A MARKAL-based Analysis to Assess the Role of Natural Gas and Power Plant Retirements for Future Energy Scenarios in the US

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Uncertainty in the US energy sector

- Previous work done by the Office of Research & Development at US EPA applied the Future Scenarios Method to develop Energy Future scenarios*

Future Scenarios Method steps:

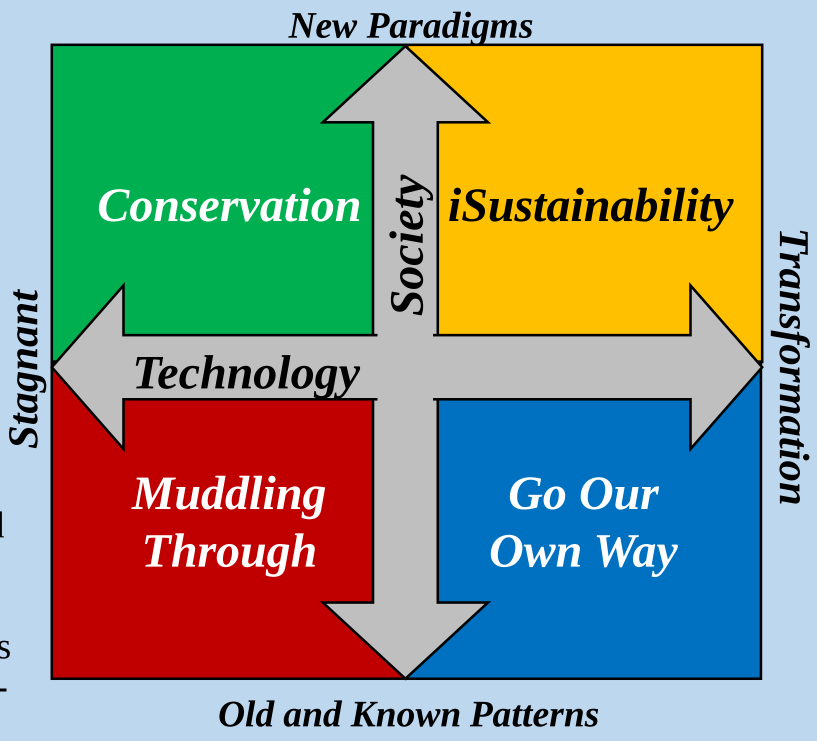
- Conducted a workshop to gather expert opinion from internal and external experts
- Selected the two most important uncertainties and developed a scenario matrix: technology evaluation and societal preferences
- Constructed narratives describing the matrix's four scenarios
- Developed a 2x2 scenario matrix. The method is adaptable, however, and could be used to develop more or fewer scenarios

*Manuscript in preparation: ‘"Evolution of the US energy system and related emissions under varying social and technological development paradigms: Plausible scenarios for use in robust decision making"’ by Brown et. al (2017)

Scenario matrix to capture energy sector uncertainties

Conservation is motivated by environmental considerations. Assumptions include decreased travel, greater utilization of existing renewable energy resources, energy efficiency and conservation measures adopted in buildings, and reduced home size for new construction.

iSustainability is powered by technology advancements, and assumes aggressive adoption of solar power, battery storage, and electric vehicles, accompanied by decreased travel as a result of greater telework opportunities.



Muddling Through has limited technological advancements and stagnant behaviors, meaning electric vehicle use would be highly limited and trends such as urban sprawl and increasing per-capita home and vehicle size would continue.

Go Our Own Way includes assumptions motivated by energy security concerns. These assumptions include increased use of domestic fuels, particularly coal and gas for electricity production and biofuels, coal-to-liquids, and compressed natural gas in vehicles.

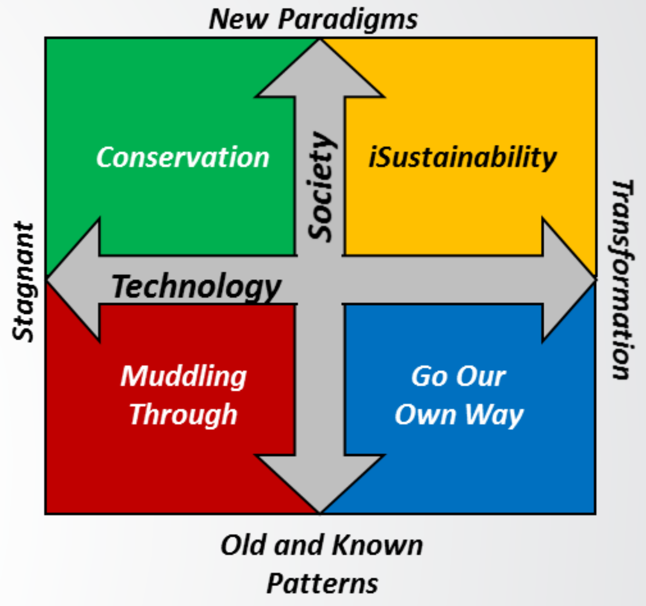
‘Role of future scenarios in understanding deep uncertainty in long-term air quality management’ by Gamas et. al (2015)

