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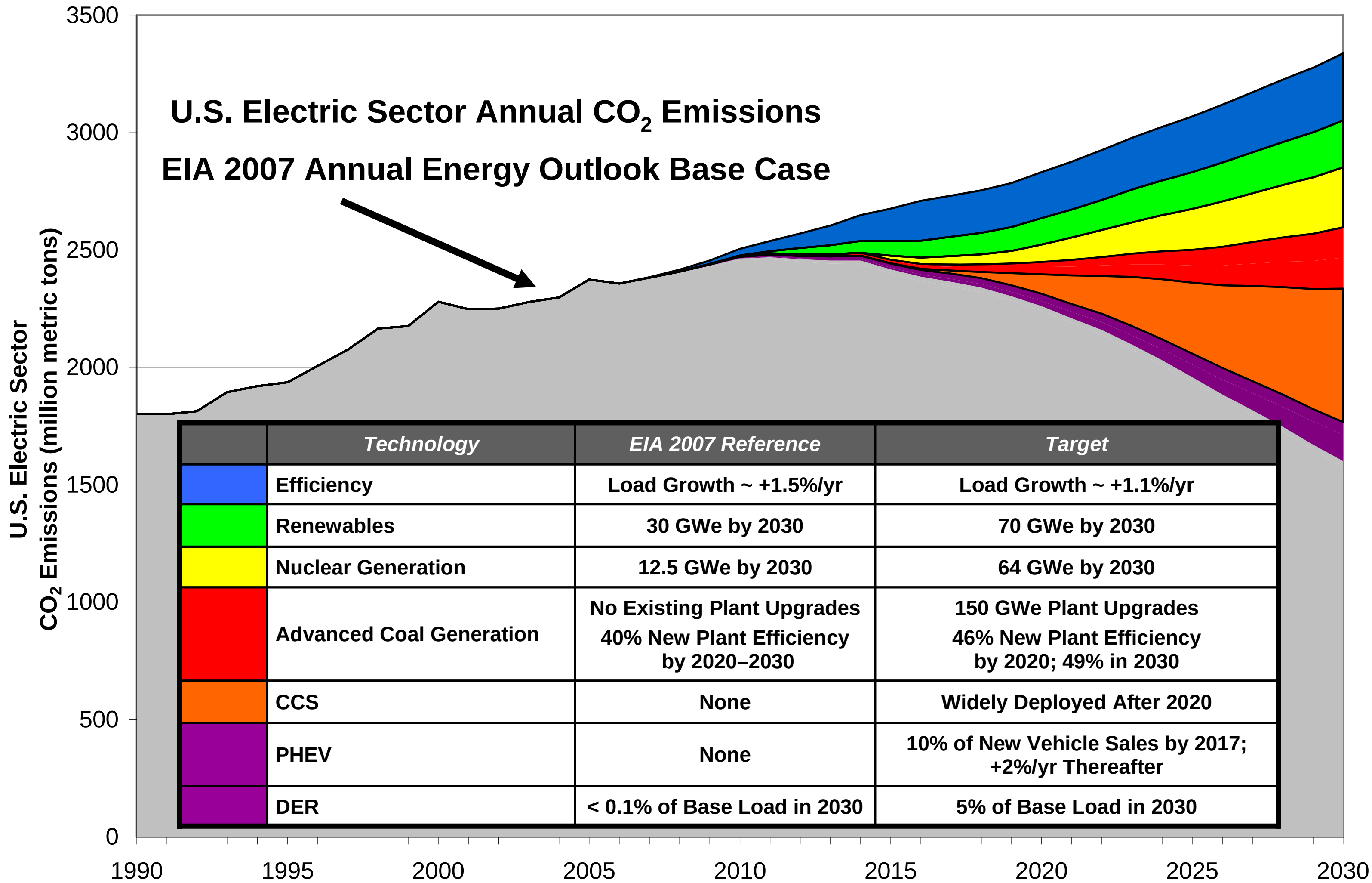
Electricity Technology in a Carbon-Constrained Future

Carnegie-Mellon University
November 28, 2007

Revis James
Director, Energy Technology Assessment Center

What CO_2 emissions reductions from the U.S. electricity sector are technically feasible?

CO_2 Reductions … Technical Potential*



	Technology	EIA 2007 Reference	Target
(blue)	Efficiency	Load Growth ~ +1.5%/yr	Load Growth ~ +1.1%/yr
(green)	Renewables	30 GWe by 2030	70 GWe by 2030
(yellow)	Nuclear Generation	12.5 GWe by 2030	64 GWe by 2030
(red)	Advanced Coal Generation	No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030	150 GWe Plant Upgrades 46% New Plant Efficiency by 2020; 49% in 2030
(orange)	CCS	None	Widely Deployed After 2020
(purple)	PHEV	None	10% of New Vehicle Sales by 2017; +2%/yr Thereafter
(purple)	DER	< 0.1% of Base Load in 2030	5% of Base Load in 2030

** Achieving all targets is very aggressive, but potentially feasible.*

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What are the economic impacts of different technology strategies for CO_2 emissions reductions from the U.S. electricity sector?

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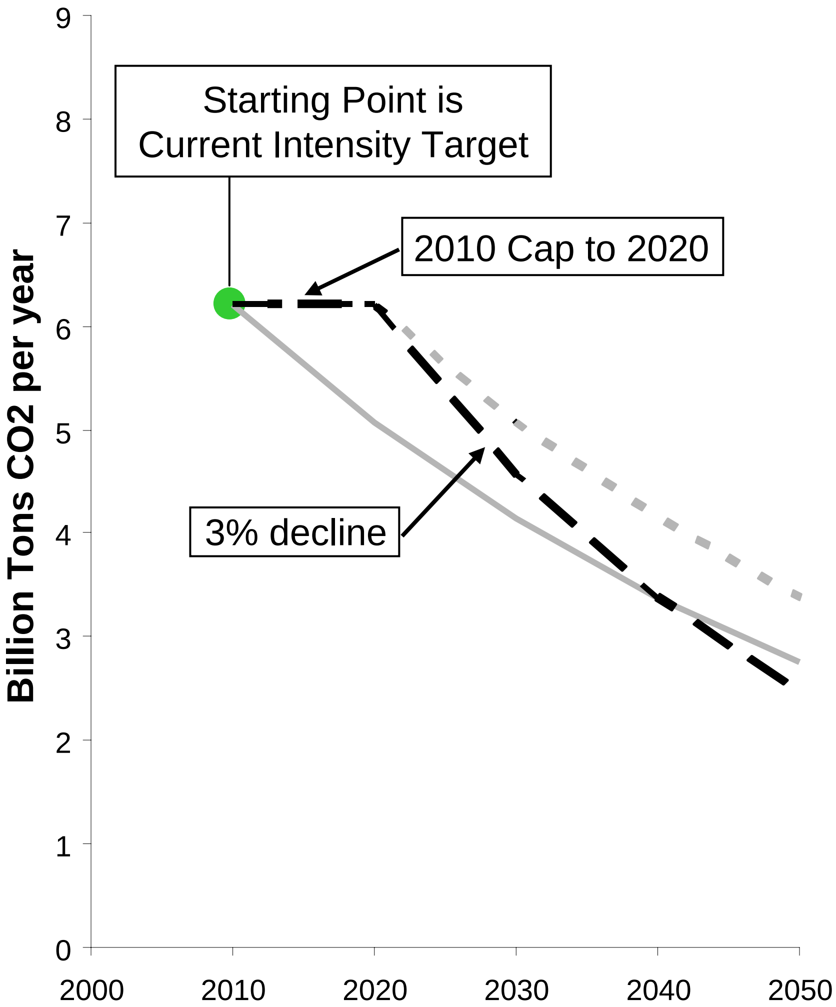
Assumed U.S. Economy-Wide CO_2 Constraint

