survey: R-R Solution Seems Appropriate

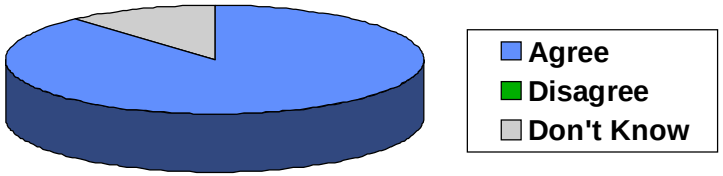
Distributed Generation Growth?



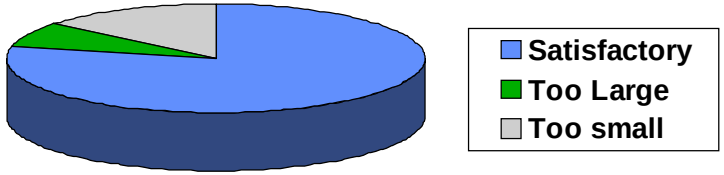
Market Perceived for R-R's NGT?



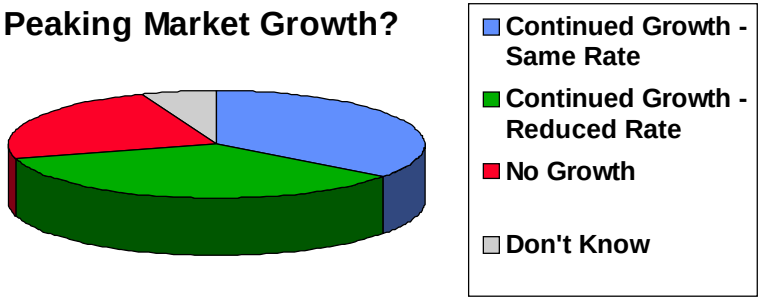
Future Mid-Merit Market?



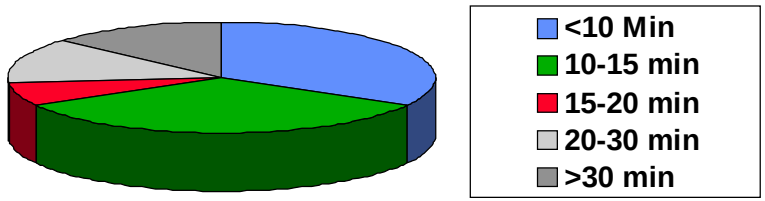
70-80 MW Size?



Peaking Market Growth?



How Fast Should Start Time Be?