Additional uncertainty components within the US energy system

- With alternative electricity generation and vehicle technologies becoming economically feasible for commercial scale applications, the **US electric power generation** and **vehicle fleet** mix may undergo **significant changes**
- The uncertainty in **upstream methane emissions** from **natural gas fired electricity** could offset the benefits of transitioning from coal to NG fueled power plants
- Economic factors and societal perceptions of risks associated with operation of fossil-fired and nuclear power plants may result in **early shut-down of coal** or **nuclear power** plants
- Changes in international **trade-relations** and creation of new trade routes could result in changes in the price and magnitude of the import and export of fuels resulting in changes in the electric power sector
- These changes could also impact domestic production of industrial goods

Analysis Incorporating Additional Uncertainties in Energy Sector

- The four energy future scenarios are modified to each consider twelve different cases to include:
  - Early retirement/ Extended lifetime of coal and nuclear plants
  - Changes in oil and natural gas prices
  - Changes in natural gas exports
  - Changes in assumptions regarding the upstream methane leakage rates for natural gas-fired electricity
- These cases are then implemented in EPA's MARKAL database for further analysis



MARKAL case studies

<table>
<tr><th>MARKAL Case Studies</th><th>Spike in Natural Gas Exports (%)</th><th>Upstream CH_4 emission rate from Natural Gas power plants (%)</th><th>Oil and Natural Gas Price Spike (%)</th><th>Coal Plant Life (years)</th><th>Nuclear Plant Life (years)</th></tr>
<tr><td>Base</td><td>0%</td><td>2.3%</td><td>0%</td><td>50</td><td>50</td></tr>
<tr><td>1</td><td rowspan="12">15%</td><td rowspan="6">11.7%</td><td rowspan="3">15%</td><td>40</td><td rowspan="2">60</td></tr>
<tr><td>2</td><td rowspan="2">60</td></tr>
<tr><td>3*</td><td>40</td></tr>
<tr><td>4</td><td rowspan="3">0%</td><td>40</td><td rowspan="2">60</td></tr>
<tr><td>5*</td><td rowspan="2">60</td></tr>
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<tr><td>7</td><td rowspan="6">2.3%</td><td rowspan="3">15%</td><td>40</td><td rowspan="2">60</td></tr>
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<tr><td>9*</td><td>40</td></tr>
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<tr><td>11*</td><td rowspan="2">60</td></tr>
<tr><td>12*</td><td>40</td></tr>
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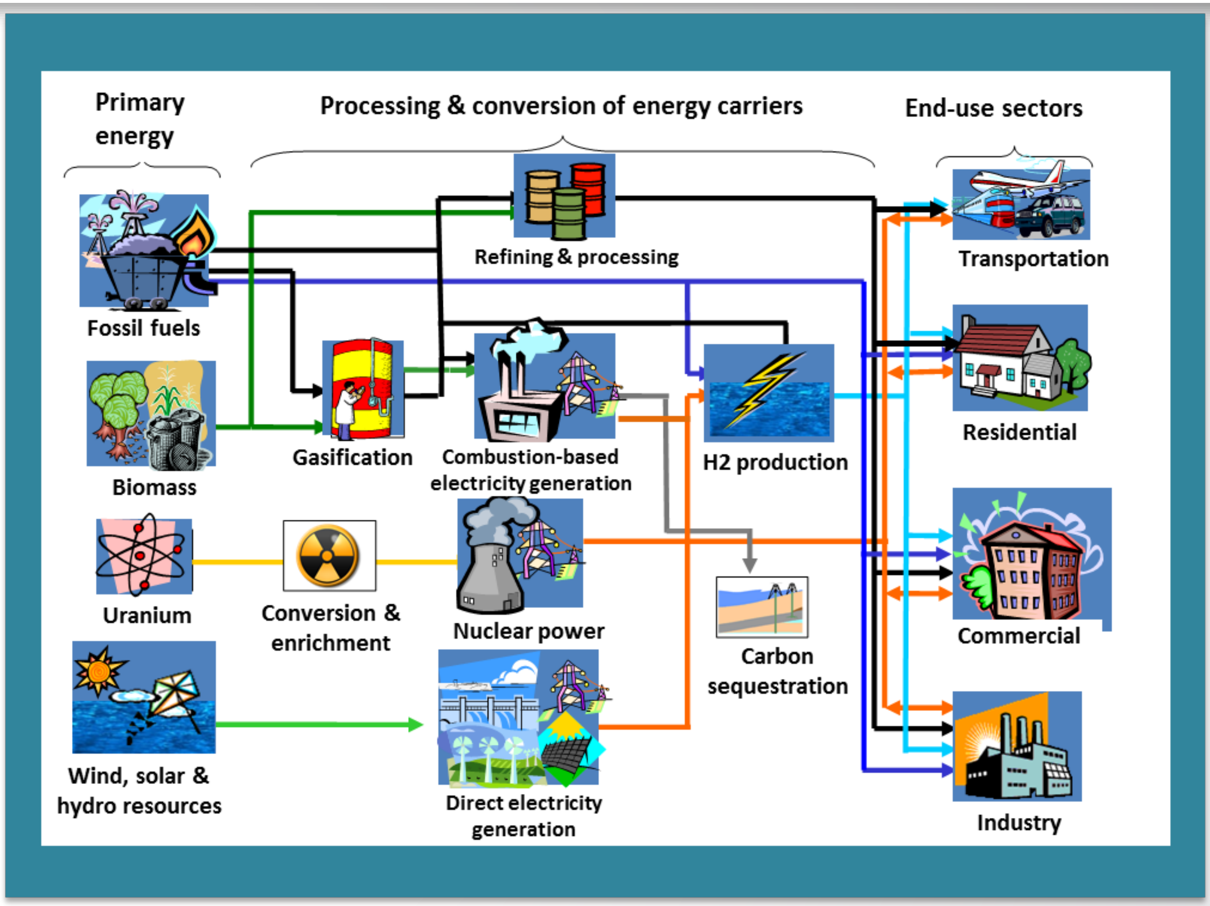
*The MARKAL cases that did not demonstrate significant changes relative to base/ other cases are in gray colored font