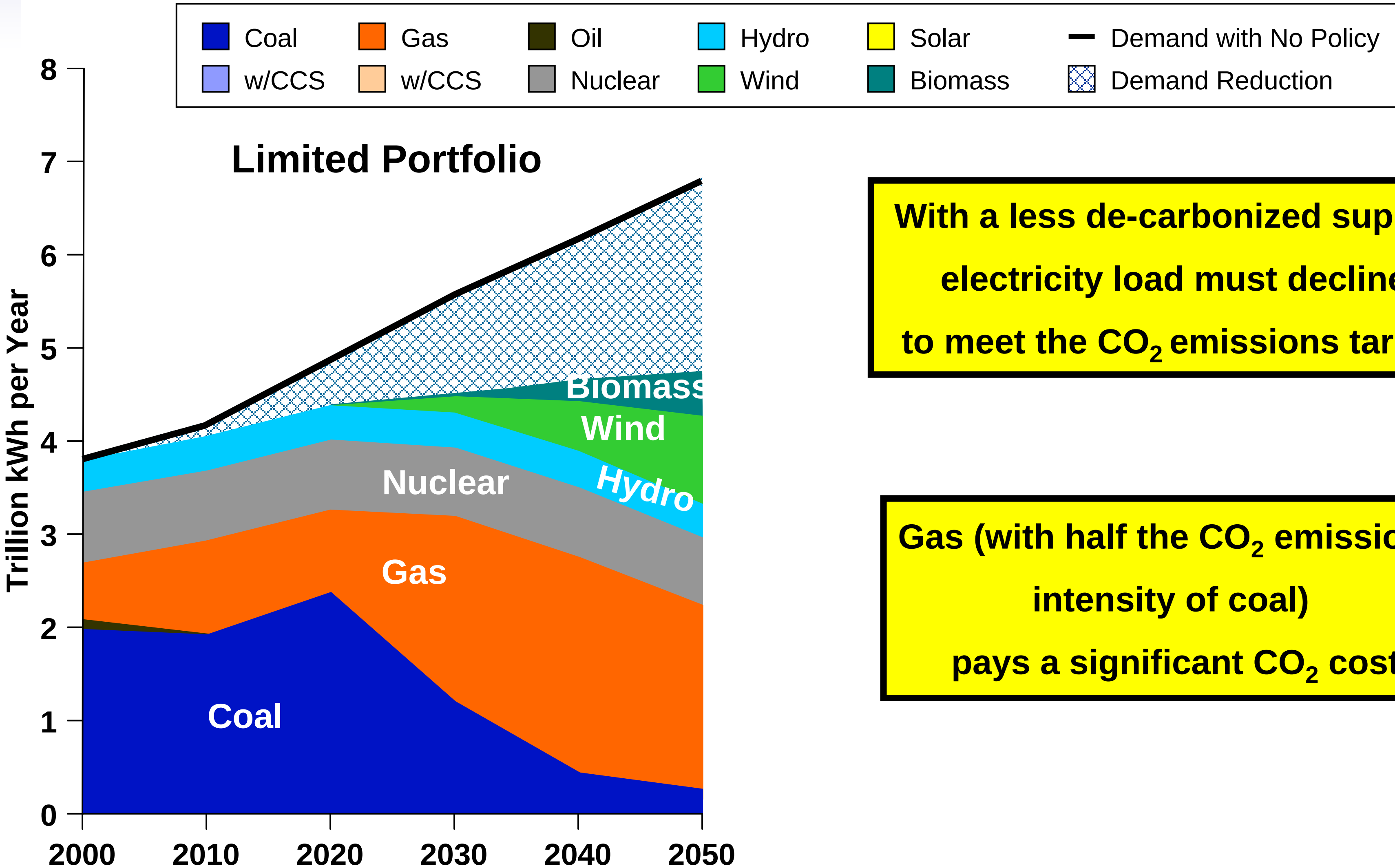


- **Analyzed three different economy-wide CO_2 constraints**
- **PRISM electric sector CO_2 profile most closely modeled by economy-wide constraint which:**
  - *-Caps emissions at 2010 levels until 2020*
  - *-Requires 3% decline beginning in 2020*

Electricity Technology Scenarios

	Full Portfolio	Limited Portfolio
Supply-Side		
Carbon Capture and Storage (CCS)	Available	Unavailable
New Nuclear	Production Can Expand	Existing Production Levels
Renewables	Costs Decline	Costs Decline Slower
New Coal and Gas	Improvements	Improvements
Demand-Side		
Plug-in Hybrid Electric Vehicles (PHEV)	Available	Unavailable
End-Use Efficiency	Accelerated Improvements	Improvements

Meeting Economy-wide Cap* with Limited Portfolio



With a less de-carbonized supply, electricity load must decline to meet the CO_2 emissions target

Gas (with half the CO_2 emissions intensity of coal) pays a significant CO_2 cost

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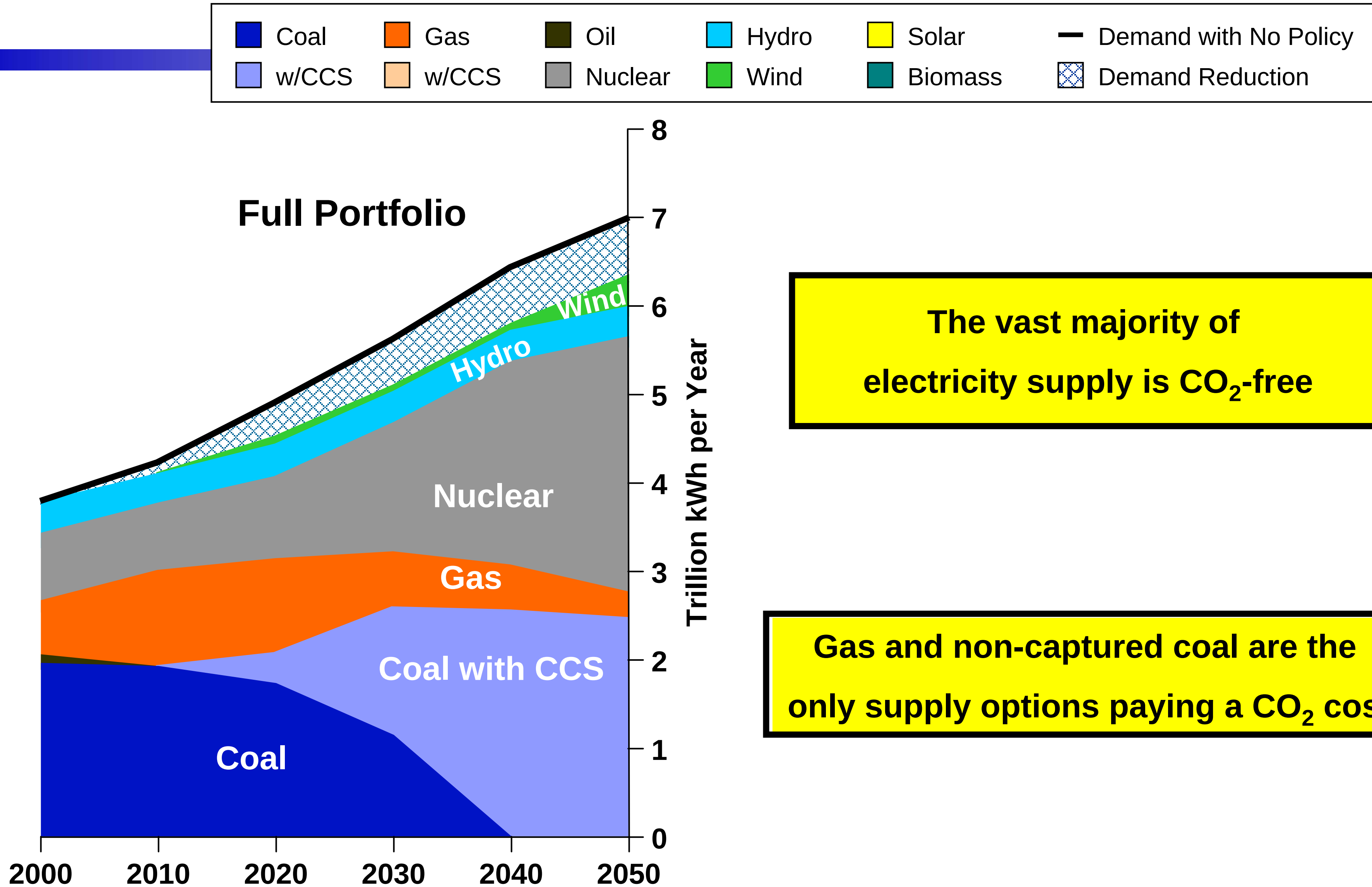
Meeting Economy-Wide Cap* with Full Portfolio



