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Energy & Water: Potential Futures

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Overview

- Connections between energy and water
- Future energy scenarios
- Water implications of future scenarios of power generation
- Water implications of producing fossil energy resources
- Water implications of changing sources of transportation energy
- Conclusions

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Connections between energy and water

- Water and energy are linked:
  - Water treatment and supply require energy
  - Water is used in power generation, oil & gas production, and, increasingly, in the production of biofuels
- Water treatment and supply accounts for less than 3% of U.S. electricity consumption, but electricity production accounts for about 36% of U.S. water withdrawals
- Without more complete understanding and careful planning, energy production may be limited by water availability

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Future energy scenarios

- Changes in energy production are likely in the future, driven by:
  - GHG and environmental policies,
  - energy security concerns, and
  - economic drivers
- These changes may have significant implications on energy-related water demands
- Predicting the future is “difficult” – a more robust approach is to use scenarios that illustrate:
  - what might happen given specified conditions
  - what would need to happen to achieve specified goals

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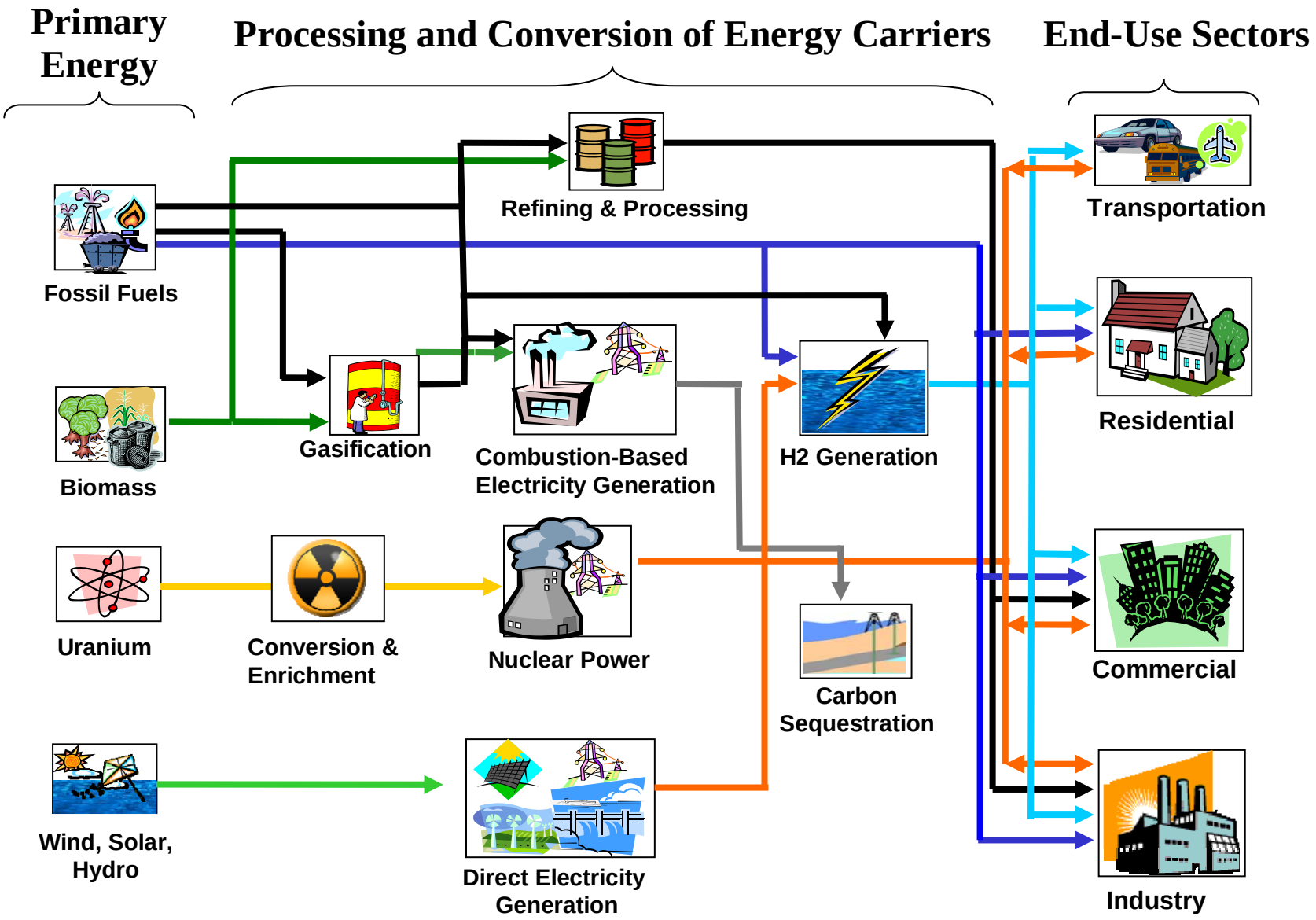
MARKAL as a tool for scenario analysis

- EPA/NRMRL uses the MARKAL (MARKet ALlocation) energy system model to evaluate scenarios of future energy production and use
- MARKAL finds the least-cost mix of technologies and fuels over time to meet specified energy end-use demands, given scenarios that define technical and policy constraints on prices, costs, and technology development rates
- MARKAL is a bottom-up model that explicitly incorporates cost and performance data on energy resource, conversion, and end use technologies