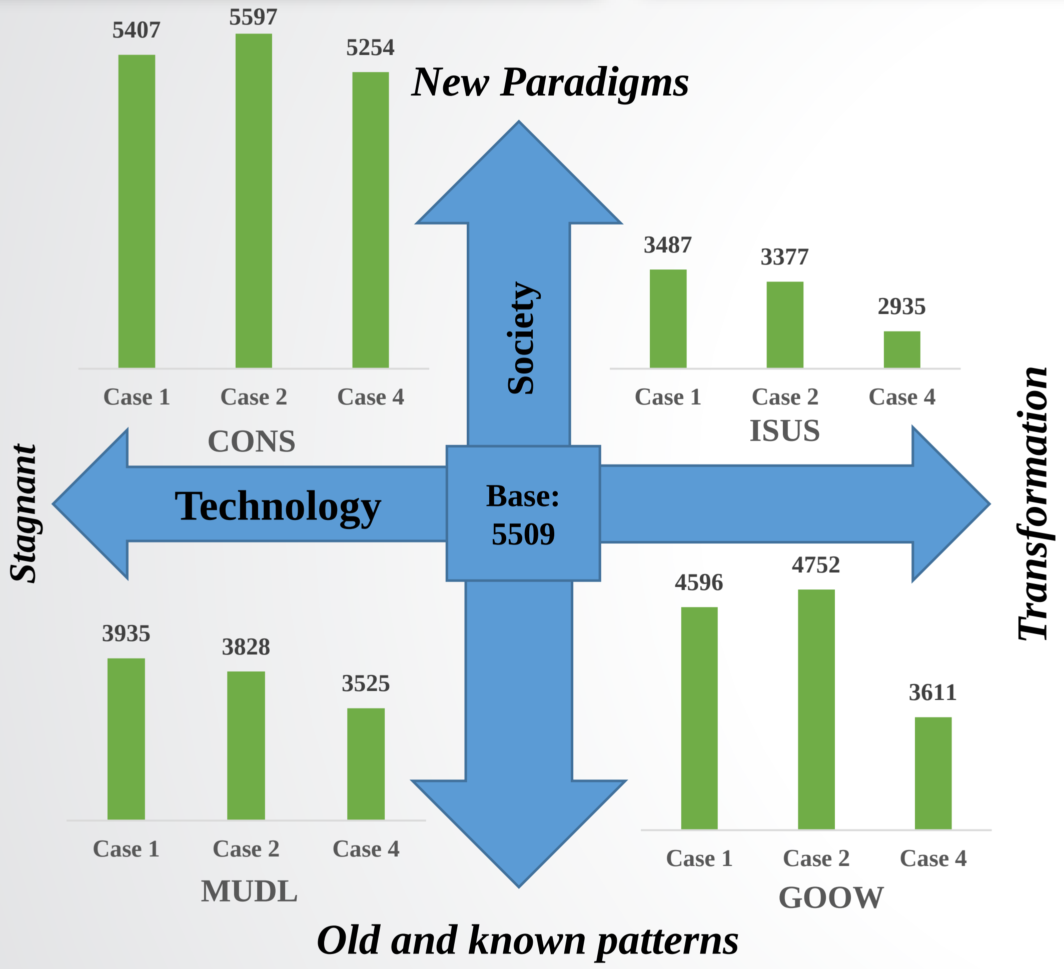
Modeling US energy system using EPAUS9r MARKAL database

- Bottom-up and technology-rich
  - Captures the full system from energy resource supply/extraction technologies to end-use technologies in all sectors
  - Energy technologies (existing and future techs) are characterized by cost, efficiency, fuel inputs, emissions
  - Technologies are connected by energy flows
  - Covers 9 US Census divisions
- Optimization
  - The model picks the "best" way (lowest system-wide cost) to meet energy demands choosing from the full "menu" of energy resources and technologies
  - The model makes these choices from 2005 to 2055, giving us a snapshot of possible future energy mixes



- Emissions and impacts
  - All technologies and fuels have air and GHG emissions characterized
  - Standards and regulations are included in the baseline, and additional policies can be modeled

Results: Coal-based electricity



Coal-based electricity generation (PJ), 2045

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
1	11.7%	15%	15%	40
2	11.7%	15%	15%	60
4	11.7%	-	15%	60
Base	2.3%	-	-	50

- Relative changes in coal based generation in all four futures with respect to the base case ranges from mostly negative in the ISUStainability and MUDdLing through futures to ~0% change in CONServation and Go Our Own Way (GOOW) futures