The vast majority of electricity supply is CO_2-free

Gas and non-captured coal are the only supply options paying a CO_2 cost

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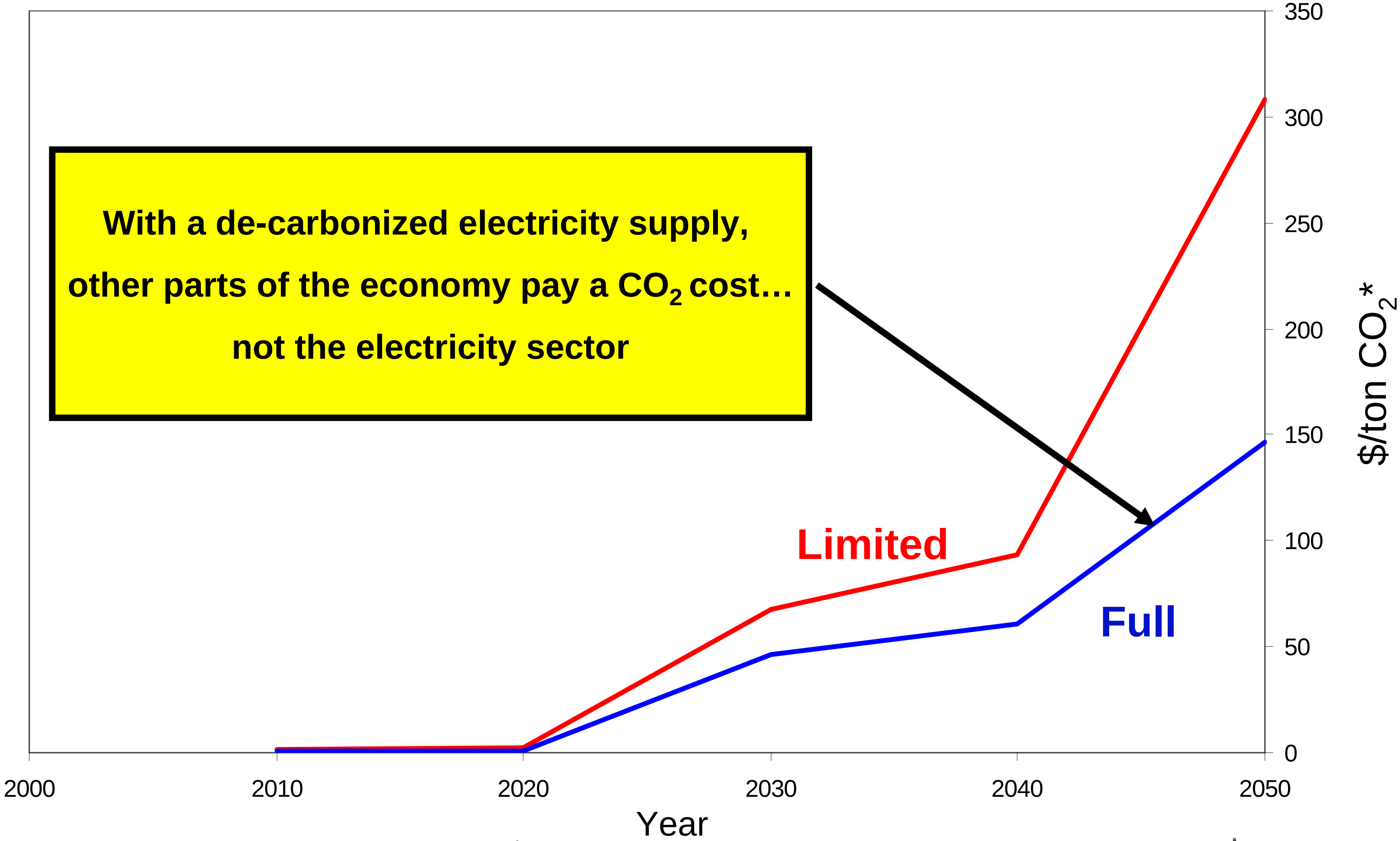
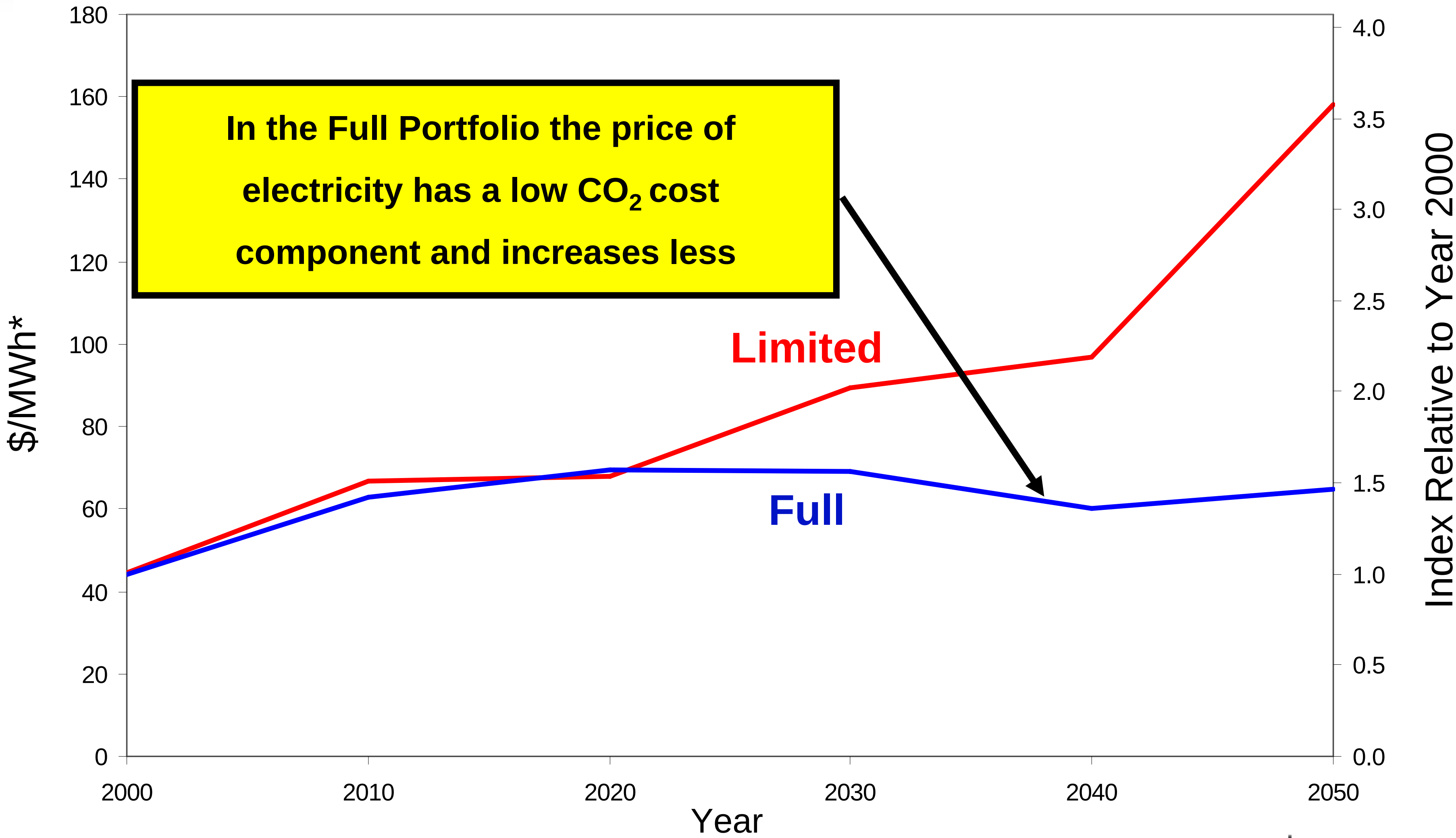
CO_2 Emission Cost : Economy-Wide



*Real (inflation-adjusted) 2000$

Wholesale Electricity Price



*Real (inflation-adjusted) 2000$

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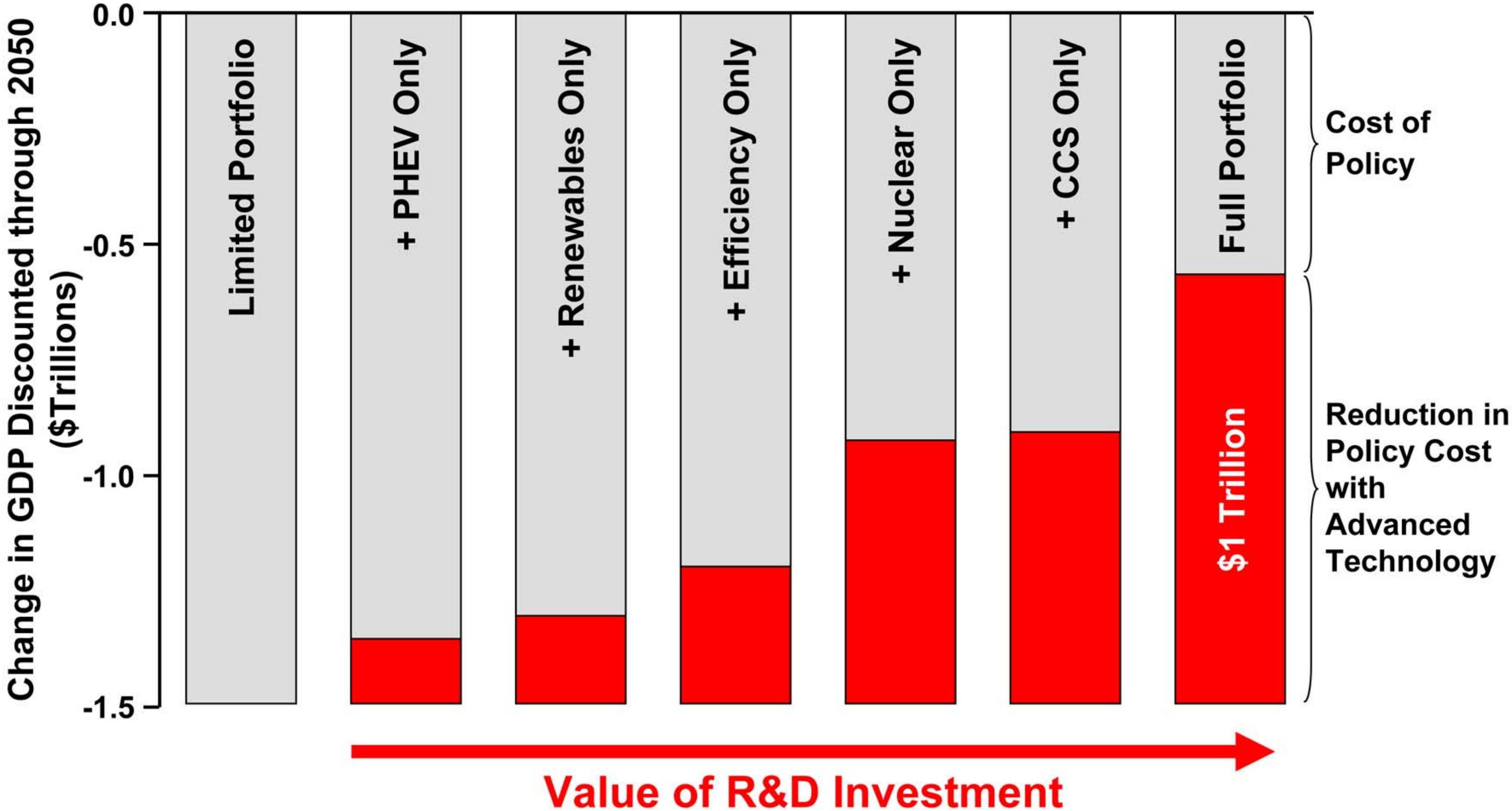
Full Technology Portfolio Reduces Costs of a CO_2 Emissions Reduction Policy by 60%



(In Year 2000 $)

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How do we achieve the necessary technology capabilities to reduce electricity sector CO_2 emissions?

