Reduced Water Impacts Resulting from Deployment of Advanced Coal Power Technologies

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Executive Summary

- The objective of this analysis is to evaluate the effect that increased deployment of advanced coal conversion technologies from FE R&D has on domestic water use and consumption
- A new IGCC power plant with a re-circulating water system consumes 375 gallons of water per MWh net generation. This is low compared to a subcritical PC with recirc at 675 gallons/MWh and a nuclear power plant at 700 gallons per MWh
- The 65 GW of incremental IGCC deployments resulting from FE R&D in the business-as-usual scenario result in a 10% decrease in the average water usage per MWh of power from coal in 2030
- In a carbon constrained policy scenario the effects of IGCC deployments on water use are more significant than in the BAU. FE R&D caused a 20% decrease in the average water usage per MWh of power from coal in 2030
- None of the NEMS results indicated that FE R&D would cause an increase in the aggregate amount of power sector water consumption (billions of gallons per year), even though in most cases FE R&D caused a slight increase in overall generation due to lower power prices.
- A scenario where existing coal-fired power plants are retrofitted with CO2 capture is water-use-neutral as long as the retrofits are coupled with a move from once-through to recirculation water systems.

Objective and Scope

- **Objective: Assess water use and consumption in the U.S. electricity supply sector through 2030.**

- **Scope –** Step changes in water use and consumption per kWh of generation can be achieved by moving to re-circulating or dry systems. In this analysis we hold the type of water system constant (assuming a steady progression toward re-circulating and dry) and evaluate the impact of advanced power island technology.

Talk Outline

- **Primer information on water impacts of power generation**
  - Why worry about water?
  - Water use versus consumption
  - Once-through, retention ponds, and recycle systems
  - Sources of water use in PC and IGCC power plants
  - Effects of sulfur and CO2 control

- **Analysis Methodology**
  - Exercising the NEMS model
  - Scaling factors for water use and consumption
  - Assumptions about water systems

- **Water impacts Cases**
  - IGCC in the BAU scenario
  - IGCC in a scenario with a $25/mtCO2 tax
  - PC retrofits in a scenario with a $25/mtCO2 tax

- **Future work**

Why worry about water?

Peer Review Feedback

In December 2006 DOE conducted a peer review of its benefits estimation efforts. Among other comments, the reviewers noted the absence of non-emissions environmental benefits:

"I would suggest the environmental metrics include relevant measures of non-air pollution, including water, nuclear, and (if relevant) solid."

"The environmental metrics do not capture many of the *real* environmental impacts. For example, there are water quality, air quality, and land impacts related to the realization of the energy system."

Why worry about water?

Power Plant Deployments

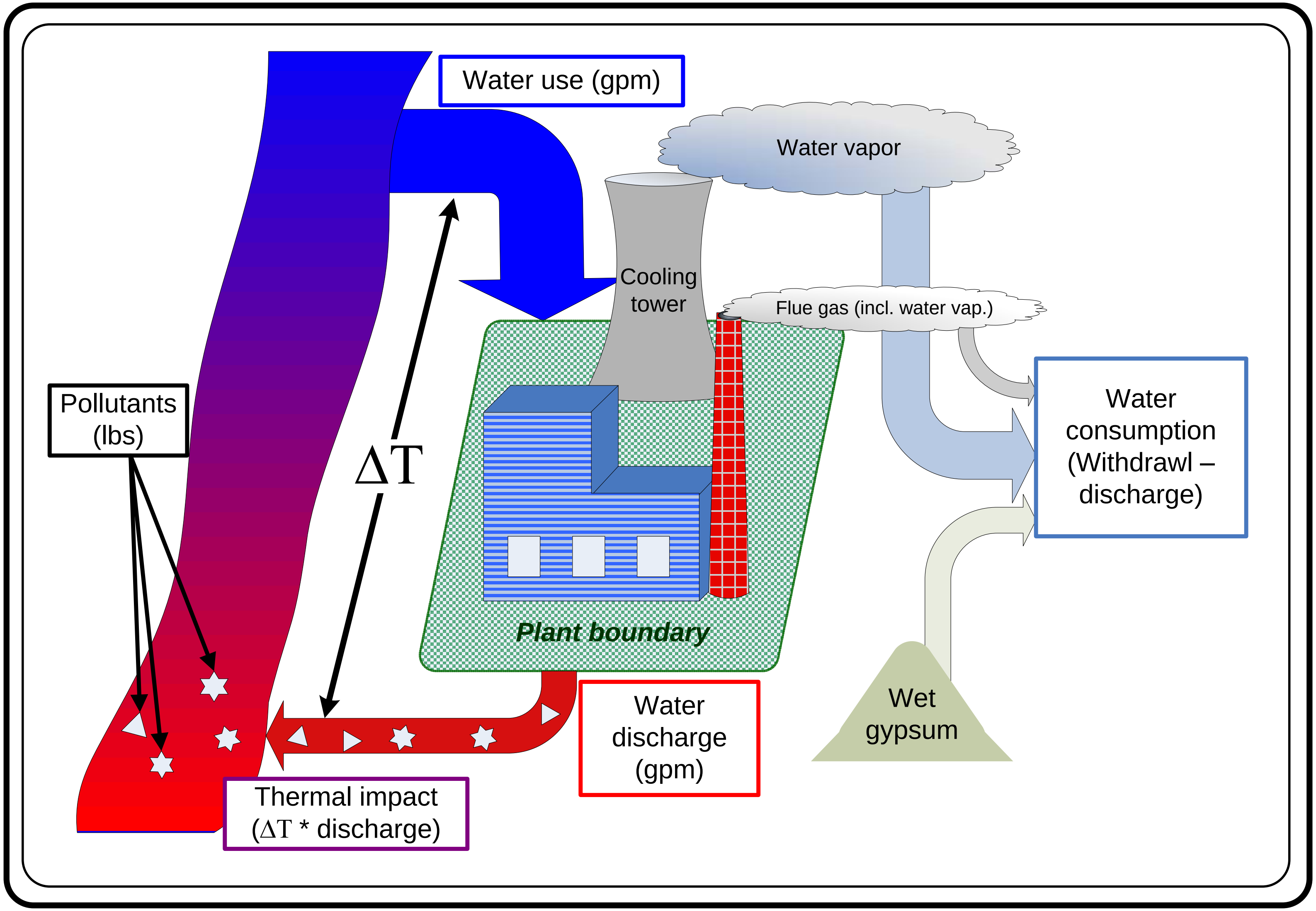
- **Georgia Drought Limits Power Production**
  - *Atlanta Journal-Constitution*, November 2007
- **Suspension of Regulations Establishing Requirements for Cooling Water Intake Structures**
  - EPA, July 2007
- **Idaho May Adopt Moratorium on Coal Power Due to Water Issues**
  - *Reuters*, March 2006
- **Sempra Energy Halts Gerlach Project Study**
  - *Associated Press*, March 2006
- **California's Efforts to End Use of Sea Water to Cool Plants Could Jeopardize 24 GW**
  - *POWERnews*, March 2006