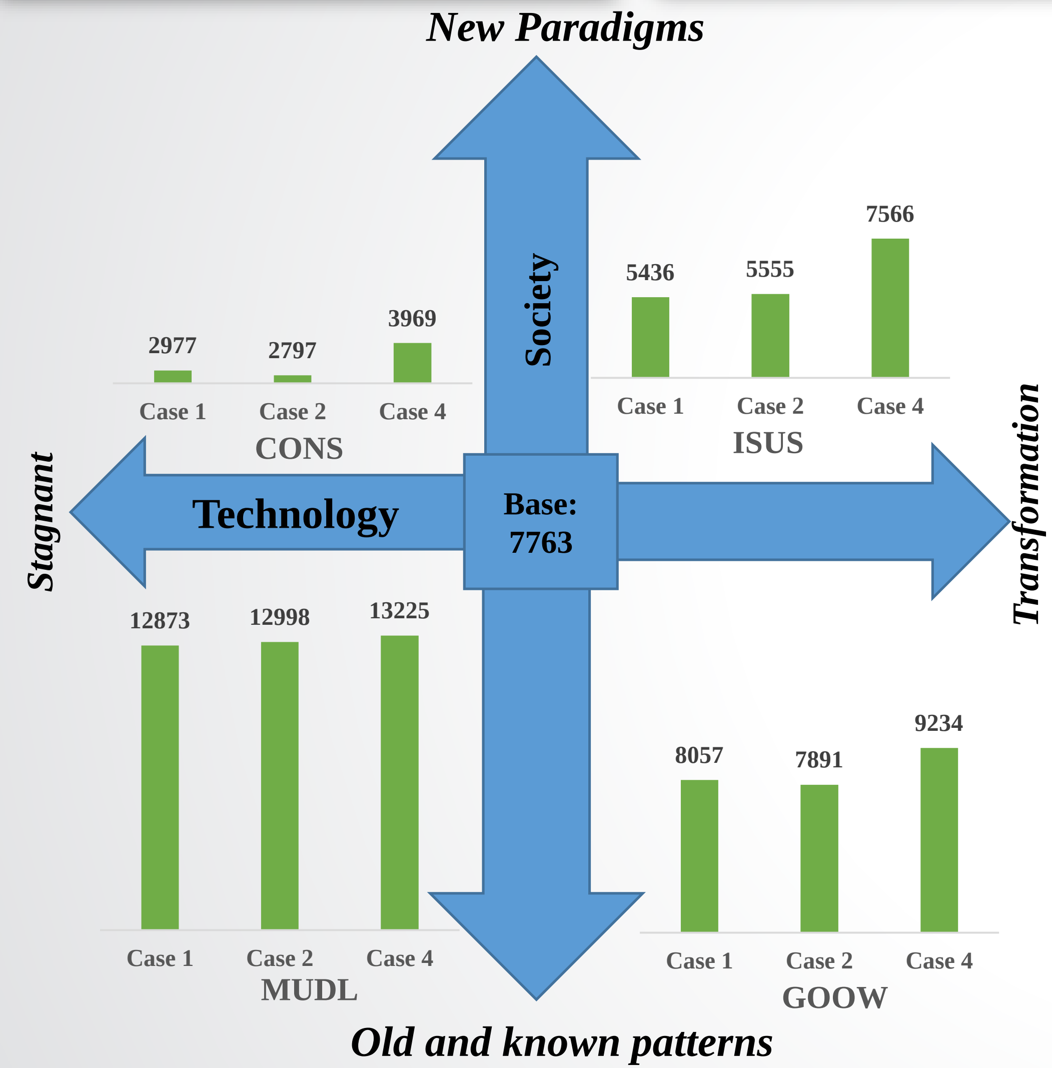
- Slight increase in coal based generation observed when there is an extension of coal plant life (case 1 vs. case 2) for CONServation and Go Our Own Way (GOOW) futures

- Absence of price spike in NG+Oil results in lower coal based electricity (case 1 vs. case 4) for all four futures

- Despite stagnant technology and no social trends in improving sustainability in the MUDdLing through future, electricity generation is found to depend more on NG than coal

- CONServation future has lower demand allowing it to use more coal-fired electricity