Key Technology Challenges

<u>ALL</u> of the following technology advancements will be needed in order to have a full portfolio of technologies available for reducing CO_2 emissions over the coming decades:

1. Smart grids and communications infrastructures to enable end-use efficiency and demand response, distributed generation, and PHEVs.

2. A grid infrastructure with the capacity and reliability to operate with 20-30% intermittent renewables in specific regions.

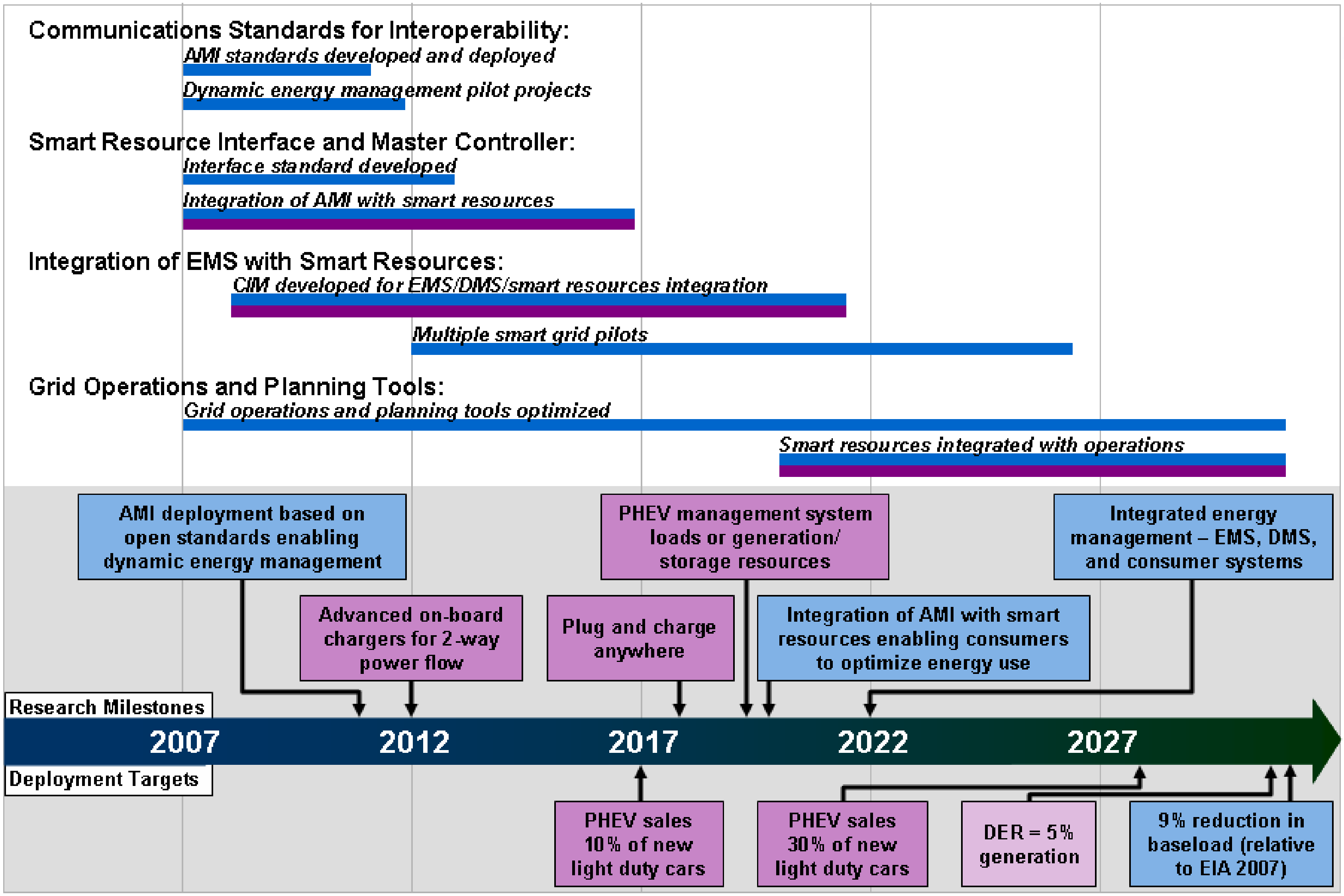
3. Significant expansion of nuclear energy enabled by continued safe and economic operation of existing nuclear fleet; and a viable strategy for managing spent fuel.