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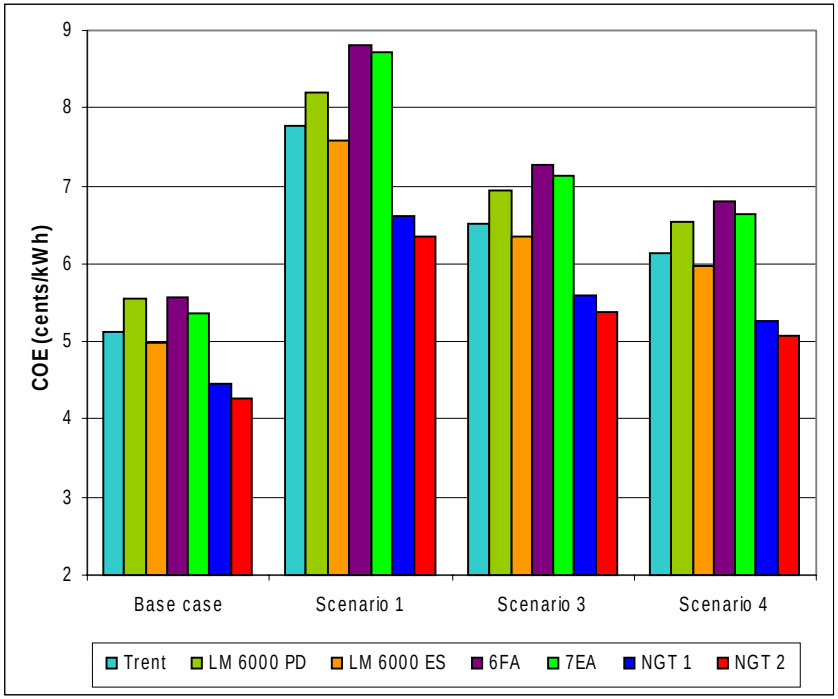
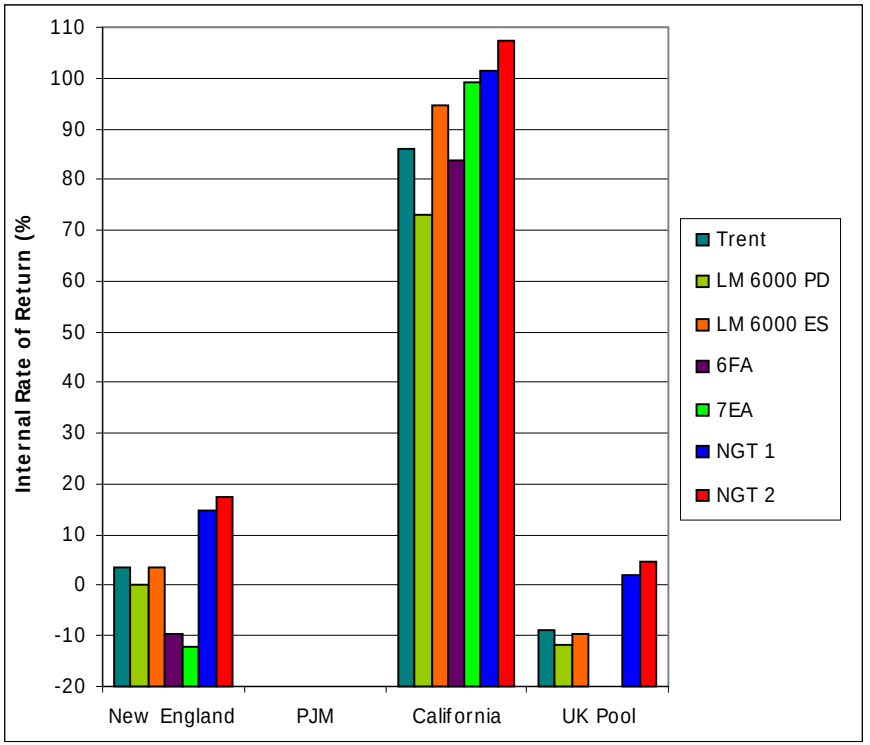
R-R's NGT - Economic Benefits to Operators

COE Comparison - Mid-Merit Operation
NGT vs. Simple Cycle Machines



IRR Comparison - Spot Market Trading
Example



Base case
Reference Case in EIA Annual Energy Outlook - 2001

Scenario 1
High gas price (2 x base case)

Scenario 3
Gas price 1.5 x base case, CO2 tax in later years

Scenario 4
Low longer-term gas prices, high CO2 taxation

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Public Benefits of R-R's NGT

- **Assuming 34 NGT units (2550 MWs) per year installed in U.S.:**
  - CO_2 Emissions - Cumulative 15 Year Savings
    - Compared to Simple Cycle GT, 150 million tonnes savings
    - Compared to Coal Plant, 630 million tonnes savings
    - $3B savings in CO_2 trading credits (assumed @ $20/tonne) cf simple cycle GT
    - $12.6B savings in CO_2 trading credits (assumed @ $20/tonne) cf coal plant
  - Fuel (natural gas) Consumption - Cumulative 15 Year Savings
    - Compared to Simple Cycle GT, 2.6 trillion cubic feet savings
    - $8.3B fuel cost savings compared to Simple Cycle GT
- **$2.1 billion/yr potential export sales from 2006 (assumed 54 units/yr)**
- **Lower risk approach allows earlier availability to market**
- **Flexible characteristics allow for viable and efficient operations even in changing market conditions**

Summary

- **R-R's NGT concepts have been approached from an "economic viability" perspective:**
  - Leveraging available hardware and technologies to lower risk, investment, and time to market; and
  - Applying these in innovative ways to develop a solution that will provide customers with improved return on investment (ensure deployment) while providing extensive public benefits.
- **R-R's NGT concepts (Wet Intercooled/Wet Recuperated; Super Steam Injection):**
  - Meet DOE NGT goals;
  - Seem to be appropriate for the future marketplace;
  - Provide substantial economic benefits to operators; and
  - Provide substantial public benefits.
- **R-R is encouraged by the results of this study. However, the significant technical & market risks and the large investments required make launching an NGT product very difficult in today's business environment.**