Schematic of energy flows in MARKAL



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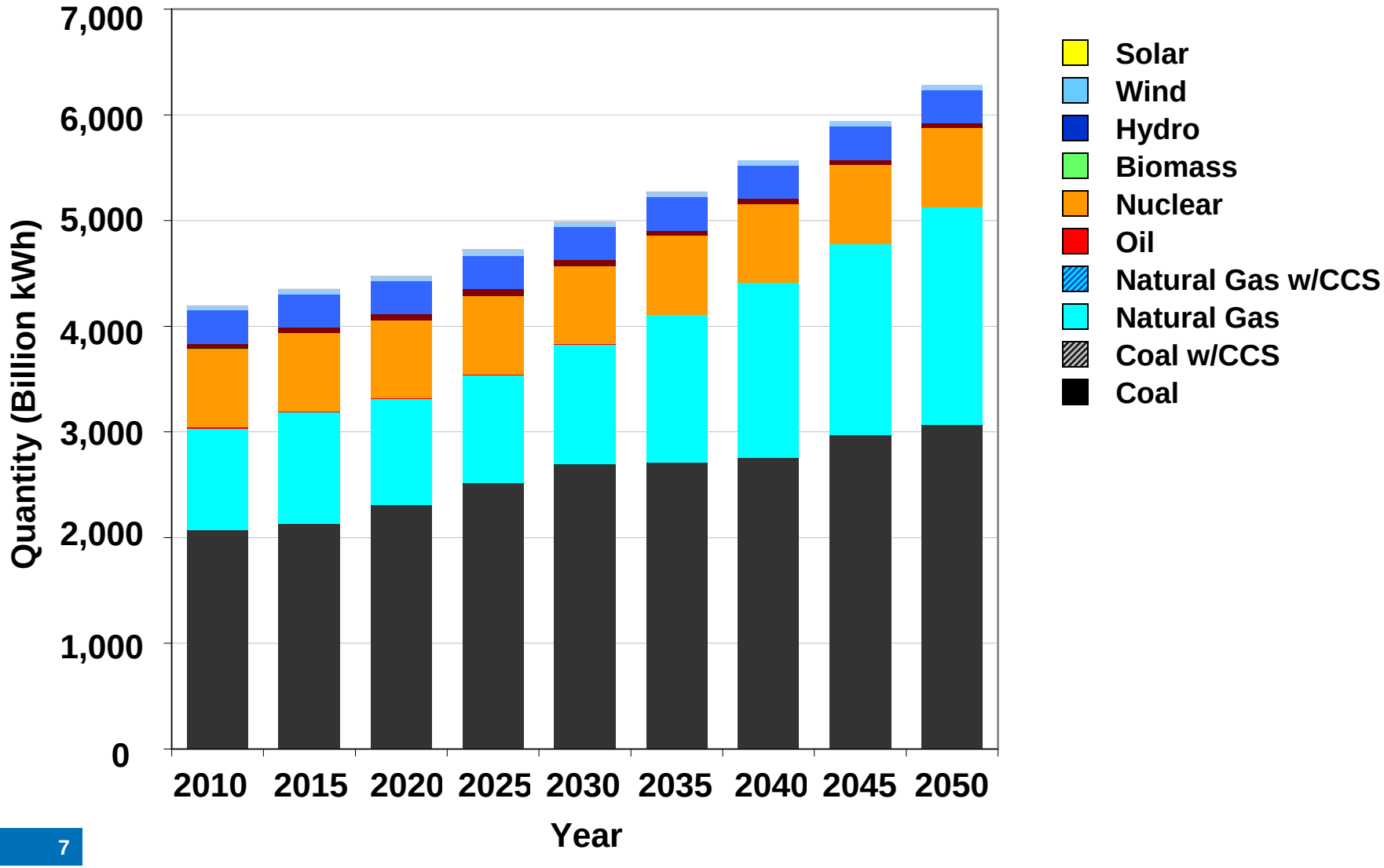
Scenarios for water analysis

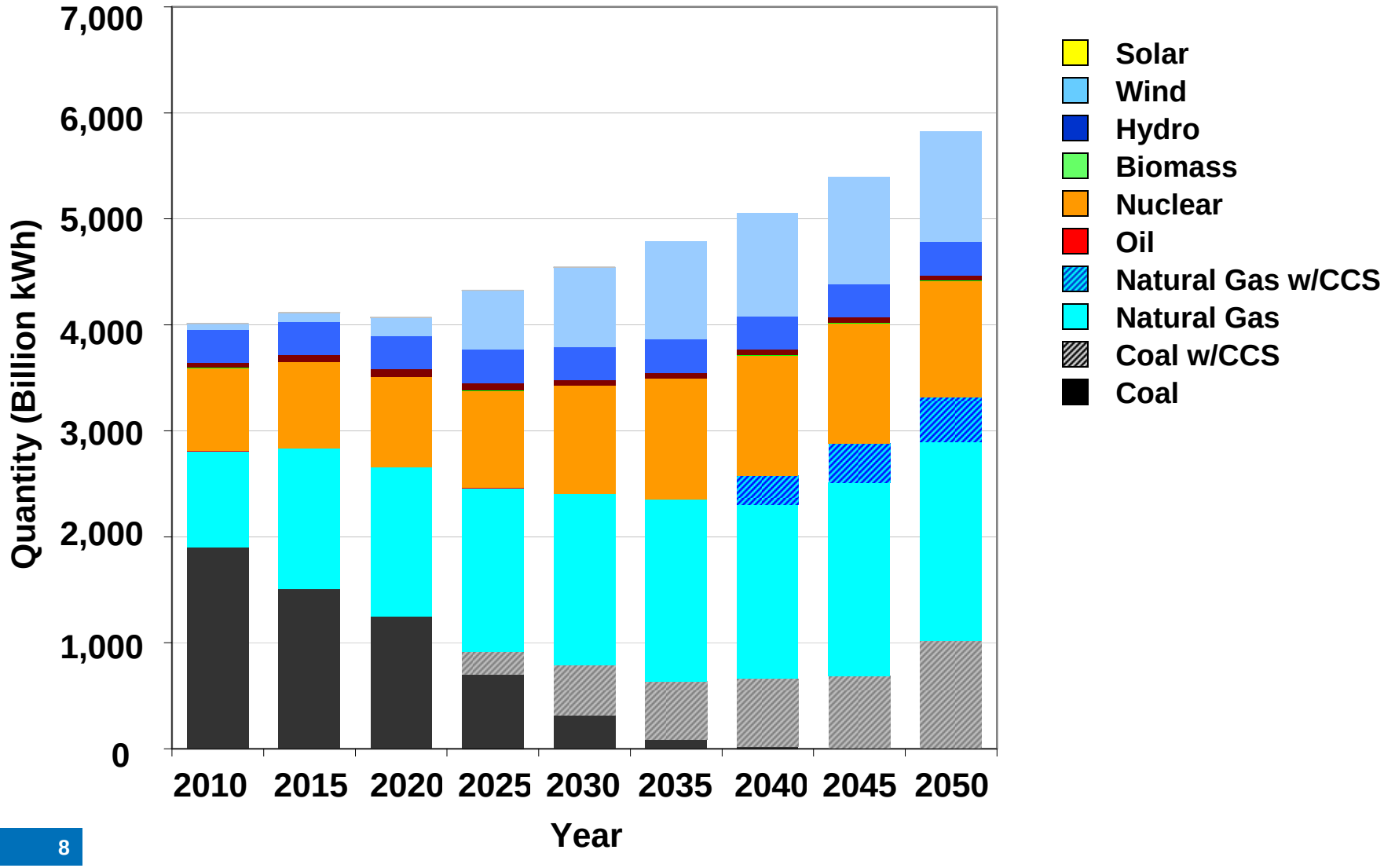
Five scenarios are presented here:

1. Business as usual (BAU): Assumes status quo for air and energy policies (e.g., no greenhouse gas regulation), while extending past trends on technology development, economic growth, and energy demands
2. Baseline GHG policy (GHG-Base): Assumes energy system CO_2 reductions similar to those resulting from the Waxman-Markey bill. Renewable growth is strong; carbon capture and sequestration (CCS) is commercialized in 2025
3. GHG policy with nuclear and CCS focus (GHG-Nuke/CCS): Same as GHG-Base, but assumes nuclear and CCS technologies are the focus of the mitigation effort
4. GHG policy with renewables and natural gas focus (GHG-Ren/Gas): Same as GHG-Base, but assumes limited expansion of nuclear power and CCS capacity; CCS unavailable until 2030. GHG reductions achieved using renewables and natural gas
5. GHG policy with aggressive light duty vehicle electrification (GHG-LDV): Same as GHG-Base, but assumes rapid adoption of electric-capable vehicles

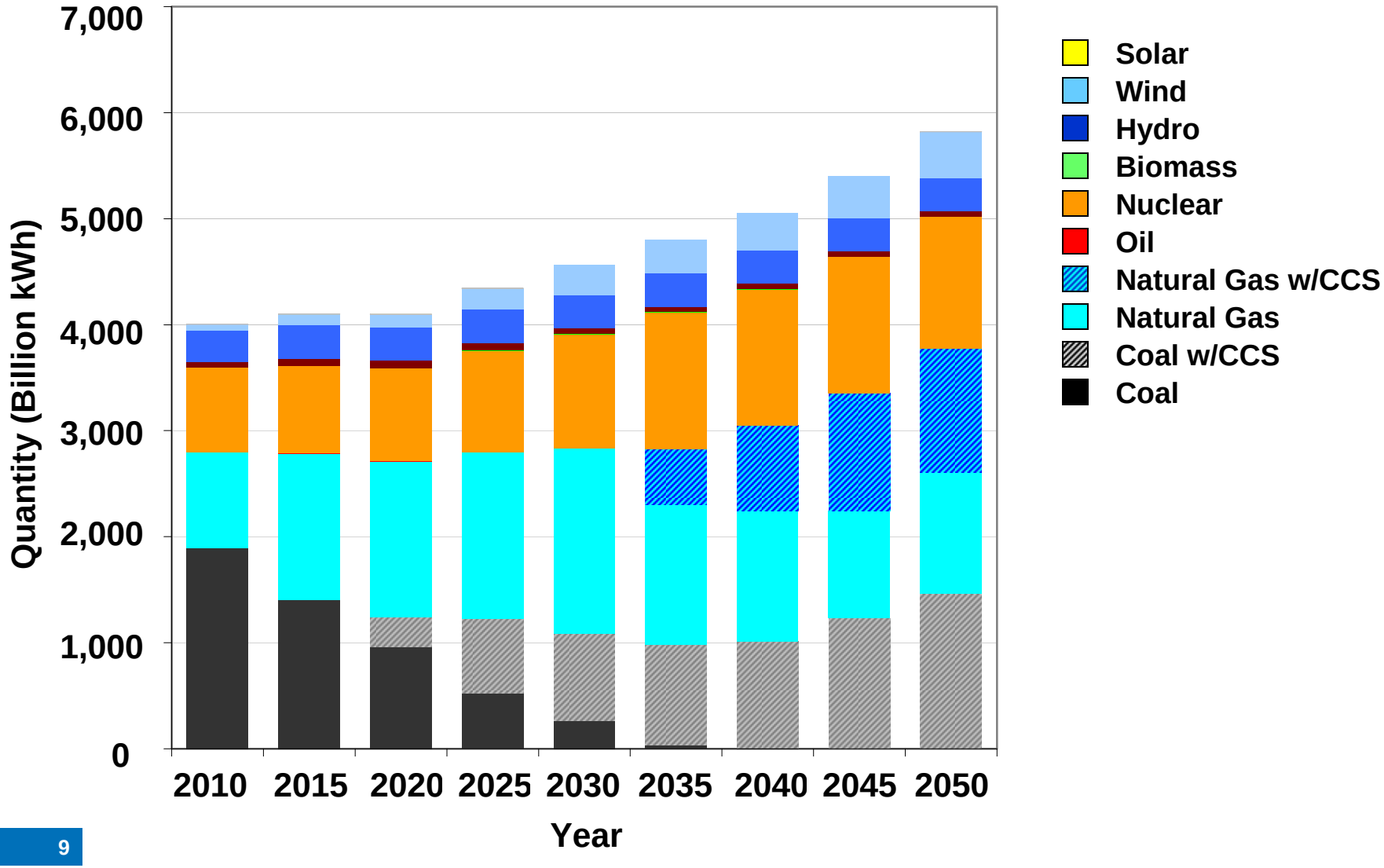
Electricity generation by technology
Business as usual (BAU) case