4. Commercial-scale coal-based generation units operating with 90+% CO_2 capture and storage in a variety of geologies.

Provides the Basis for Four Technology Pathways

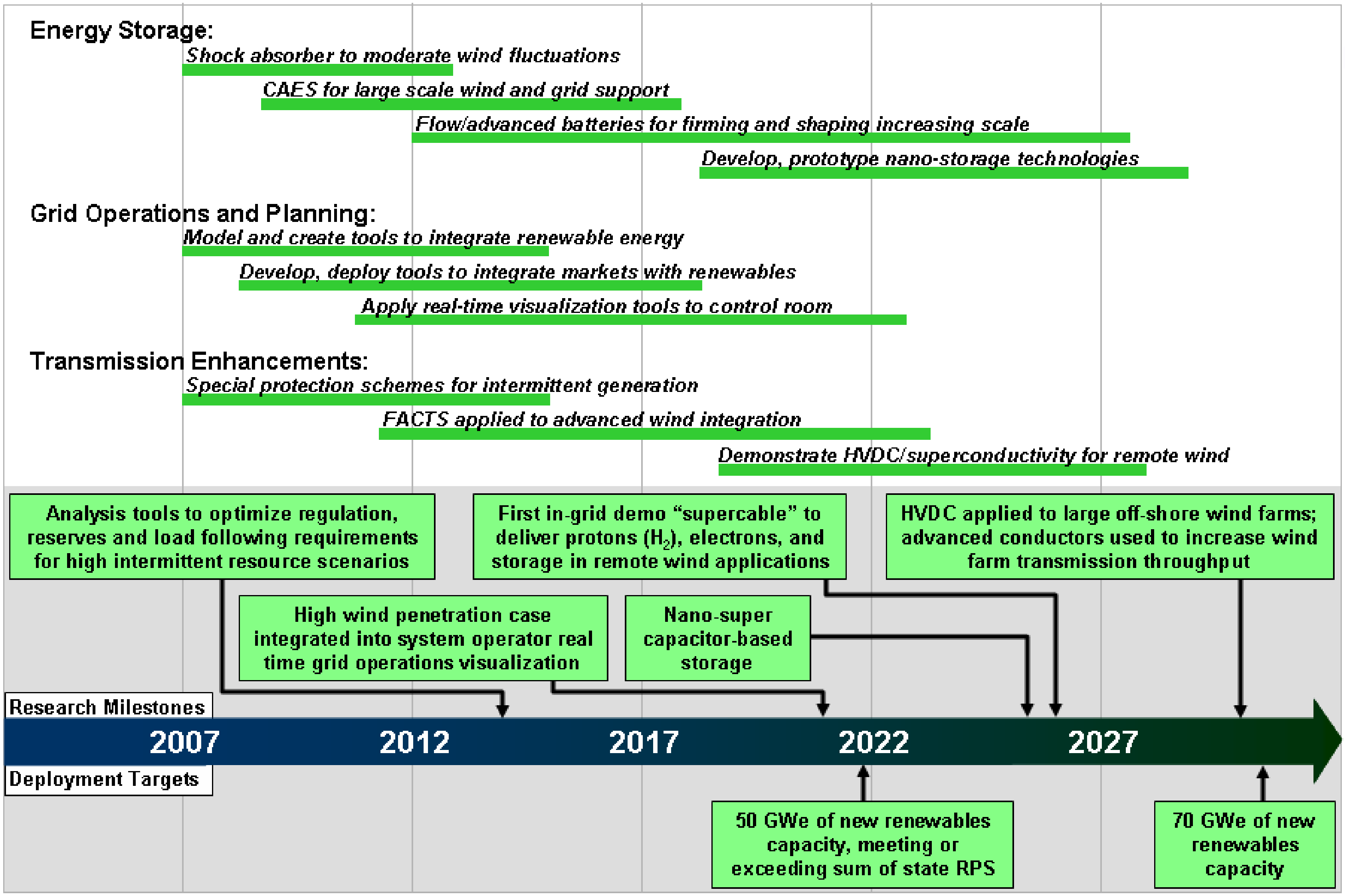
Distribution Enabled Technology Pathway

Efficiency, Distributed Energy Resources, Plug-In Hybrid Electric Vehicles

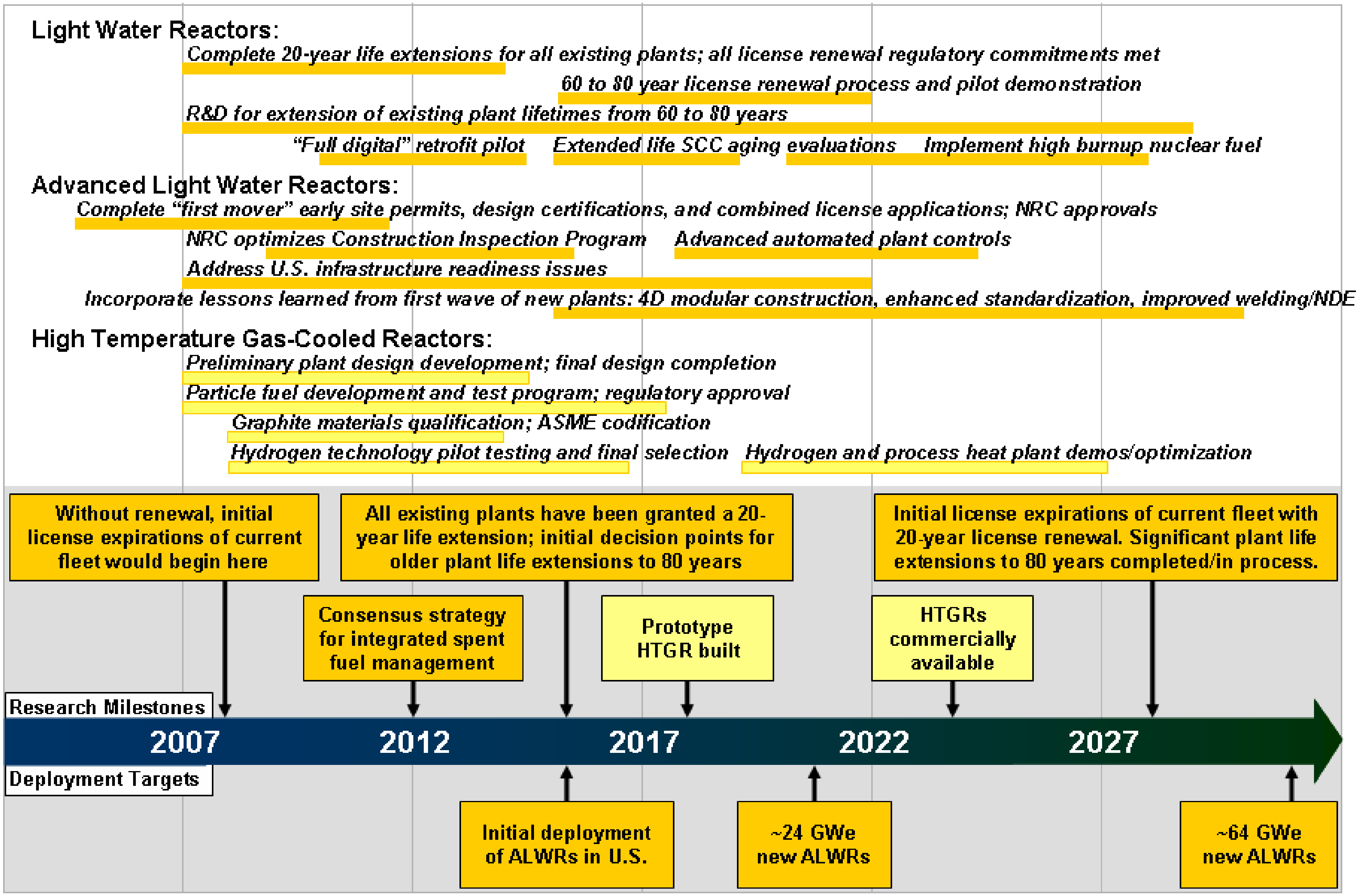


Grid Enabled Technology Pathway

Renewables Integration and T&D Efficiency Improvement



Nuclear Technology Pathway



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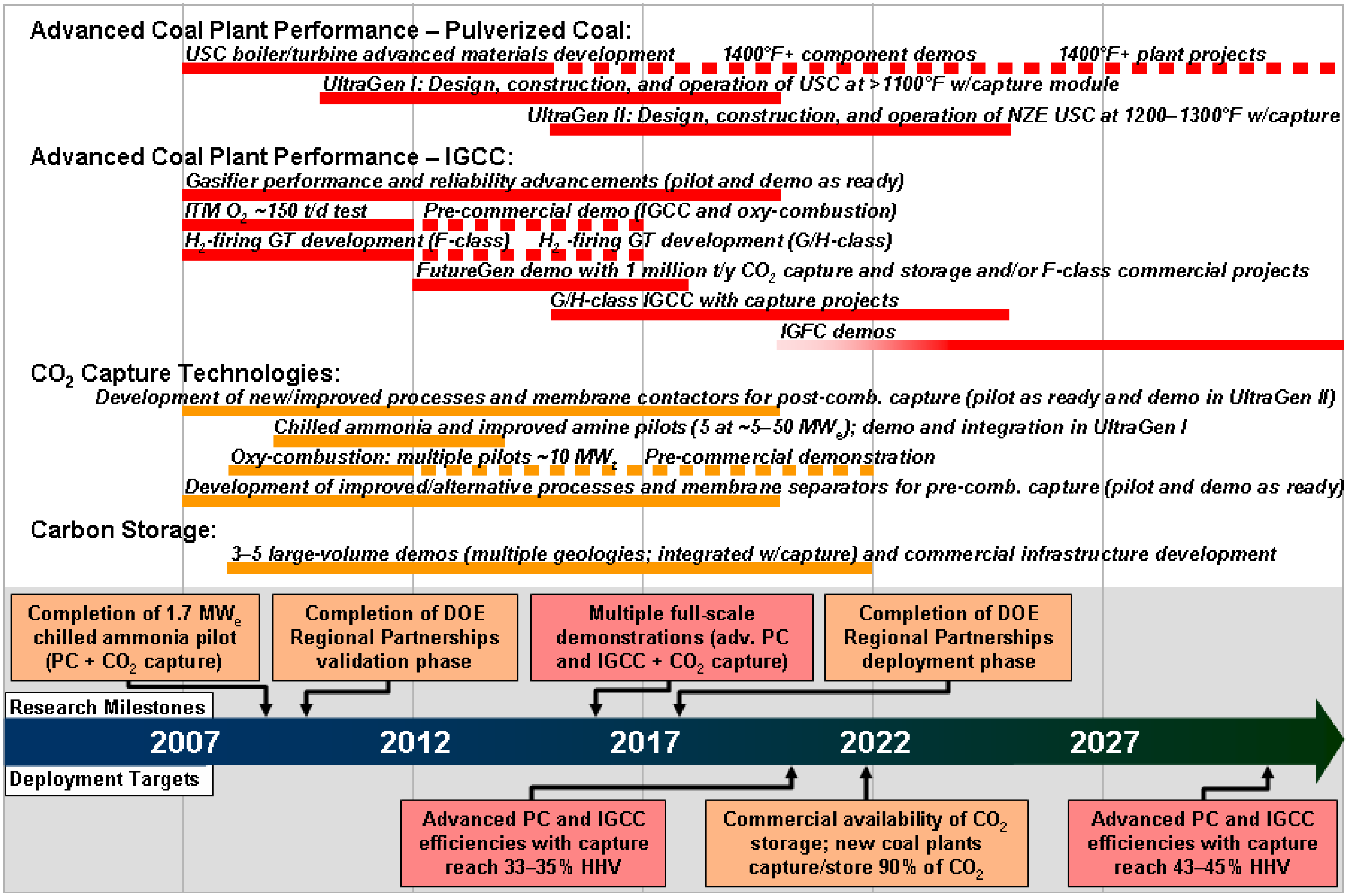
Advanced Coal With CCS Technology Pathway



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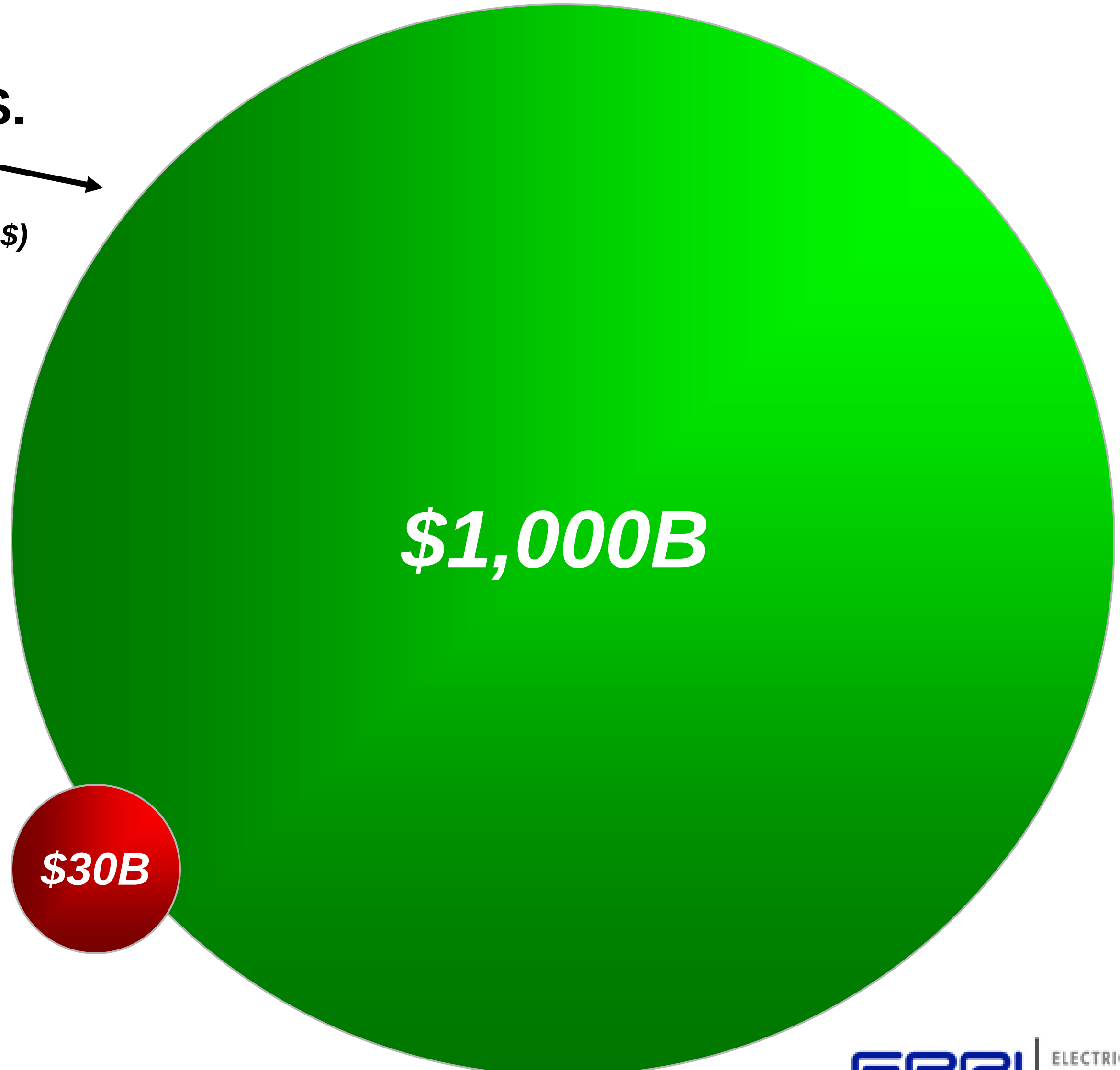
Research, Development and Demonstration is a good investment