May 2006 Issue of Power Magazine

Water Impacts Primer: Definitions

- **Water use:**
  - water metered from a raw water source and used in power plant processes for any and all purposes
- **Water consumption:**
  - amount of water lost during electricity generation, typically through evaporation to the air
- **Thermal impacts:**
  - Product of the water discharge flow times the raise in temperature
- **Entrained chemicals/solids**
  - Pollutants added to or concentrated by power plant processes to the effluent water stream

Definitions for a typical recirc PC plant w/ FGD

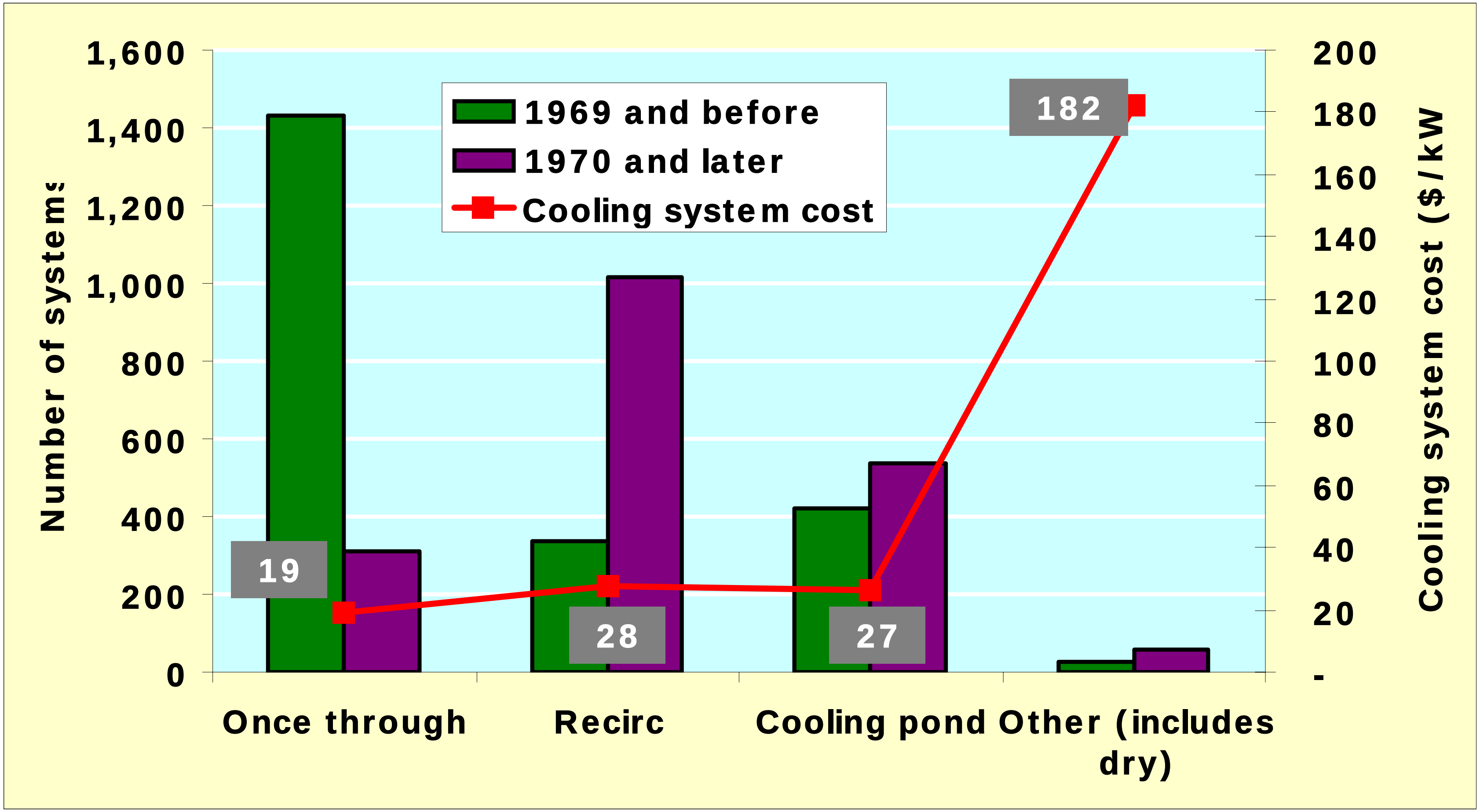


Different water use systems

- **Once-through:** Cooling water withdrawn and then directly discharged to source
- **Cooling ponds:** Heat is rejected to a pond (requires large and suitable area)
- **Recirculating system:** Cooling water sprayed down a cooling tower and loses heat through evaporation
- **Dry cooling:** Cooling water flows through an air-cooled heat exchanger

Comparison of systems		Water consumption: Low	Water consumption: Mod.	Water consumption: High
Water usage	Low	Dry cooling		Recirculating
	Mod.		Cooling pond	
	High	Once-through		

Cooling system cost and market share



Currently, once-through systems dominate, but regulatory pressures, especially 316(b) of the CWA, will drive new plants to use recirculating and dry cooling systems

Source: Analysis of EIA 767 database (2005 release) for cooling system distribution and costs, Energy Velocity for capacity data