Results: NG-based electricity



NG-based electricity generation (PJ), 2045

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
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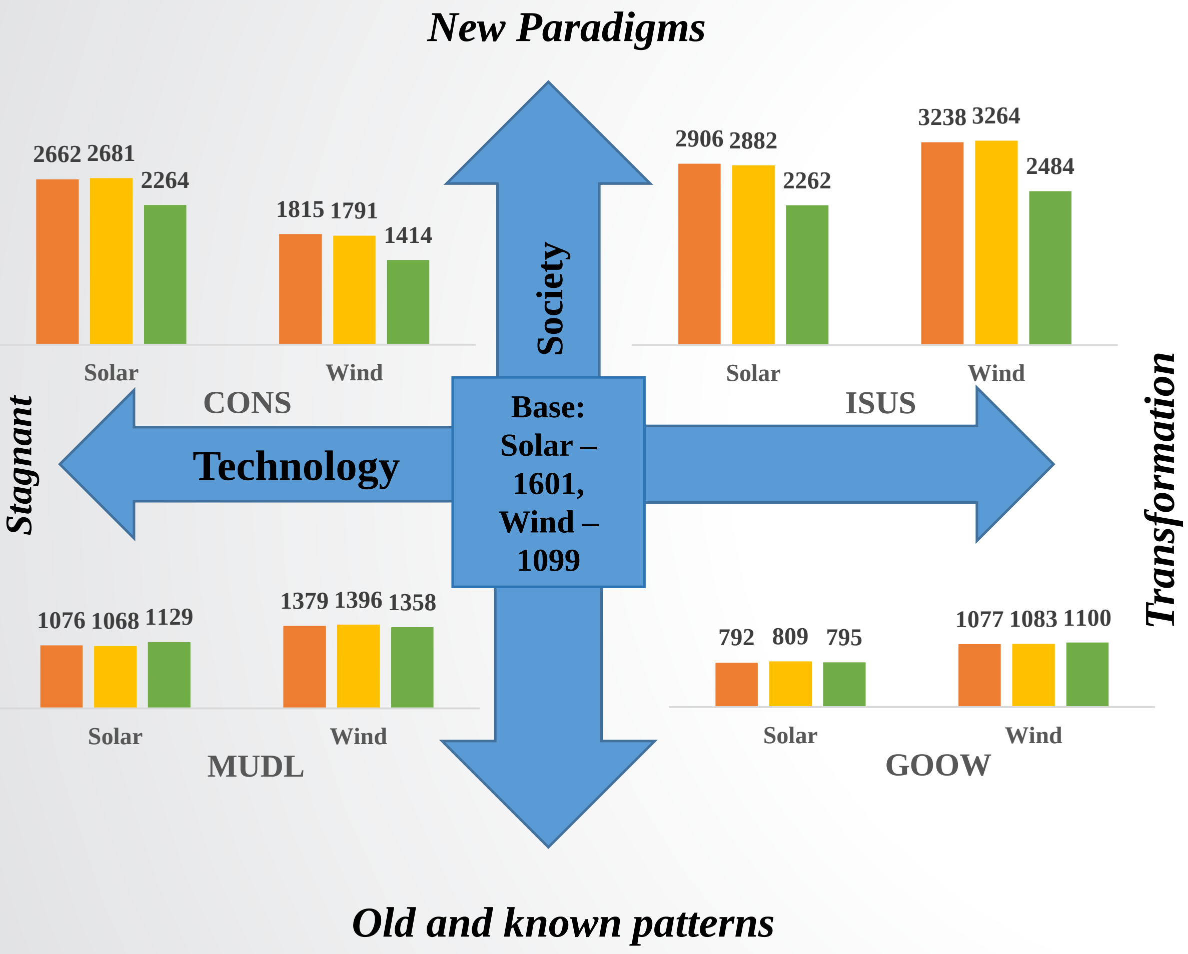
- For all four futures, absence of price spikes in NG results in increase in NG-based electricity generation (Case 1 vs. Case 4)
- For the Go Our Own Way (GOOW) and CONServation futures, there is a slight decrease in NG-based electricity for extension in coal plant lifetime (Case 2 vs. Case 1)
- MUDdLing through future demonstrates a ~45% increase in NG-based electricity relative to base case
- Go Our Own Way shows 3-14% increase in NG-based electricity relative to base, when there are no price spikes or early retirements of coal units.

Results: Renewable electricity



Renewable electricity generation (PJ), 2045

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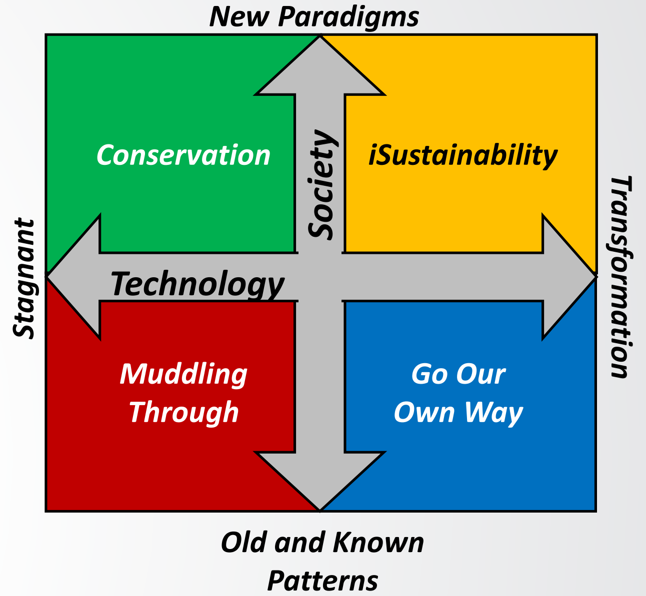
- Renewable electricity generation increased in ISUStainability and CONServation futures, for cases when there is a price spike in NG + Oil
- In both MUDdLing through and Go Our Own Way futures, renewable electricity generation is lower, and showed relatively lower sensitivity to price spikes and coal plant life extensions
- For all futures except for MuDdLing through, results indicated ~189 PJ geothermal electricity
- ~1100 PJ of hydo-electricity was observed across all four future scenarios