Avoided Cost to U.S. Economy

(2000-2050, present value in 2000 $)



RD&D Investment

(2005-2030, present value in 2000 $)

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Strategic R&D Collaboration – EPRI and Electricité de France

Carnegie-Mellon University
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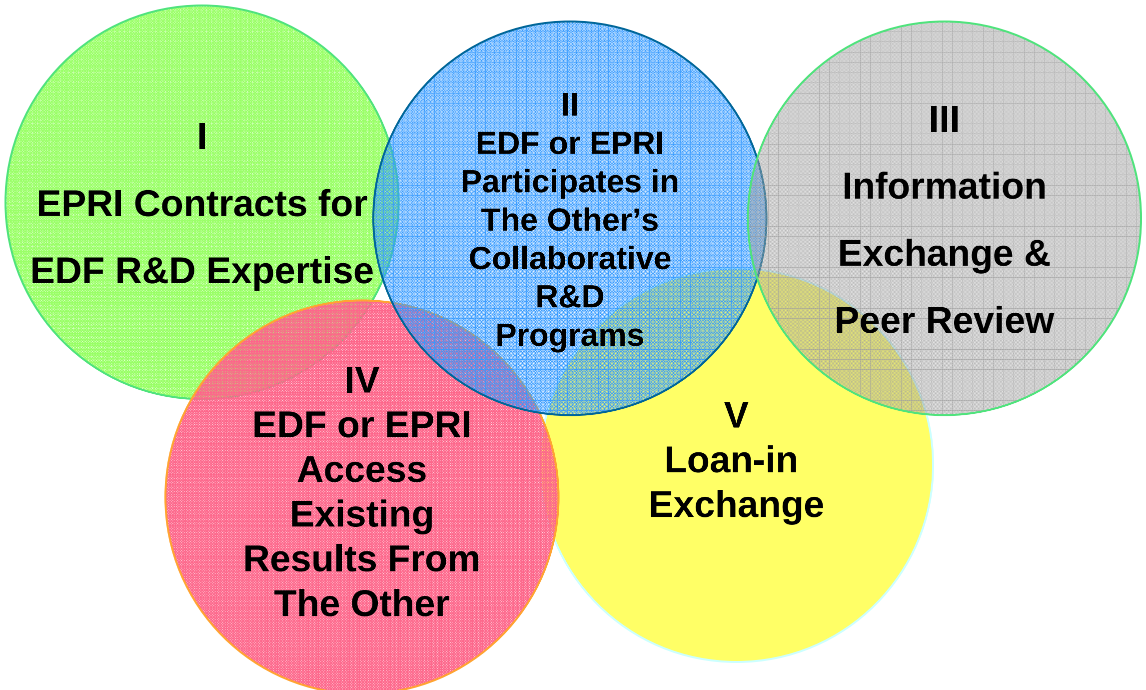
EPRI and Electricité de France

- EPRI/Electricité de France (EdF) Memorandum of Understanding
- Background on Electricité de France (EdF)
- EPRI/EdF Strategic Collaborations
- Lessons Learned
- Conclusions

EDF-EPRI Collaboration Framework



One or more dimensions might apply to each collaboration

Each dimension should have its own value proposition and supporting agreement

Five unique and synergistic relationship dimensions

Successful Collaboration Development ***A Checklist***

- ✓Specific collaboration description
- ✓Clear objectives of each organization and value proposition
- ✓Key expectations or deliverables
- ✓Relevant collaboration dimensions
- ✓Accountabilities for each organizations
- ✓Alignment on priority and schedule
- ✓Executive sponsors, where appropriate

Collaboration Principles

- Many collaboration ideas are a good thing
  - It's OK that not all lead to actual collaborations
- Working with the business directions and operating constraints of each organization is important
- A proactive effort to openly, candidly, and quickly assess collaboration ideas is best
- Regularly tracking and communicating progress

EPRI and Electricité de France

- *MoU*
- *Background*
- *Collaborations*
- *Lessons Learned*
- *Conclusions*

- Signed 5/23/03 by Yves Bamberger, Director, EdF Research & Development and Kurt Yeager, President and CEO, EPRI.
- Create a strategic technical partnership with the EdF R&D organization.
- Collaborate on strategic planning and projects.
- Substantially increase the value of R&D for EPRI members, EdF Group.
- Identify several collaboration areas, other actions.
- Revis James assigned as on-site program manager (Jan 2004 – Jun 2006)

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EPRI and Electricité de France

- *MoU*
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- Revenues: € 58 932 million
- Customers: 37.8 million
- Employees: 156 600
- Capacity: 128.2 GWe
- Generation: 633 TWh
  - nuclear: 71%
  - fossil fired: 21%
  - hydro: 8%
  - other renewables: 0.2%
- *Consolidated data (2006)*

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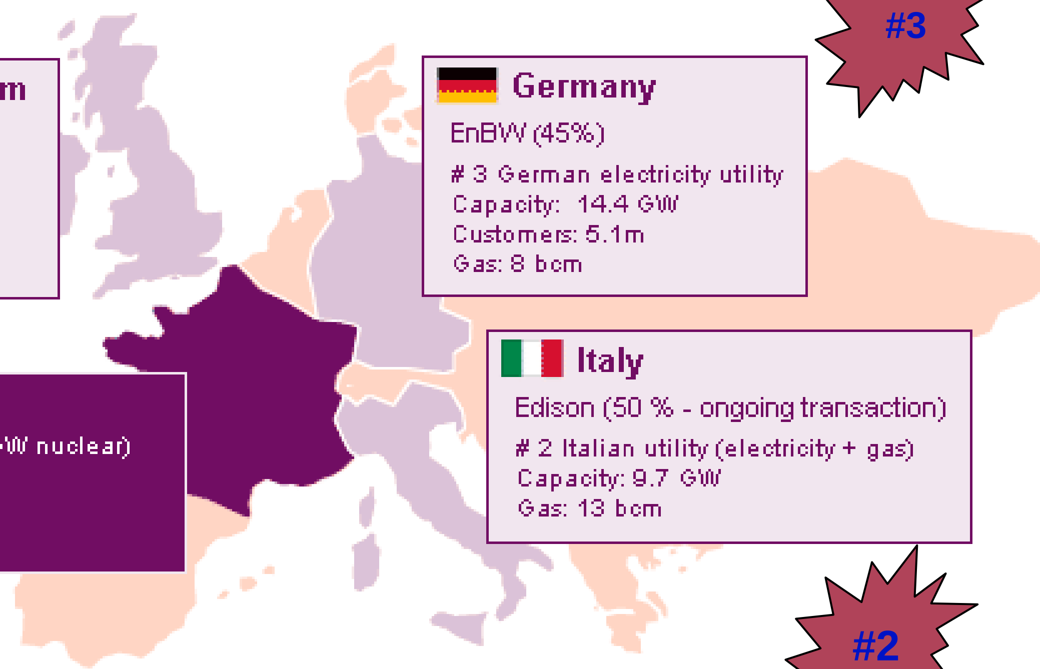
EdF Group: facts and figures



#1

United Kingdom

EDF Energy (100%)

1 distributor
Capacity: 4.8 GW
Customers: 6m
Gas: 3 bcm

Germany

EnBW (45%)

3 German electricity utility
Capacity: 14.4 GW
Customers: 5.1m
Gas: 8 bcm

#3

France

Capacity: 101 GW (63 GW nuclear)
Customers: 28m
Networks: 1 340 000 km
Gas: 3 bcm

#1

Italy

Edison (50 % - ongoing transaction)