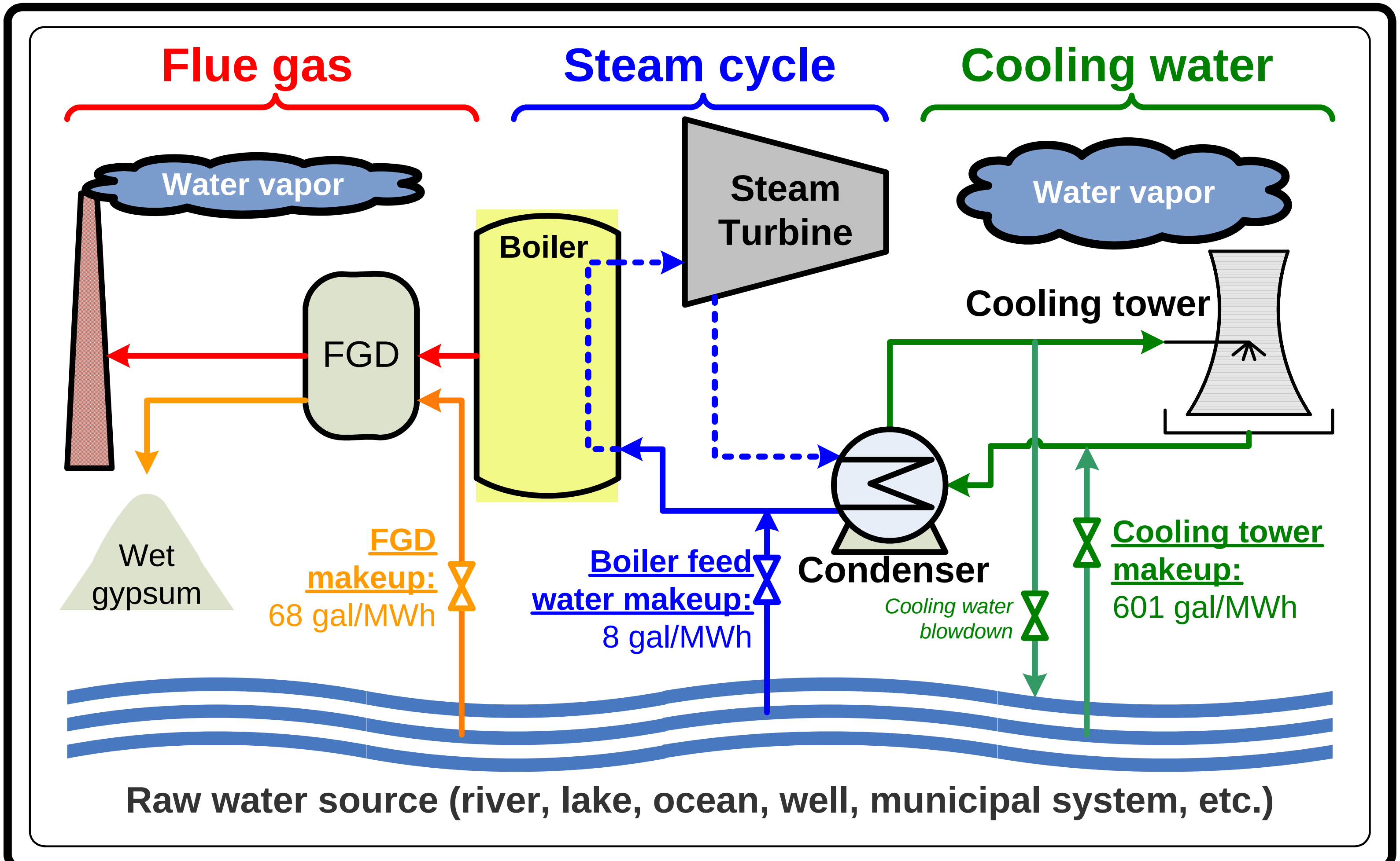
Water use in different power platforms

- 90% of the water use in a power plant is taken up in condensing steam from the steam turbine

- Combined cycle platforms use less water per kWh of net generation because the steam bottom cycle accounts for only about 35-40% of the total plant power.

- Higher temp/pressure steam cycles use less water per kWh, proportional to their efficiency (kWh/btu steam)

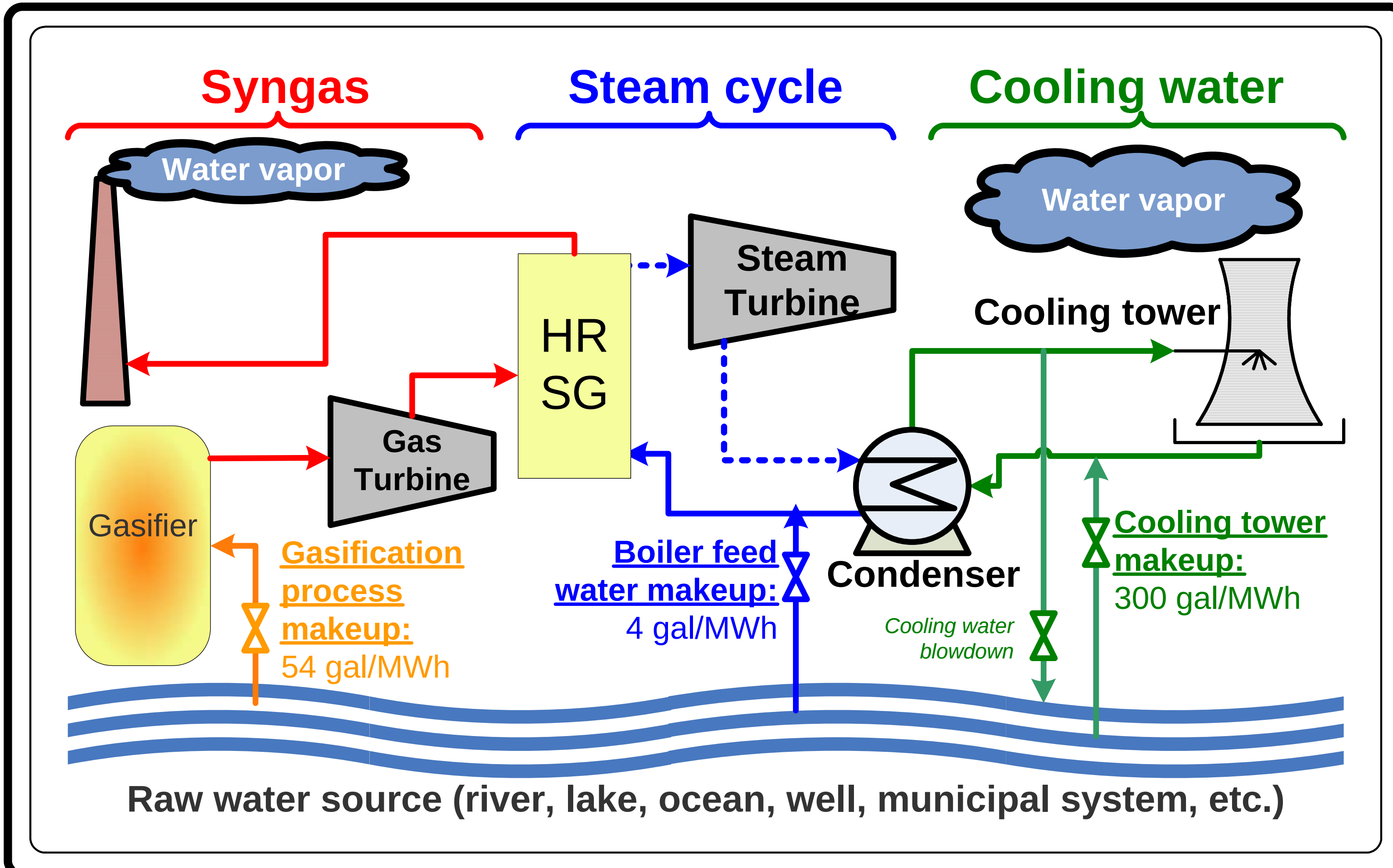
PC Plant water flows and make-up (recirc system)
Subcritical, bitiminous coal with heat rate 9,300 BTU/kWhr