Results: Vehicle fuel mix

Billion Vehicle Miles Travelled by vehicle fuel type for Case 4, 2045

Energy Future	Year	Conventional gasoline - Internal Combustion Engine	Diesel-Internal Combustion Engine	Liquid Petroleum Gas	Electric Vehicle	Hybrid Gasoline and Electric Vehicles	85% Ethanol Fuel
ISUS	2045	26.2	31.6	0.0	1030.6	0.0	0.0
CONS	2045	26.2	31.6	0.0	0.0	0.0	2888.3
MUDL	2045	3295.5	40.7	0.0	0.0	460.8	210.0
GOOW	2045	30.0	36.2	0.0	0.0	2502.6	0.0
BASE	2045	3008.2	36.2	0.0	360.1	0.0	157.3
All futures	2005	2642.77	19.2	11.02	1.92	0	7.87



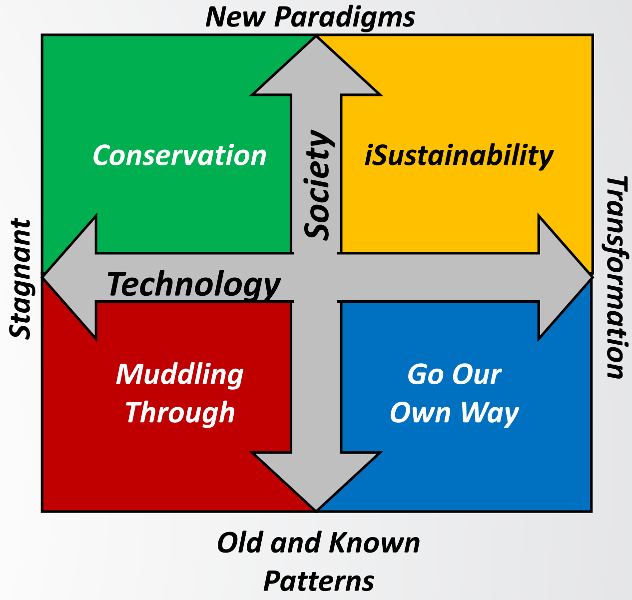
- 2005 is a calibration year in the MARKAL model so the vehicle fuel mix is the same across all futures including the base case
- NG+Oil Price spikes or coal plant extensions do not result in significant changes in the vehicle fuel mix for any given future, and hence are not presented here

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
4	11.7%	-	15%	60
BASE	2.3%	-	-	50

Results: Electricity Prices (normalized)

Electricity prices normalized by base scenario electricity prices		Average Price	Peak Price	LCOE
ISUS	Case 1	1.02	1.03	1.03
	Case 2	1.03	1.03	1.02
	Case 4	0.95	1.02	1.02
CONS	Case 1	1.17	0.96	1.01
	Case 2	1.17	1.01	1.01
	Case 4	1.09	0.85	1.02
MUDL	Case 1	1.00	0.71	1.15
	Case 2	1.01	0.71	1.14
	Case 4	0.98	0.66	1.18
GOOW	Case 1	1.31	1.50	1.35
	Case 2	1.29	1.51	1.34
	Case 4	1.22	1.36	1.34
Base Scenario		1	1	1

- Peak and LCOE values are lower in the absence of price spikes in domestic NG and oil (Case 4 vs. Case 1) for all four futures
- Go Our Own Way (GOOW) future showed the highest increase in electricity prices relative to the Base Scenario
- Despite decreased demand levels in the CONServation future, this is the second most expensive followed by ISUStainability and MUDdLing through futures



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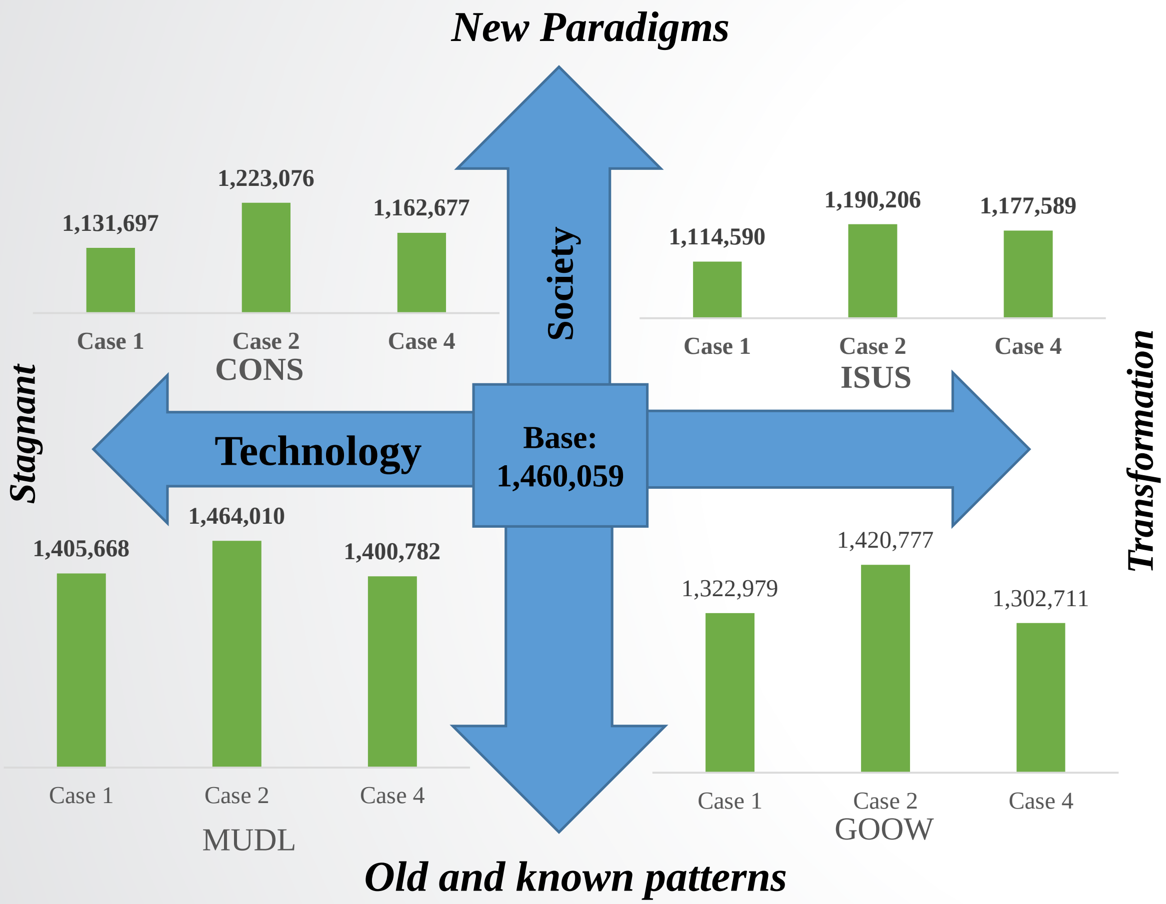
Results: Water consumption in electricity sector