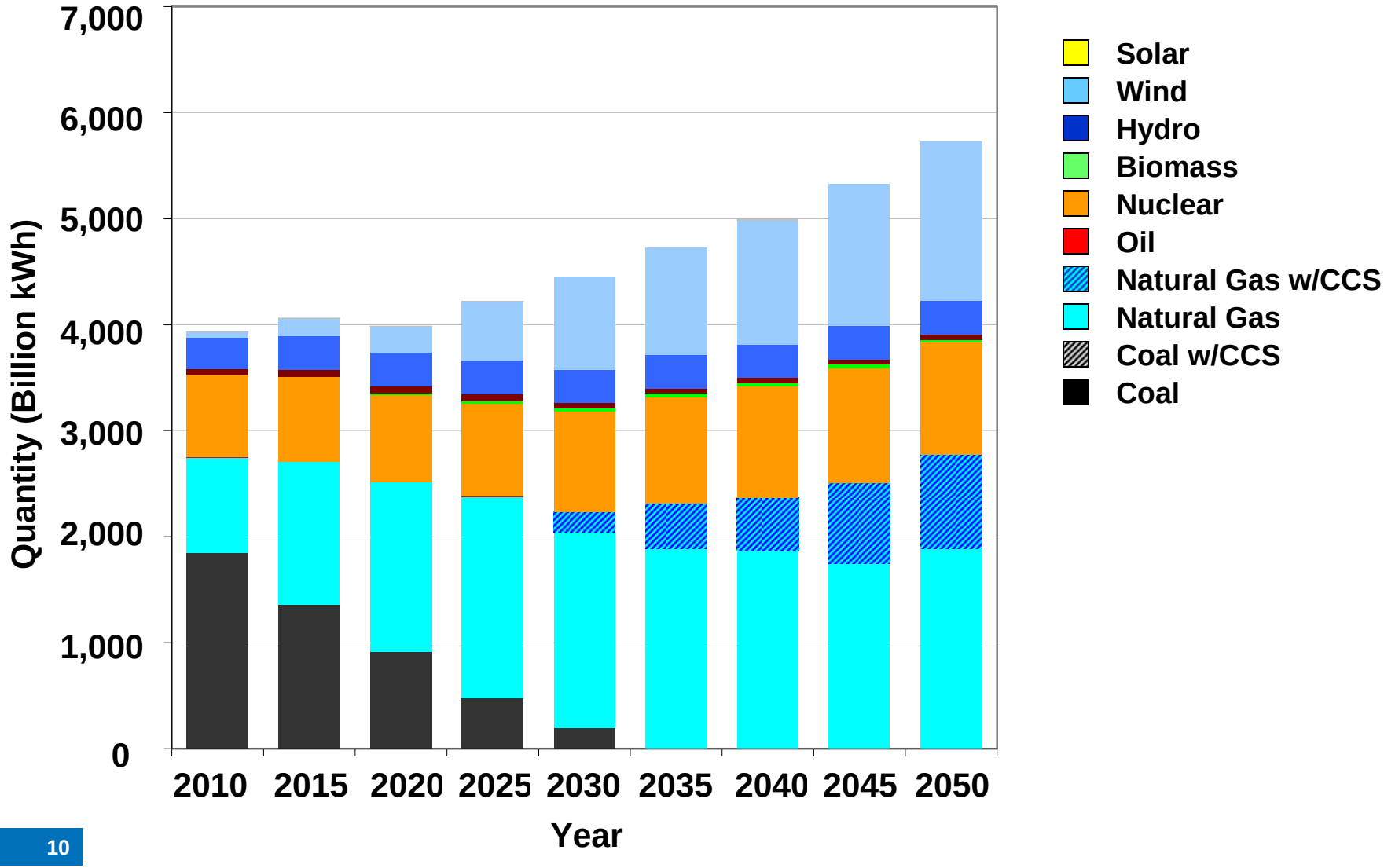
Electricity generation by technology
GHG policy – base case