Data source: *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1; National Energy Technology Laboratory; http://www.netl.doe.gov/energy-analyses/baseline_studies.html*

IGCC water flows and make-up (recirc system)

Slurry-fed, bituminous coal, with heat rate 8,700 BTU/kWh



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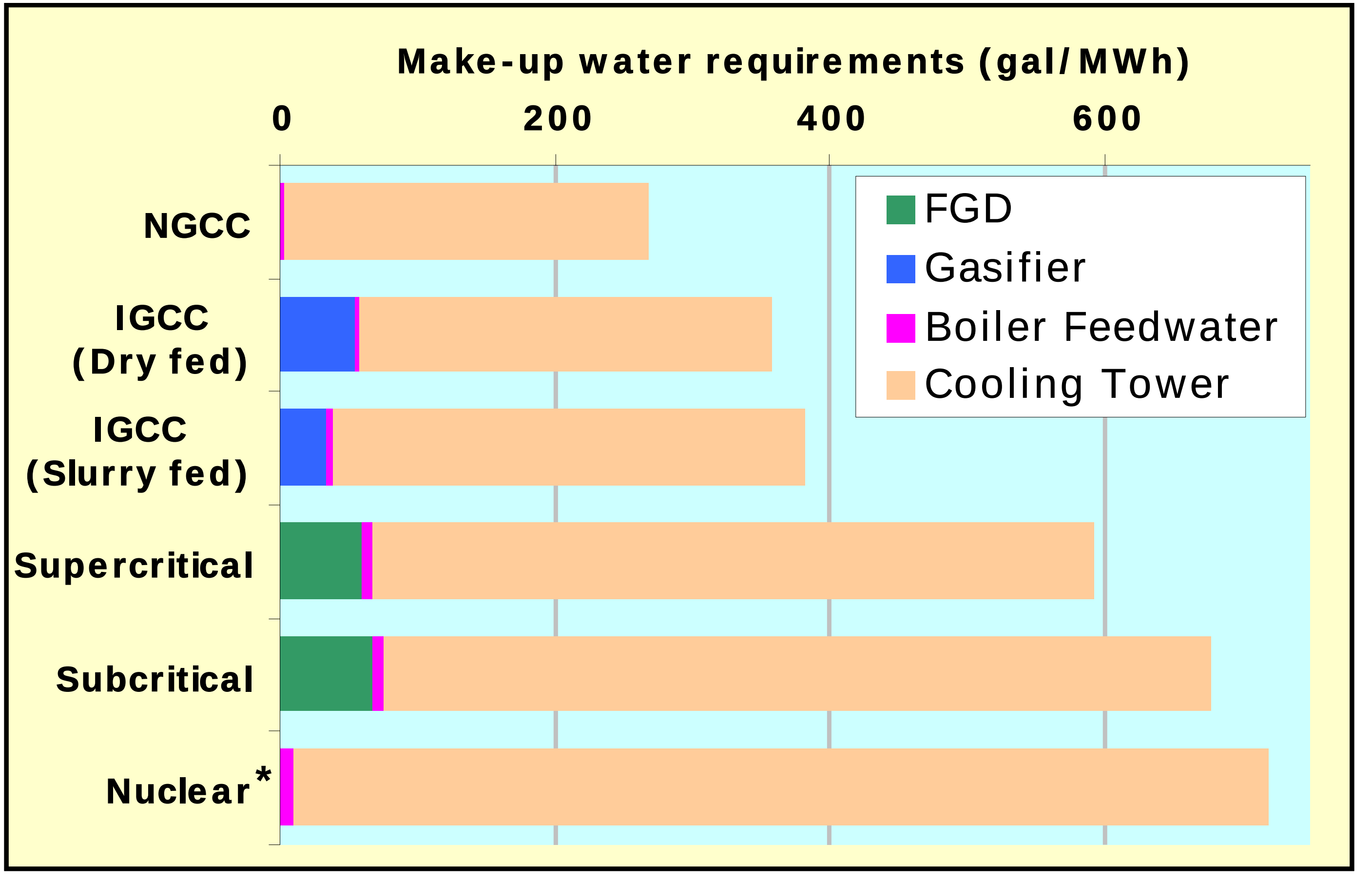
Water consumption for recirc plants



***Nuclear has the highest consumption because the steam cycle is lower temperature and less efficient design due to fuel cladding limitations**

Source: Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1; National Energy Technology Laboratory; http://www.netl.doe.gov/energy-analyses/baseline_studies.html

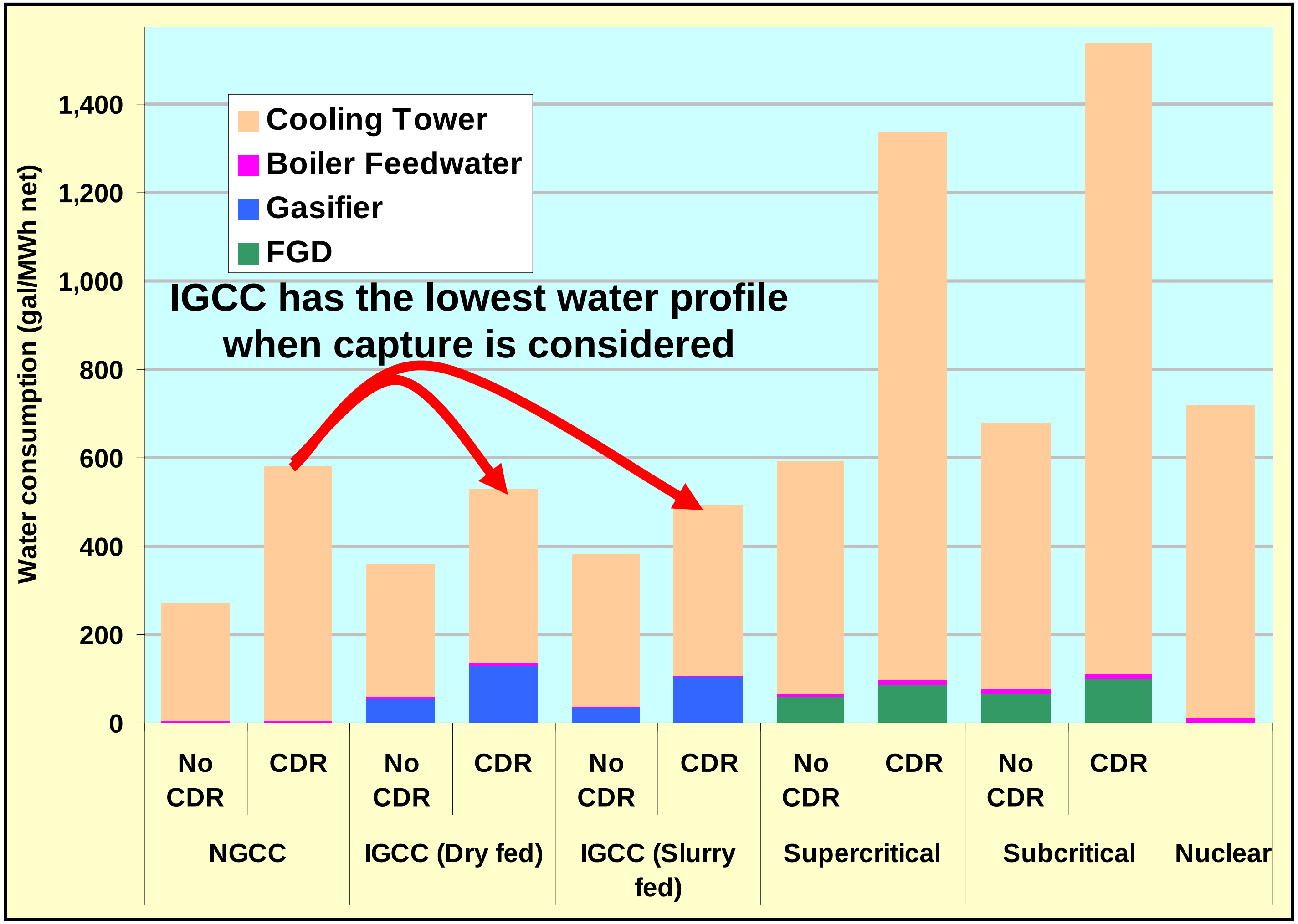
Power plants with CO_2 capture use more water per kWh of generation than plants without CO_2 capture