Water consumption (million gallons), 2045

- Water consumption is the water lost to evaporation or other losses due to electric power generation not returned to original water body

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
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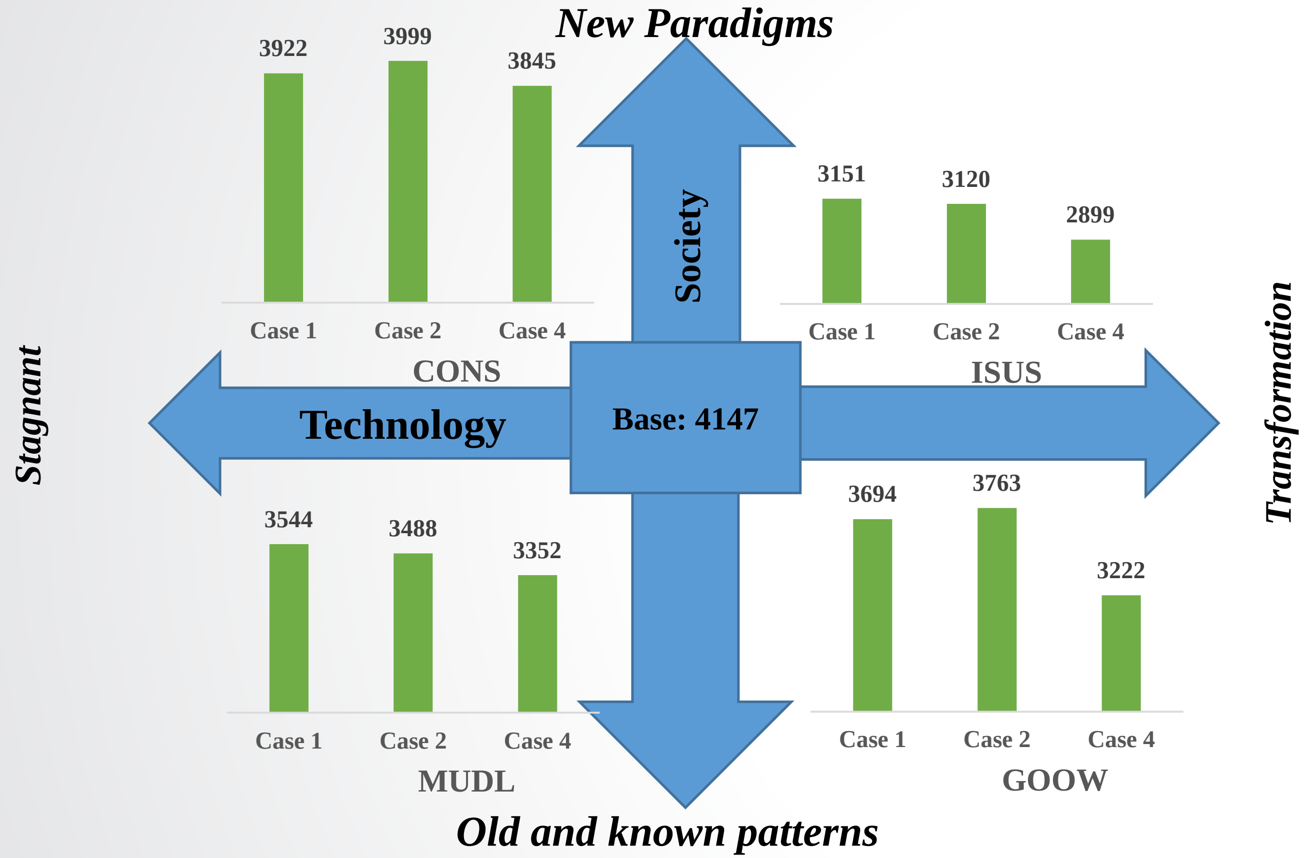
- Water consumption is found to increase with an extension of coal plant lifetime (Case 1 vs. Case 2) for all four energy futures
- The MUDdLing through and Go Our Own Way (GOOW) futures show higher water consumption levels due to higher dependence on conventional electricity generation
- Looking at the water withdrawal metric instead of water consumption may demonstrate slightly different trends of water use (back-up slide)
- Other factors such as thermal pollution of water may need to be considered to provide a comprehensive analysis of impacts of energy system uncertainty on water resources