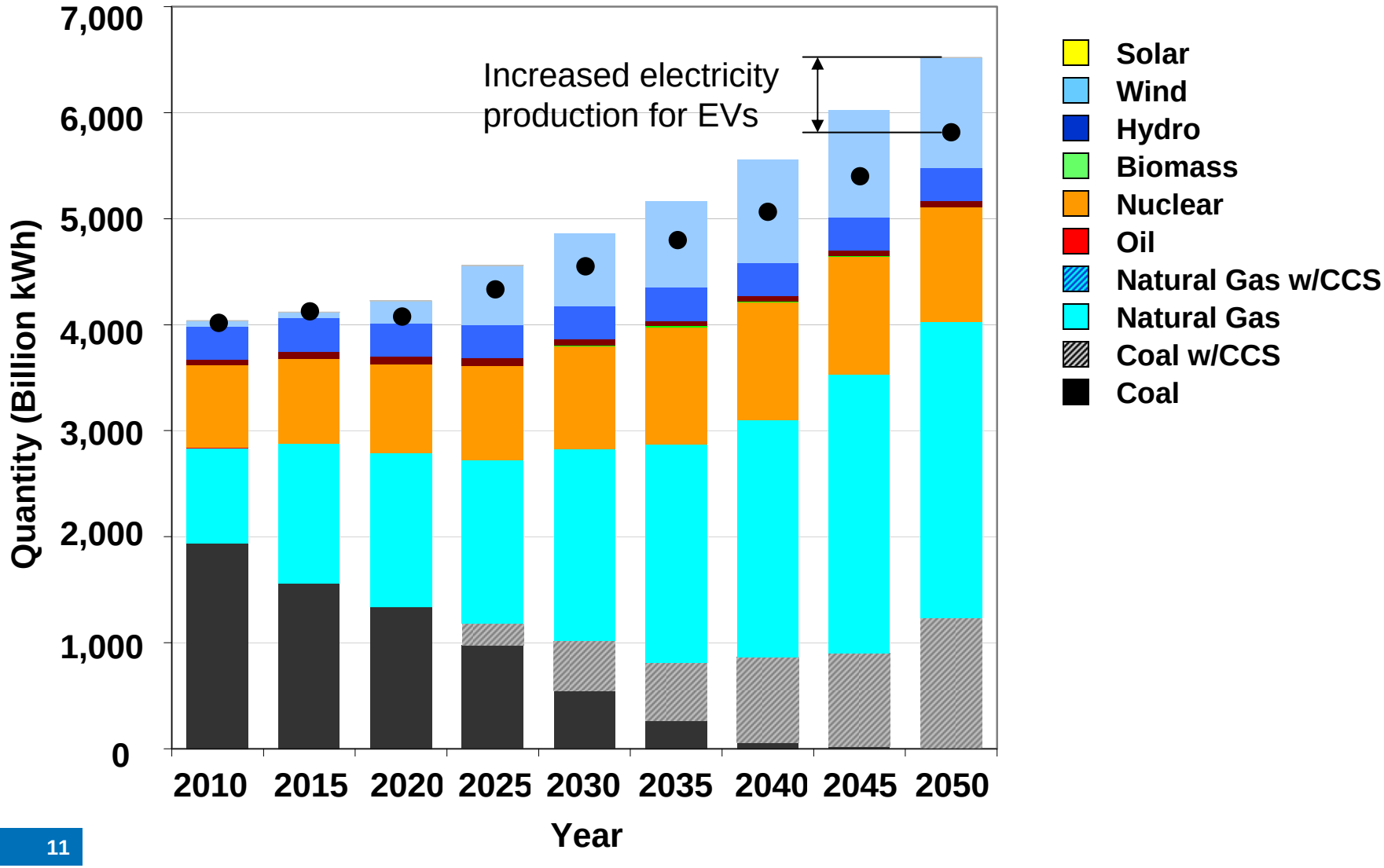
Electricity generation by technology
GHG policy – nuclear/CCS focus



Electricity generation by technology
GHG policy – renewable/natural gas case



Electricity generation by technology
GHG policy – base with LDEV case



What do these scenarios imply for water demands for power generation?

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Power generation

- Steam-electric plants currently withdraw an average of just under 13 gallons of fresh water per kWh of power generated (over all cooling and generation technologies)
- This totals 143 billion gal/day of fresh water, compared to 29 billion gal/day of fresh water withdrawal for residential use
- Consumption rates are highest for nuclear plants, followed by conventional steam-electric plants, and lowest for combined cycle plants
- The generation and cooling technologies used will impact water demand and consumption

Withdrawal values from: U.S. Department of the Interior, 2009. Estimated Use of Water in the United States in 2005. U.S. Geological Survey, Washington, DC.