- Increases in water consumption with addition of CO_2 capture compared to no capture plant
  - IGCC 15%
  - NGCC: 86%
  - Supercritical PC: 125%

NGCC requires post-combustion CO_2 capture, while IGCC can capture in-process. This leads to lower water use for IGCC

- Reasons for increased water consumption:
  - Parasitic loads and steam use reduce overall plant efficiency
  - State-of-the-Art CO_2 capture technology (amines and selexol) requires significant cooling loads
    - acid gas absorption
    - flue gas cooling
    - water wash
    - CO_2 compressor intercooling

Water consumption w/ & w/o carbon dioxide recovery (CDR)



Analysis Methodology

- **Exercising the National Energy Modeling System (NEMS) model**
- **Scaling factors for water use and consumption**
- **Assumptions about water systems**

Exercising the NEMS model

– NEMS is a fully integrated model – allows analysis of trade-offs between electricity generating technologies as input parameters are changed

– However, NEMS does not directly calculate water impacts of power plants

– We estimate water impacts exogenously based on
  1. the reported amount of annual power generation from the different types of power plants in the NEMS runs
  2. data on the types of cooling systems installed in existing power plants.
  3. assumptions about the types of water cooling systems used in future deployments

Analysis Approach

Generation | **Scaling function** | **Water Impact**

Electricity Generation (MWh) for Technology “A” – **Reference Case** x Scaling Function For Technology “A” (gal/MWh) = **Water impact of Technology “A” For Reference Case**

Electricity Generation (MWh) for Technology “A” – **With R&D Case** x Scaling Function For Technology “A” (gal/MWh) = **Water impact of Technology “A” For “With R&D” Case**

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Water benefit Of the “With R&D” Case

Can perform for all 22 generation technologies modeled in NEMS or by program area or all ESE

Repeat for each water impact

Water Cooling System Assumptions

- Cooling systems at existing PC power plants are converted to recirc and cooling pond, and once-through are preferentially retired, by 2030 mix is assumed to be:
  - 10% once-through
  - 70% recirculating
  - 20% cooling pond
- New IGCC and PC use lower impact cooling systems, post 2010 systems assumed to be:
  - 75% recirculating
  - 5% cooling pond
  - 20% dry
- No dry cooling assumed at nuclear power plants for safety reasons, post 2010 cooling assumed as:
  - 50% recirculating
  - 25% pond
  - 25% once-through

Proportions of water cooling systems

Plant type	Once-through		Recirculating		Cooling Pond		Dry	
	2007	2030	2007	2030	2007	2030	2007	2030
Existing PC	18%	10%	69%	70%	13%	20%	0%	0%
New PC	10%	0%	75%	75%	10%	5%	5%	20%
IGCC	10%	0%	75%	75%	10%	5%	5%	20%
IGCC w/ CDR	-	0%	-	75%	-	5%	-	20%
NGCC	15%	5%	45%	50%	2%	5%	38%	40%
Nuclear	38%	25%	44%	50%	18%	25%	0%	0%

Analysis assumes a shift away from once-through systems in favor or recirculating and dry systems. Nuclear and existing PC are assumed to avoid dry cooling completely.

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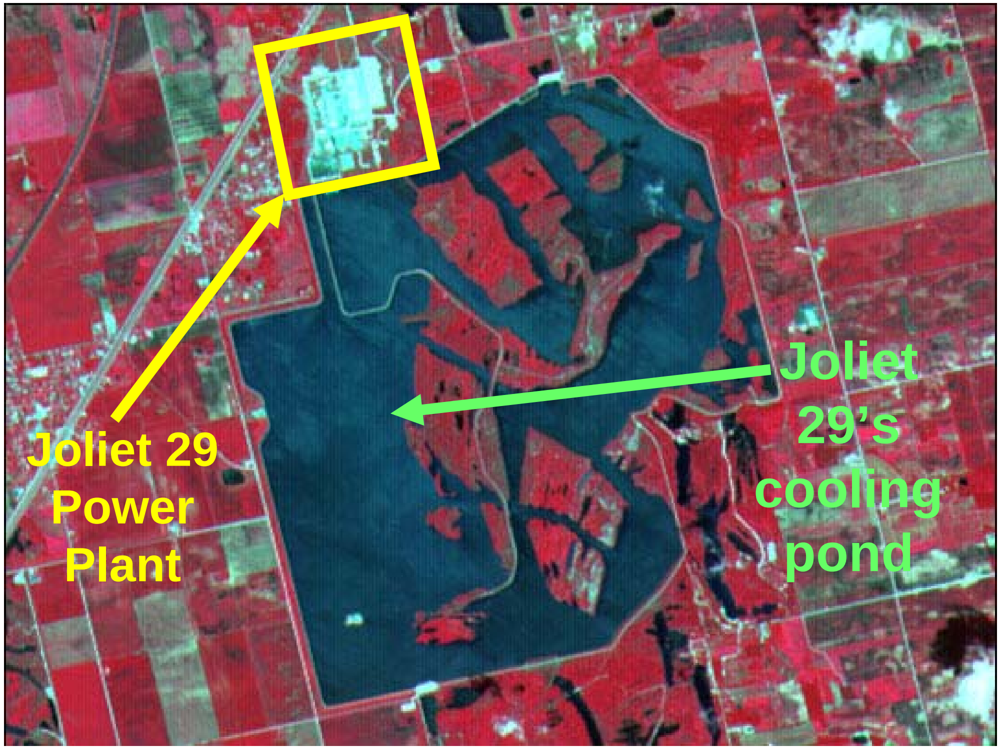
Why do cooling ponds see little growth?