2 Italian utility (electricity + gas)
Capacity: 9.7 GW
Gas: 13 bcm

#2

EDF Trading

Volumes handled : electricity (745TWh)
gas (116 bcm)
coal (237Mt)
oil (141 Mb)

Gas: volume handled

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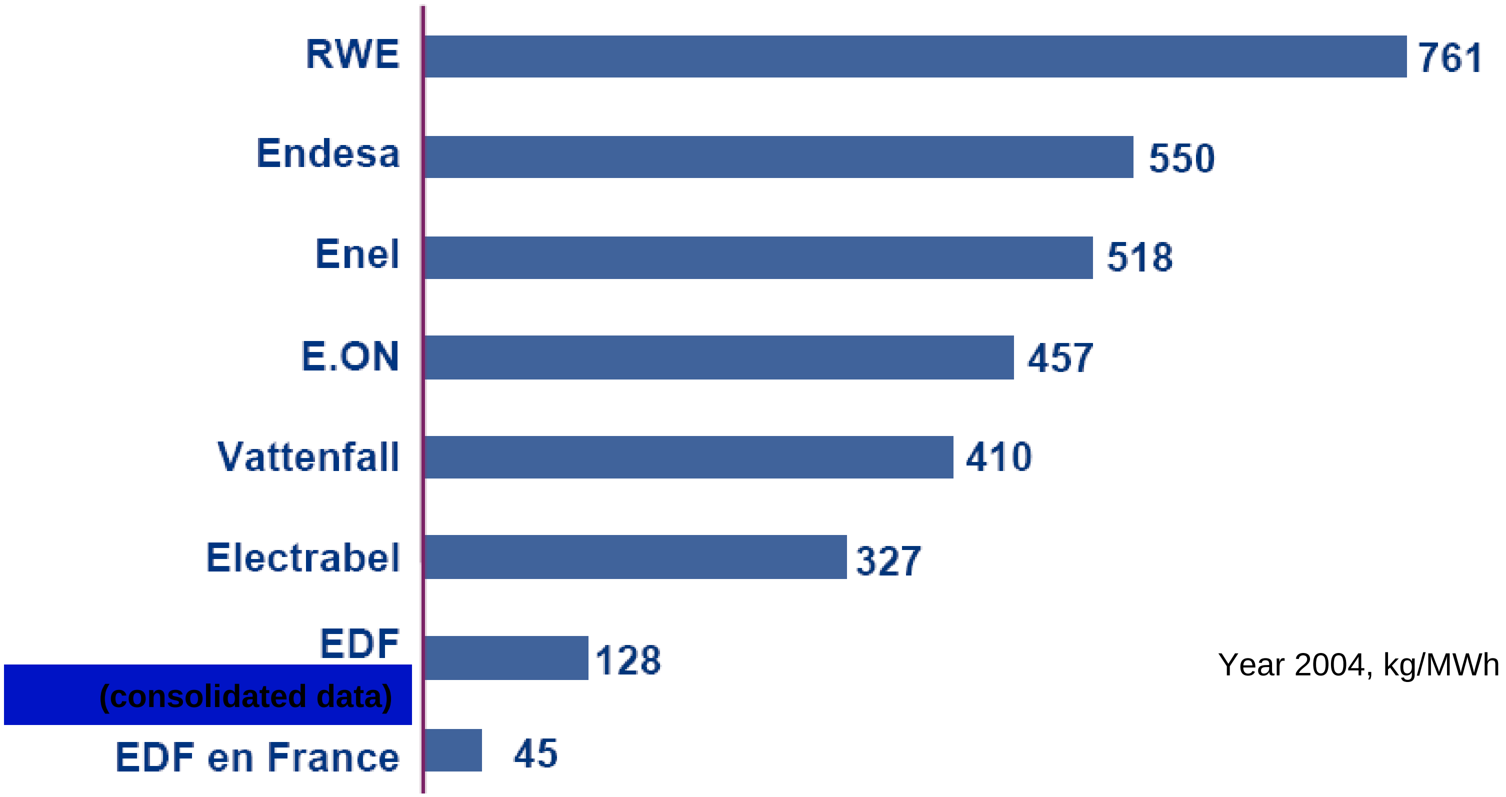
CO_2 emissions for European Utilities



Source : Enerpresse - PricewaterhouseCoopers Changement climatique et énergie - novembre 2005

EdF R&D at a glance

- **Preparing the future and new growth drivers for EDF Group**
- **Improving operational performance of EDF Group divisions**
- **Mobilising experts to support operational entities**

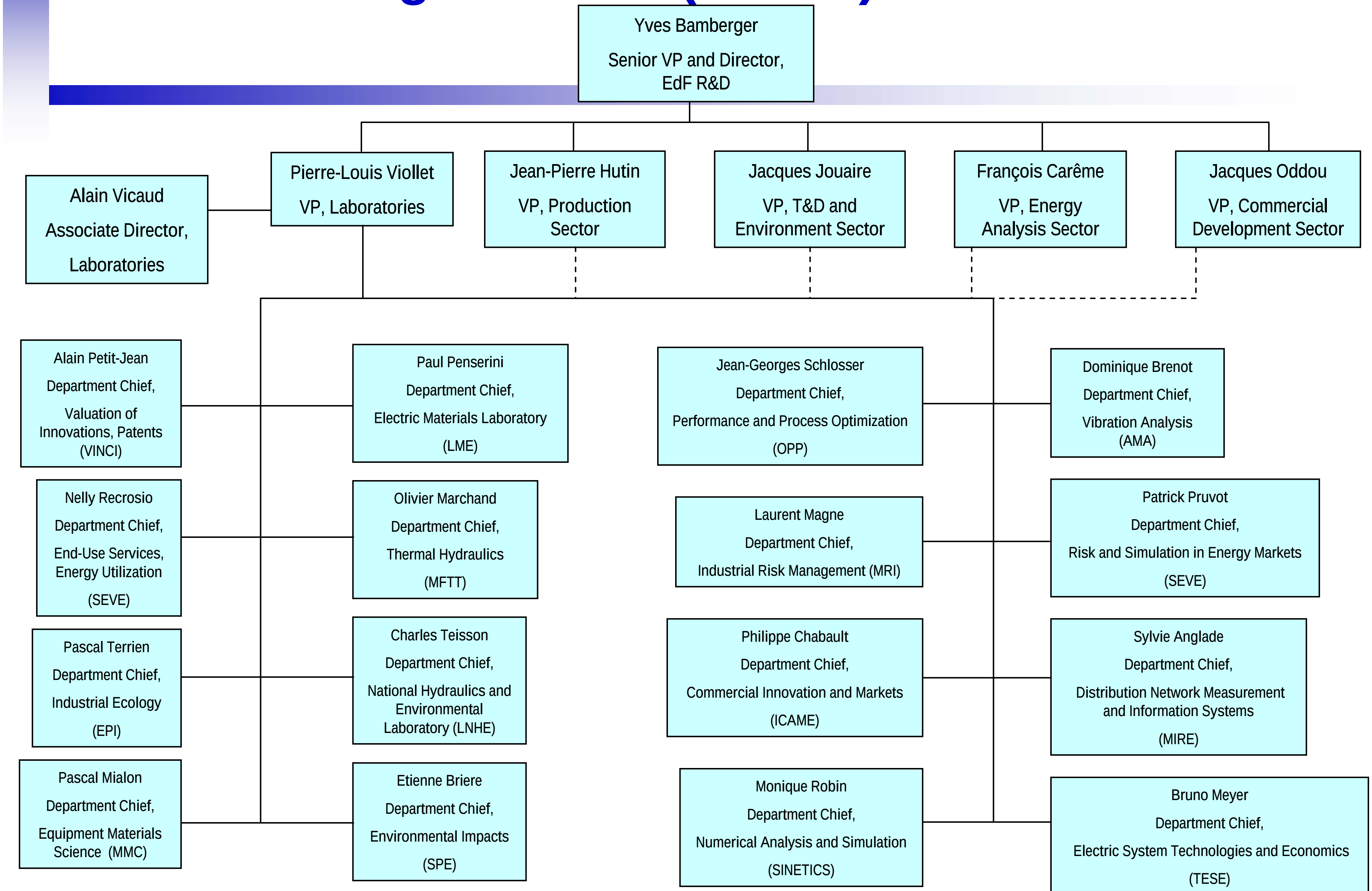
- **Approx 2 000 employees:**
  - ✓ 30% women
  - ✓ 300 PhDs and 200 doctoral students
- ✓ **150 researchers who teach at universities and engineering schools**
- ✓ **20% foreigners among employees recruited since 2003**
- ✓ **a « breeding ground » for EDF divisions**

R&D budget :