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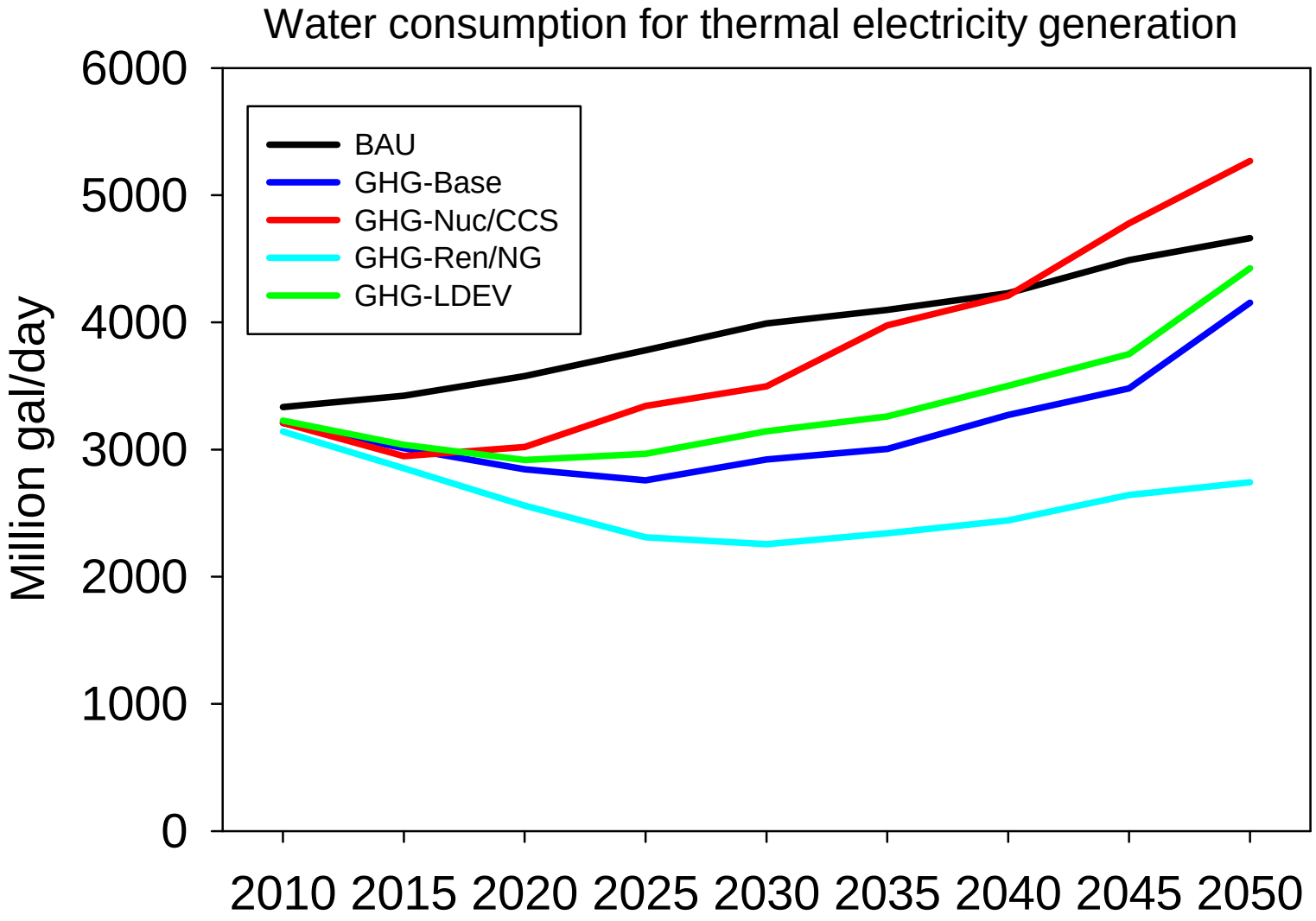
Power generation – carbon capture

- Carbon capture will add to this demand, because of the lower net plant efficiency and the process cooling needs (as much as 26,000 gal/ton CO_2)
- The impact of carbon capture and storage systems will depend upon the success of the technology (cost and performance), and the success of other low-carbon power generation technologies
- However, it is possible that an additional 75 billion gal/day may need to be withdrawn to meet the needs of CO_2 capture systems
- The impacts of any such increased water demand – and impacts on water quality – will be location-specific

Water consumption for power generation scenarios



Zhai, H., Rubin, E.S., 2010. Performance and cost of wet and dry cooling systems for pulverized coal power plants with and without carbon capture and storage. Energ. Policy
Ciferno, J.P., Munson, R.K., Murphy, J.T., 2010. Determining carbon capture and sequestration's water demands, Power, March 1.


What are the water implications of changing sources of transportation energy?

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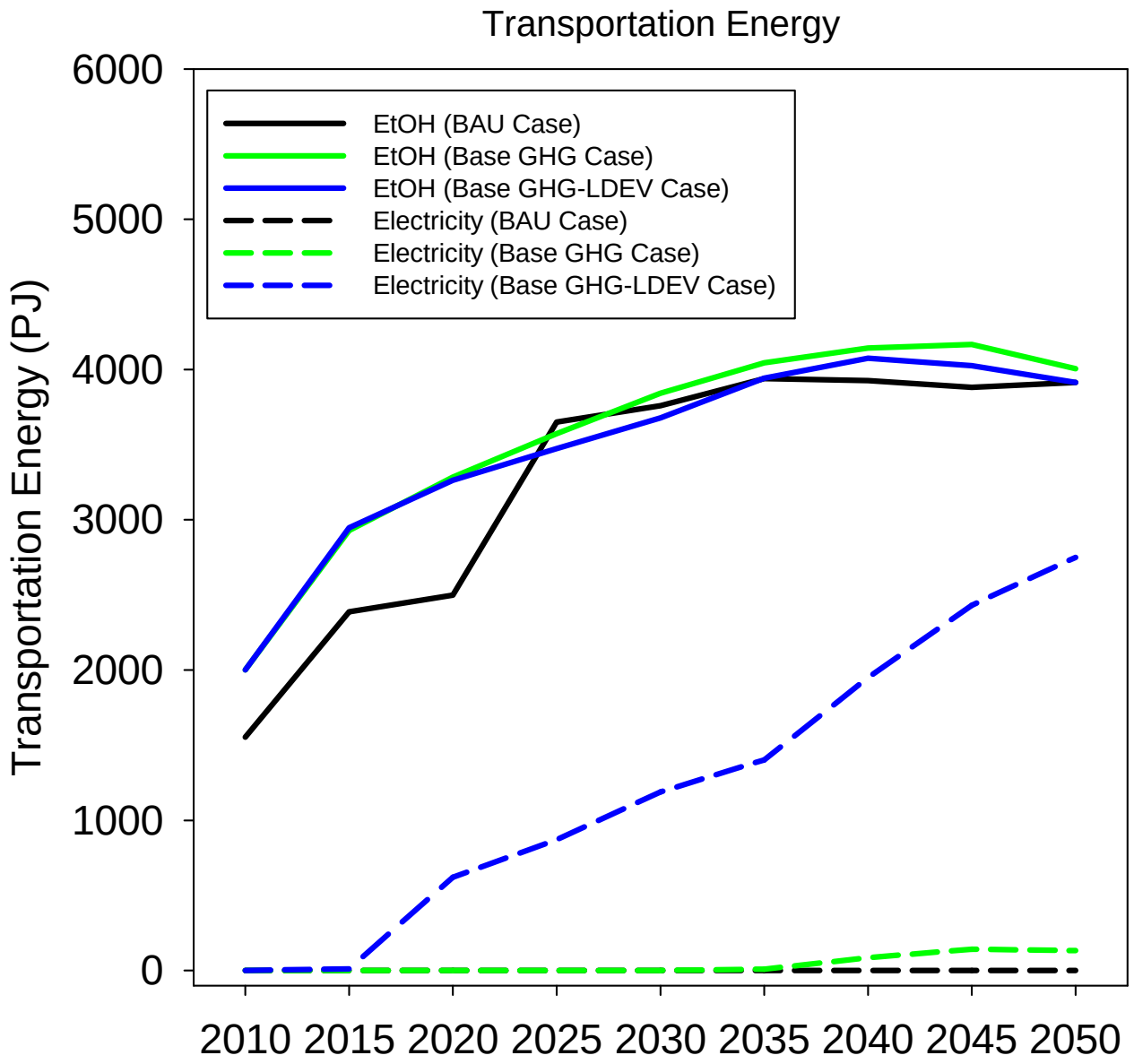
Changing transportation energy