- Cooling ponds offer moderate water consumption and use compared to other options

- However, significant area and suitable topography is required



Infrared image of the Joliet 29 power plant and its associated cooling pond showing the relative scales of each

Source: National Aeronautics and Space Administration's Visible Earth website

http://visibleearth.nasa.gov/view_rec.php?id=1716

Selected scaling factors for Water Usage (Average for deployed fleet)

Water usage (gal/MWh)	2010	2020	2030
Pre-2007 pulverized coal	7,417	6,980	6,601
Post-2007 pulverized coal	3,796	2,487	1,177
IGCC	2,188	1,403	618
IGCC w/ CDR	2,516	1,613	710
NGCC	909	866	823
Nuclear	10,981	9,428	7,875
Wood	9,615	8,534	7,454
MSW	4,900	4,349	3,799

Usage factors trend downward as more cooling systems go toward recirc or dry cooling – significant savings are realized in new deployments by using dry cooling

Sample Scaling Factor Derivation for Water Usage

Water Usage Calculation Factor	**Pre-2007 PC 2010**	**Pre-2007 PC 2030**	**Post-2007 PC 2030**
Water usage for Recirculating cooling (gal/MWh)	**463**	**463**	**566**
Percentage of plants	**69%**	**70%**	**75%**
Water usage for Once-through cooling (gal/MWh)	**27,046**	**27,046**	**22,601**
Percentage of plants	**17%**	**10%**	**0%**
Water usage with cooling pond (gal/MWh)	**17,859**	**17,859**	**15,046**
Percentage of plants	**14%**	**20%**	**5%**
Water usage with dry cooling	**0**	**0**	**0**
Percentage of plants	**0%**	**0%**	**20%**
Weighted average (gal/MWh)	**7,417**	**6,601**	**1,177**

Selected scaling factors for consumption (Average for deployed fleet)

Water consumption (gal/MWh)	2010	2020	2030
Pre-2007 pulverized coal	387	409	430
Post-2007 pulverized coal	357	351	345
IGCC	162	154	146
IGCC w/ CDR	186	177	168
NGCC	50	64	78
Nuclear	519	561	604
Wood	389	345	301
MSW	540	480	419

Some consumption factors go up with higher proportion of recirc systems

Sample Scaling Factor Derivation

Water Consumption Calculation Factor	Pre-2007 PC 2010	Pre-2007 PC 2030	Post-2007 PC 2030
Water consumption for Recirculating (gal/MWh)	394	394	456
Percentage of plants	69%	70%	75%
Water consumption for Once-through cooling (gal/MWh)	71	71	114
Percentage of plants	17%	10%	0%
Water consumption with cooling pond (gal/MWh)	737	737	53
Percentage of plants	14%	20%	5%
Water consumption with dry cooling	0	0	0
Percentage of plants	0%	0%	20%
Weighted average (gal/MWh)	387	430	345

Water impacts analyses

- **Three NEMS scenarios were run in order to isolate the effects of specific factors**
  1. IGCC in the BAU scenario
  2. IGCC in a carbon constraint scenario (\$25/tonne CO_2 tax)
  3. PC cooling system and CDR retrofits in a carbon constraint scenario (\$25/tonne CO_2 tax)

1. Water benefits of IGCC in BAU scenario

- **IGCC uses and consumes less water per MWh of electricity generation than PC**
- **R&D which drives further IGCC deployments instead of PC or older NG/Petro steam will allow the same amount of electricity generation for the less water use**

NEMS Results
Additions and retirements through 2030– Business as usual

Plant type	BAU Baseline		With FE R&D	
	Additions	Retirements	Additions	Retirements
PC	80	6	42	6
IGCC	65	-	132	-
IGCC w/ CDR	-	-	-	-
NG & Petro	79	59	72	62
Nuclear	-	3	-	3
Renew	50	-	37	-
Total	**285**	**67**	**296**	**71**

FE R&D drives significant growth in IGCC and limits PC

Generation and water usage-BAU 2030

Fuel Type	Generation, BkWh		Water usage, Bgallons		Water consumption, Bgallons	
	No R&D	FE R&D	No R&D	FE R&D	No R&D	FE R&D
Coal	3,000	3,277	20,486	20,376	1,188	1,182
NG and Petro	602	545	1,351	1,343	52	48
Nuke	796	796	6,962	6,962	534	534
Renewable	474	433	258	162	1,154	1,150
Total	4,872	5,051	29,057	28,843	2,928	2,914

Going from no R&D to FE R&D, power from coal in 2030 increases 10%, but water usage from coal stays the same

FE R&D lowers the cost of electricity which increases power consumption slightly, overall water usage from power supply goes down slightly

2. Water impacts in carbon constrained scenario

- **GHG policy modeled as a carbon value of $25/tonne (CV25)**
  - Results in a reduction of CO_2 emissions to around 2005 levels by 2030:
  - Compared the with and without R&D cases to see the water impacts

NEMS Results
Additions and retirements through 2030– CV 25 case

Plant type	CV25 Baseline		With FE R&D	
	Additions	Retirements	Additions	Retirements
PC	19	16	11	21
IGCC	18	-	58	-
IGCC w/CDR	-	-	40	-
NG & Petro	115	80	92	83
Nuclear	4	3	-	3
Renew	164	-	128	-
Total	**329**	**99**	**339**	**107**