- **373 M€ in 2006**
- **76% in EDF Divisions, 24% from corporate budget**

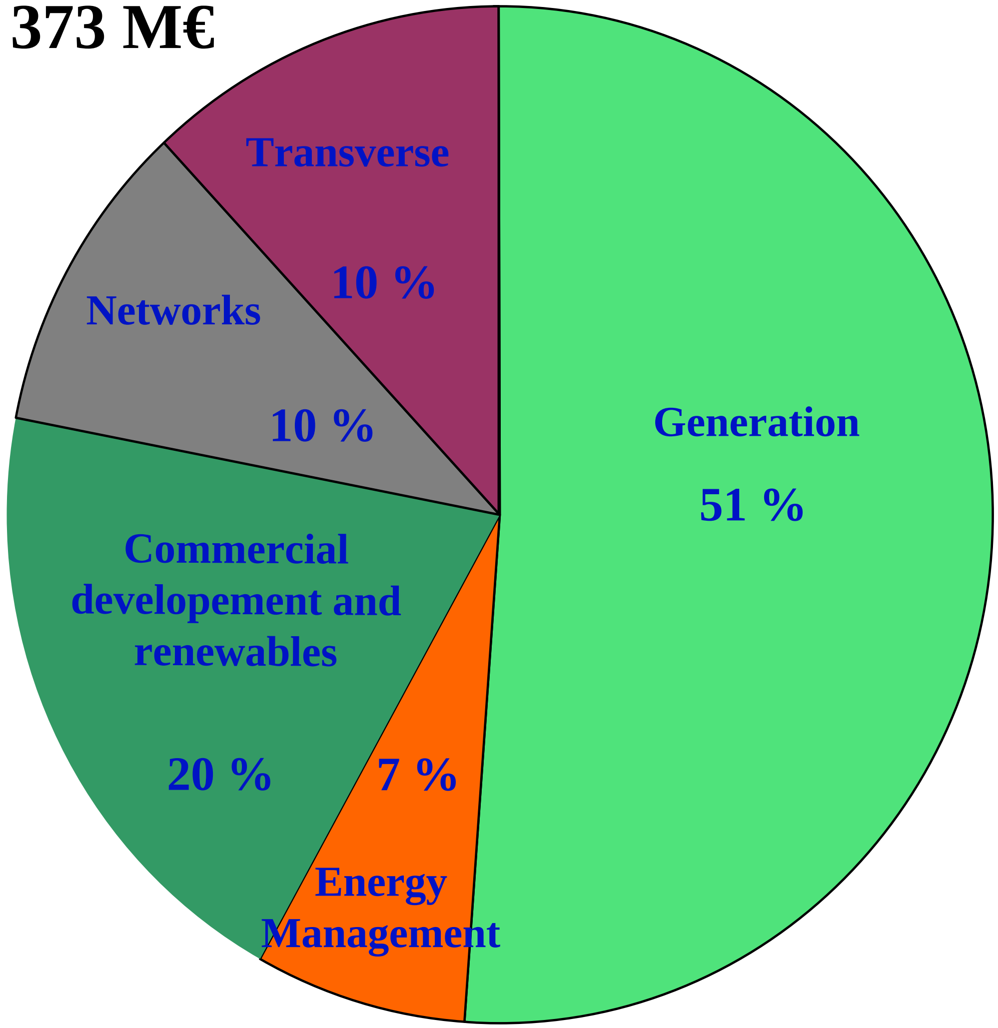
- **Partnerships with French, european and international R&D labs**

EdF R&D Organization (matrix)



74% of EDF R&D budget under contract with EdF Divisions

2006 budget : 373 M€



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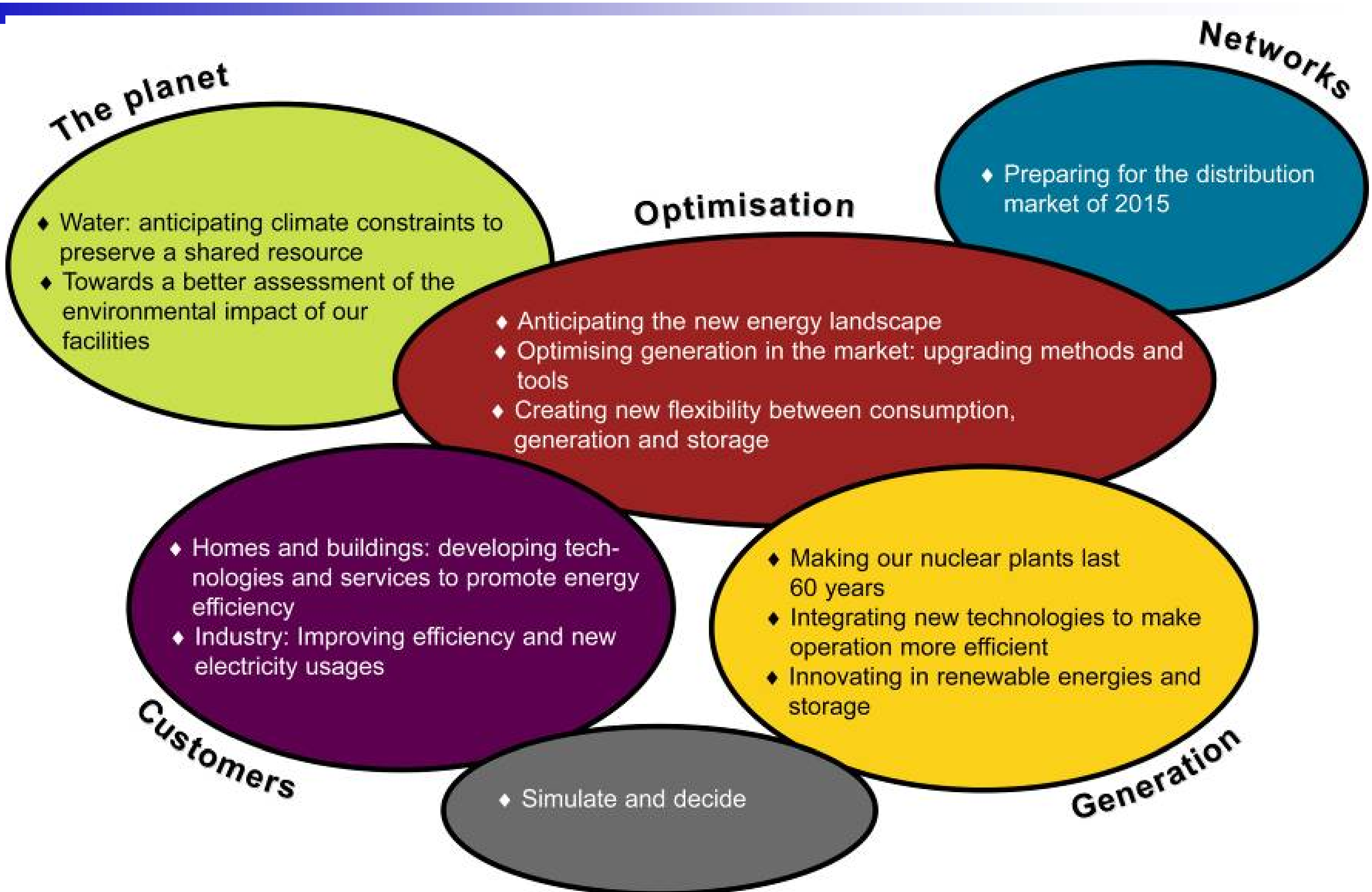
R&D Challenges for EDF Group, 2007-2009



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- **Nuclear**
  - **Materials science**
  - **Risk management**
  - **Fuels**
  - **Staff exchange**
- **Combustion Turbines/NGCC**
  - **Market simulations**
  - **Risk management**
  - **Staff exchange**
- **Energy/Water Management Collaboration**
  - **Extreme water hazards for power plants/connection to climate effects**
  - **Watershed analyses for water availability/sustainability**
  - **Staff exchange**
- **Grid Management**
  - **Program steering**
  - **Distribution system simulation & modeling**
  - **Staff exchange**
- **Strategic planning**
  - **Scenario development**
  - **Limiting Challenges/Défis, Roadmapping**
  - **Strategic Options**
- **Emerging collaboration area - Energy Efficiency**

EPRI and Electricité de France

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Similarities

- Many similar concerns – water scarcity, environmental impact of utility operations, reliability/availability of assets, deregulated markets and competition, RPS, aging workforce, life extension of assets, component reliability, etc.
- EdF R&D relationship with design/engineering, operational organizations much like EPRI relationship with member organizations.
- Nuclear fuel reprocessing, unlike U.S. But – same issue with high level waste storage.
- Regulatory structure is significantly different, but many similar drivers
  - National level is strongest, EU is coming on
  - A lot of government input to EdF Group strategy
  - But – a lot of monitoring of U.S. regulatory strategies by EU, French authorities => a lot of EdF interest in U.S. experience
- A lot of technical depth, competencies – very strong in software development, modeling across many disciplines

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Differences

- Generating fleet composition is substantially different from U.S. and from the asset mix of many U.S. utilities – primarily nuclear, followed by hydro, very little gas, coal in France.
- More meshed T&D grid, separate Transco, possibility of Disco
- Due to employment laws and concentration of resources in-house, a lot of focus on staffing/competency management. Strength is tremendous ability to apply expert skills and sustain effort. Weakness is intertia, constraints associated with retraining, redeployment of staff.
- Substantial differences in technical, research interests between needs of French asset mix and those of overseas subsidiaries.

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Personal Experience

- Personally and professionally, the French are a lot more like us than not.
- At the engineering/professional level, very competent, very hard-working.
- Know the language – make the effort.
- In collaborating, respect the cultural context, but be « American » in terms of ideas, communications – our adaptability, creativity, and willingness to experiment are admired.
- The European experience is a multi-cultural one; Europeans grow up accustomed to many languages, many cultures, a more globalized perspective due to proximity and smaller economies.

EPRI and Electricité de France

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- EdF is one of the most respected international utilities amongst international utility executives.
- Several R&D synergies between EPRI and EdF R&D.
- Need to find collaborations where EPRI and EdF strengths are complementary.
- Opportunity to evaluate/validate research priorities/results with 2 independent R&D organizations focused on electricity.

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