- Biofuel technologies are, in many cases, changing rapidly
  - Cellulosic ethanol, biomass-to-hydrocarbons, algae are all under development and can significantly change water demands
- Similarly, changes in battery technology could have a major impact on the penetration of electric vehicles and lead to much more electricity-driven transportation than is currently projected

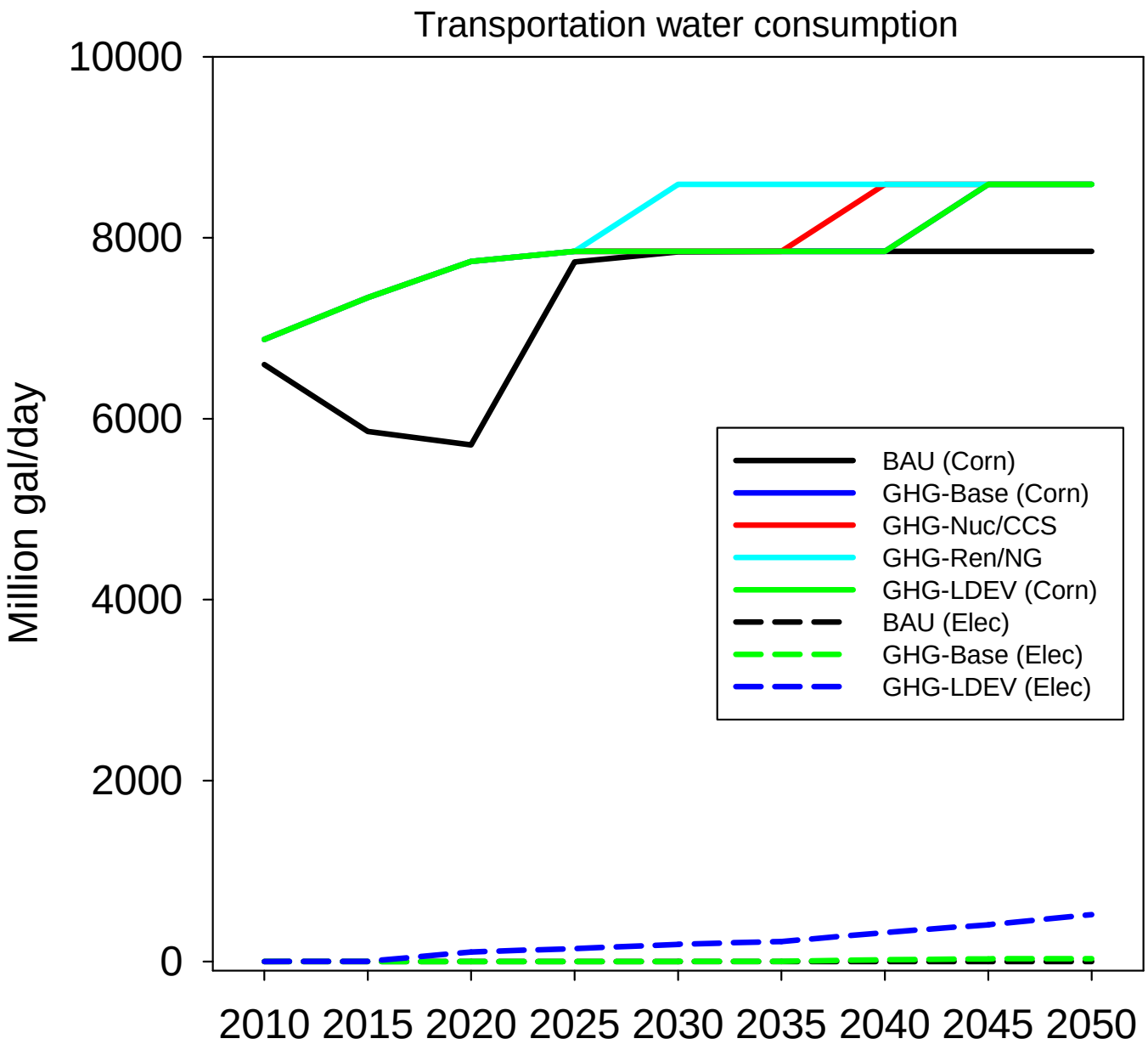


Energy from corn-grain ethanol (solid lines) and electricity (dashed lines) used in light-duty transportation for three scenarios

Transportation impacts on water

- Biofuels can require large amounts of water, especially for irrigation of corn grain used to produce ethanol
  - Requirements vary by location, from very low irrigation (5 L water per L ethanol) to very high (2138 L L^{-1})
- Electric-capable vehicles (plug-in hybrids, electric-only vehicles) will add to electricity demand and, consequently, to water consumption for power generation

Water requirements from Chiu, Y.-W., Walseth, B., Suh, S., 2009. Water Embodied in Bioethanol in the United States. Environ. Sci. Technol. 43, 2688-2692.