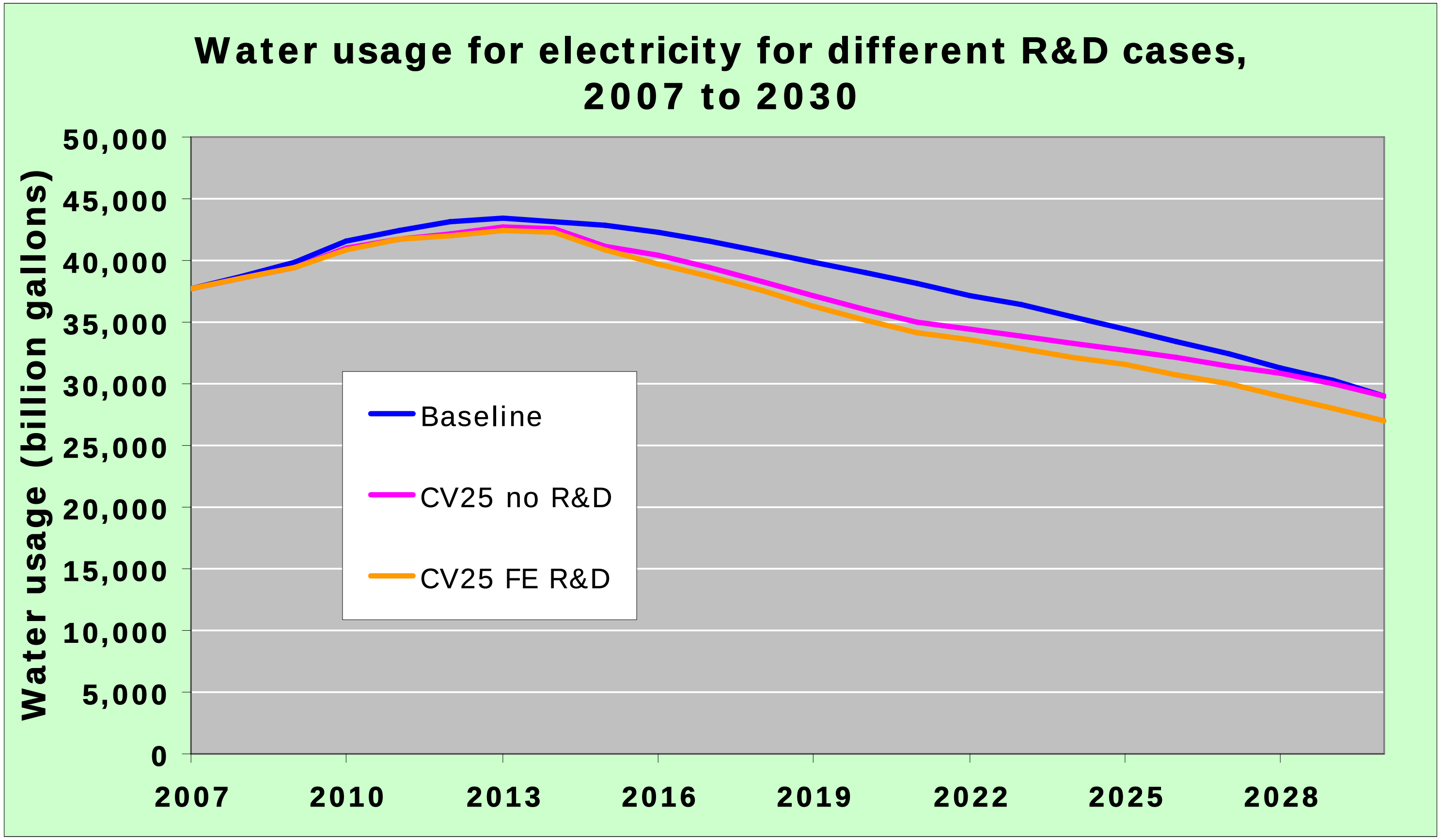
- **PC is curtailed in the CV25 scenario, renewables grow**
- **FE R&D allows for significant new IGCC deployments, pushes out 13 GW PC, 4 GW nuclear, and 36 GW of renewables**

Generation and water usage-CV25 in 2030

Fuel Type	Generation, BkWh		Water usage, Bgallons	
	No R&D	FE R&D	No R&D	FE R&D
Coal	2,234	2,559	18,672	17,839
NG and Petro	684	582	590	536
Nuke	798	796	6,977	6,962
Renewable	1,027	839	2,754	1,634
Total	4,742	4,776	28,993	26,970

Going from no R&D to FE R&D, power from coal in 2030 increases 15% while aggregate water usage from coal decreases 5% - an amplified positive effect compared the BAU policy scenario

Water usage is lower in carbon constrained cases

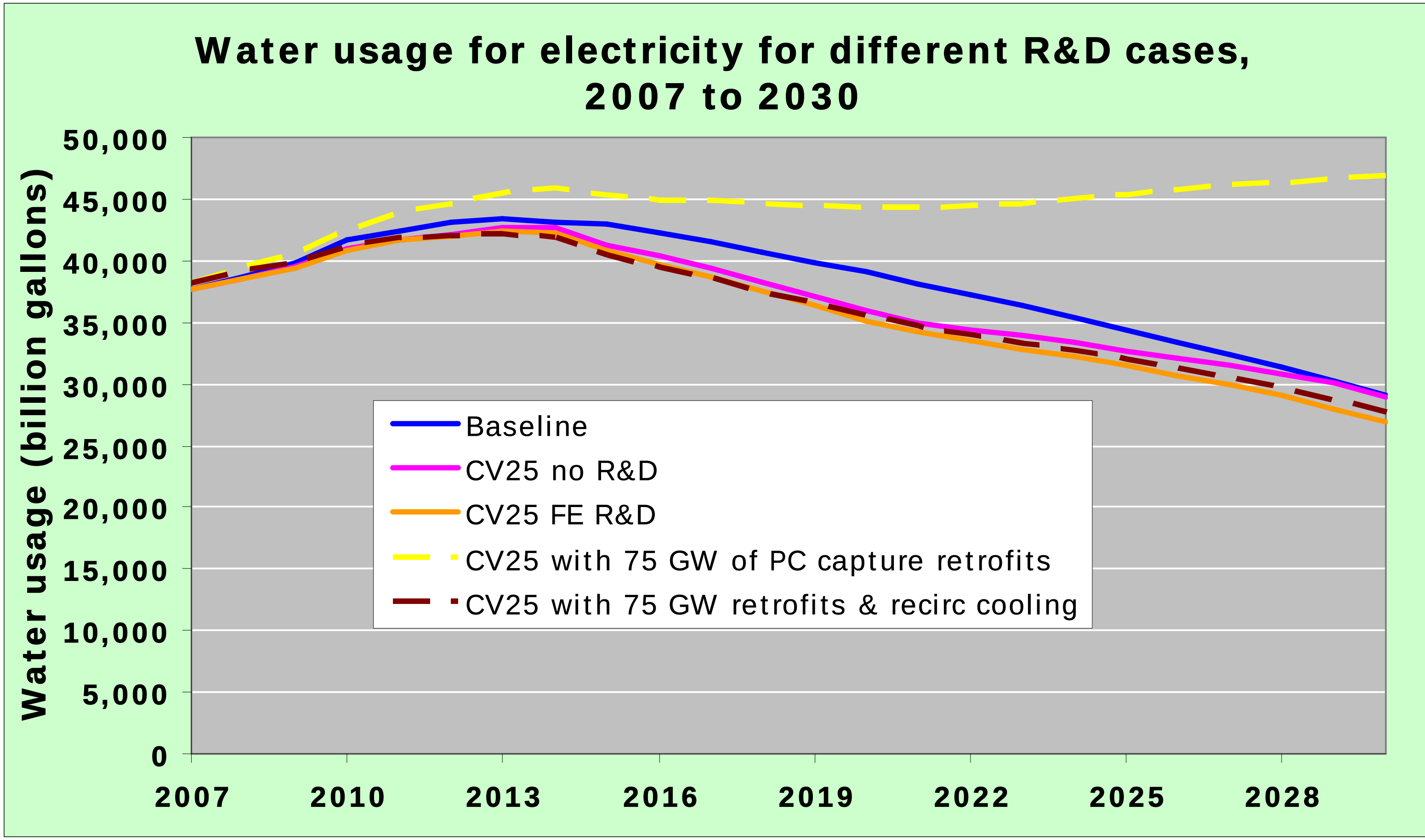


- Unexpected result – power sector water usage in 2030 decreases 7% going from the BAU to the CV 25 policy scenario
  - Due to reduced generation and accelerated retirement of existing PC

3. Water usage – PC carbon capture retrofits

- **PC retrofit scenario assumes**
  - 75 GW of existing PC plants are retrofitted with carbon capture equipment from 2010 to 2030 (with the associated increased water usage and total generation loss)
  - Concurrent retrofit of cooling systems toward recirc and dry from once-through
    - Once through, 10%
    - Recirculating, 75%
    - Dry,15%

Water usage – PC Retrofits



As expected, capture retrofits alone cause more water usage, but additionally changing the cooling systems gets usage levels back down to FE R&D levels

Conclusions

- The 65 GW of incremental IGCC deployments resulting from FE R&D in the business-as-usual scenario result in a 10% decrease in the average water usage per MWh of power from coal in 2030
- In the carbon constrained policy scenario the effects of IGCC deployments on water use are more significant than in the BAU. FE R&D caused a 20% decrease in the average water usage per MWh of power from coal in 2030
- A scenario where existing coal-fired power plants are retrofitted with CO2 capture is water-use-neutral as long as the retrofits are coupled with a switch from once-through to recirculation water systems.

Next steps

- Evaluate Levelized Cost of Electricity and efficiency impacts of different cooling systems applied to CFPPs:
  - w/ and w/o CDR
  - w/ and w/o advanced cooling system technologies
- Water impacts of alternative liquid fuels (C(B)TL, ethanol, biodiesel, etc) production technologies in transportation sector
- Adjust scaling factors to include additional water evaporated as heated effluent returns to original body of water
- Regional analyses focusing on water-scarce areas
- Incorporation of water factors into CarBen

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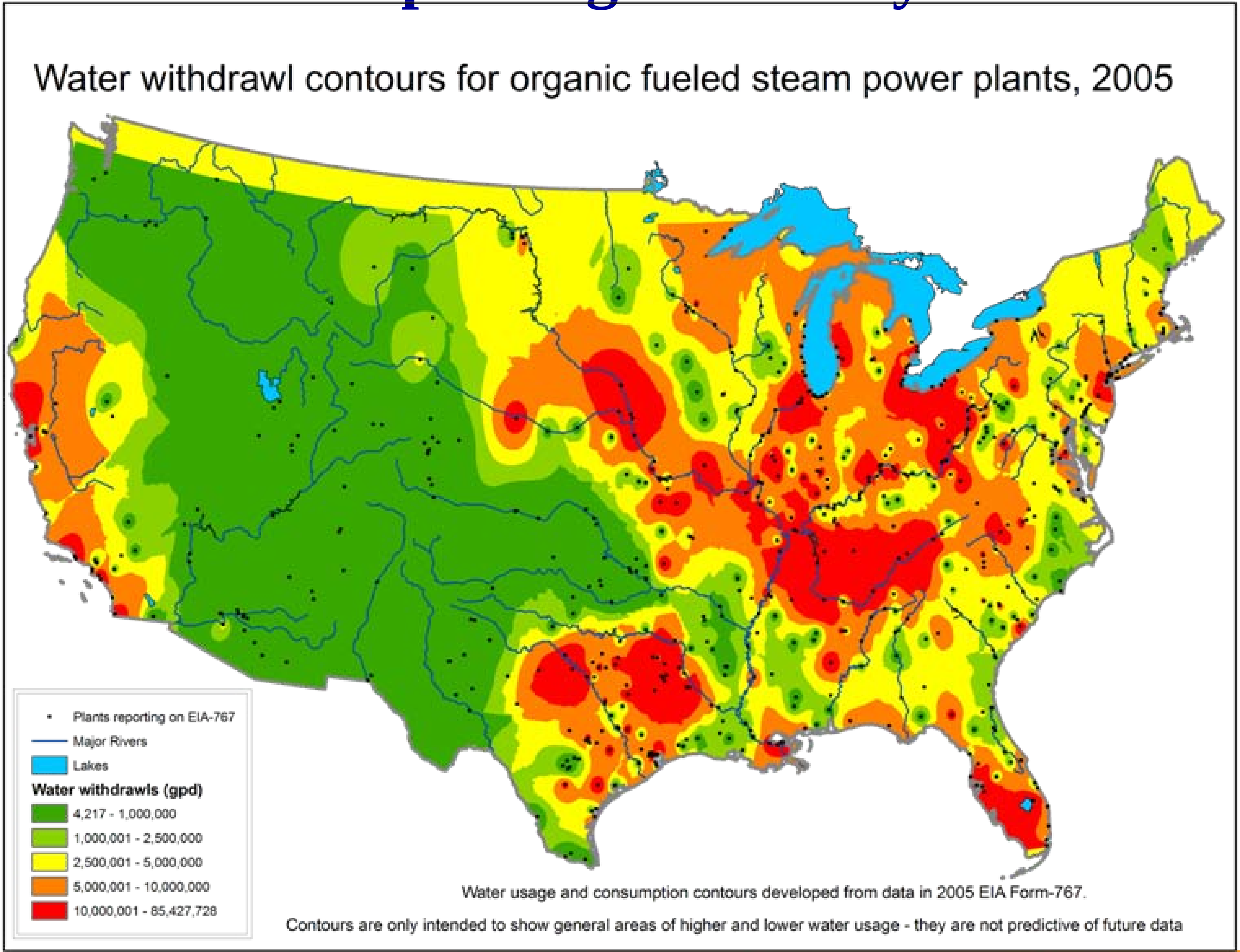
Next steps – regional analysis



Next steps – regional analysis