Transportation water consumption
Million gal/day
10000
8000
6000
4000
2000
0
2010 2015 2020 2025 2030 2035 2040 2045 2050
BAU (Corn)
GHG-Base (Corn)
GHG-Nuc/CCS
GHG-Ren/NG
GHG-LDEV (Corn)
BAU (Elec)
GHG-Base (Elec)
GHG-LDEV (Elec)

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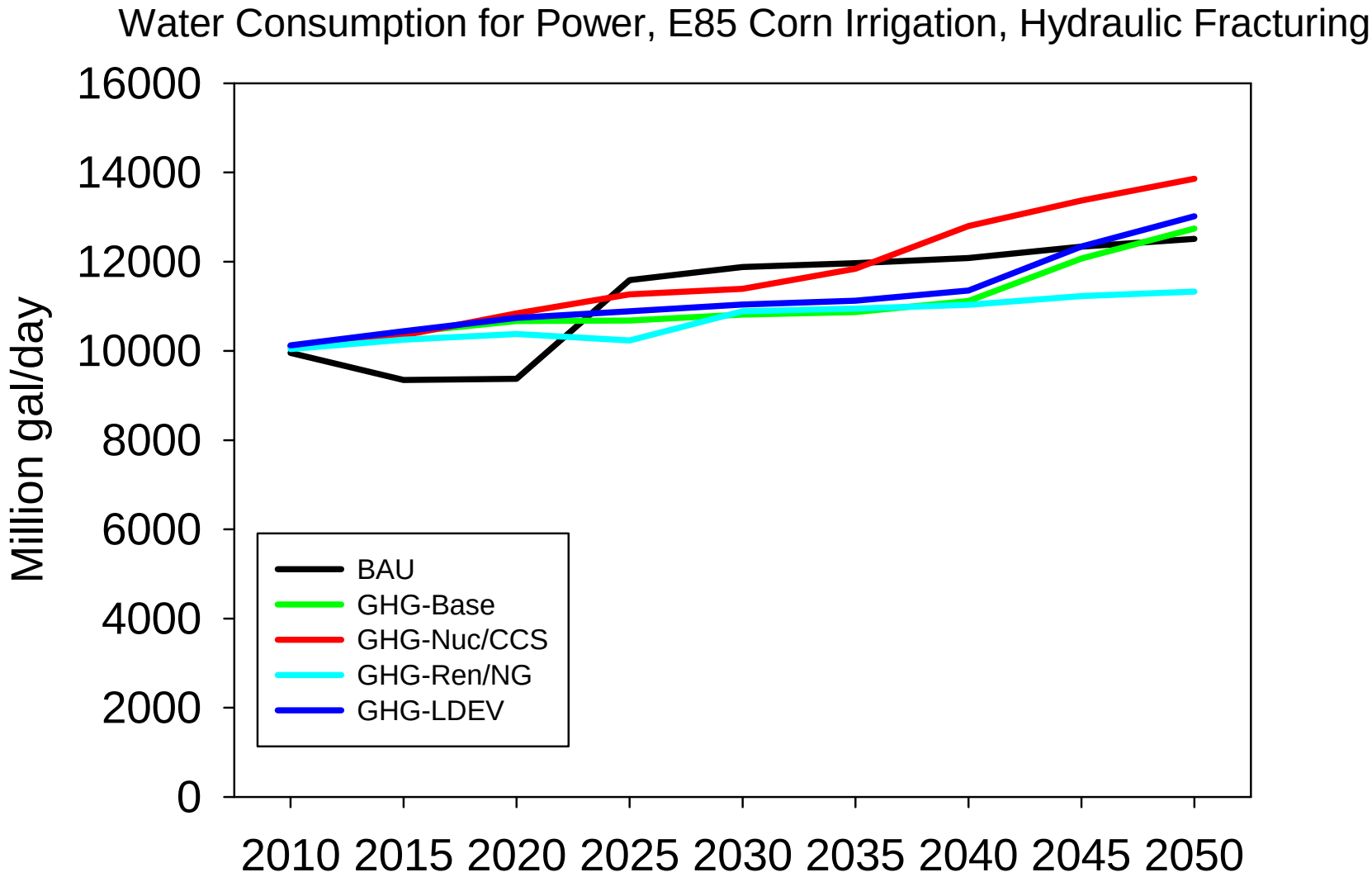
The overall picture

- The water consumption estimates shown above happen concurrently across these different sectors
- These results do not include other water demands, such as those associated with coal mining
- New technologies, such as algae-based fuels, can have major impacts on these estimates, but are not considered here
- These are national-level estimates – regional or local changes may be significantly different, and may drive the potential for implementing some of the scenarios shown in this analysis

Total water demand implied by future scenarios



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Insights

- A strategy focused on nuclear and coal/CCS consumes considerably more water than indicated in other power generation scenarios
- Water consumption for corn-grain ethanol is considerably higher than for any other sector evaluated here
- Increased EV reliance does not reduce corn-grain ethanol use (and the associated water consumption), but reduces gasoline consumption

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Conclusions

- Changes in the U.S. energy system due to climate, environmental, energy, and other policies can significantly impact the demand for water
- The impacts of these changing water demands will occur at a local scale
- Nationally, all scenarios evaluated increase water consumption beyond business as usual
  - However, it is expected that there will be some regions that will require less water and others that will require more

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Future work

- Work is underway to evaluate the regional water demand impacts of different energy scenarios
- Evaluations are also planned to examine impacts of increased use of closed loop cooling and other approaches to reduce energy-related water consumption
- Additional water demands, such as that for coal mining, are also being examined