Results: PM_{10} Emissions



PM_{10} emissions (kTonnes), 2045

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
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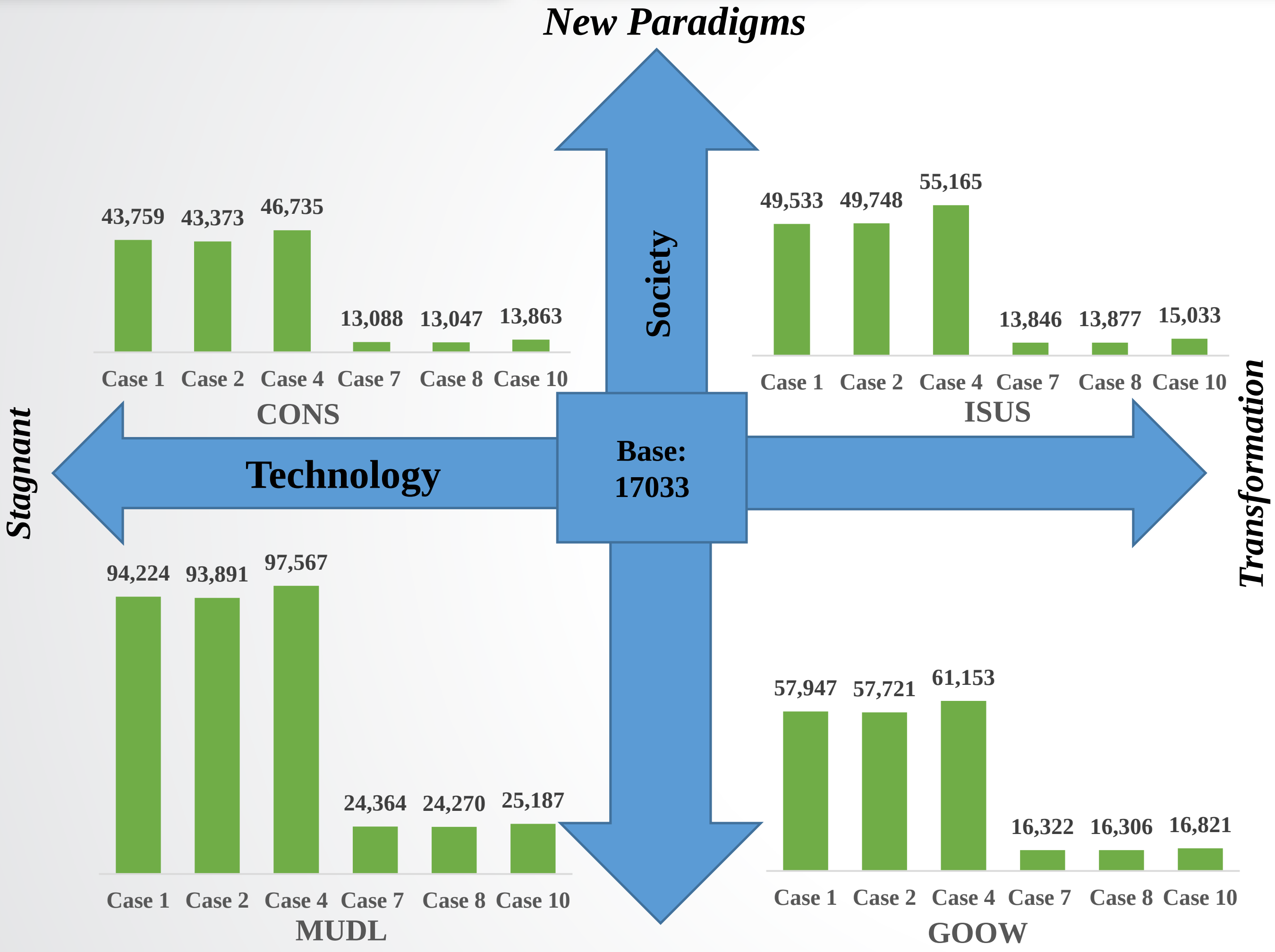
Base	2.3%	-	-	50

- PM_{10} emissions increased with coal plant life extensions for the CONServation and Go Our Own Way (GOOW) futures
- ISUStainability future with a high proportion of low carbon energy sources has the lowest PM_{10} emission rates
- The MUDdLing through, Go Our Own Way and CONServation futures show progressively higher emission rates

- PM_{10} emissions in all the four futures are lower than the base scenario

Results: CH_4 Emissions



CH_4 emissions (kTonnes), 2045

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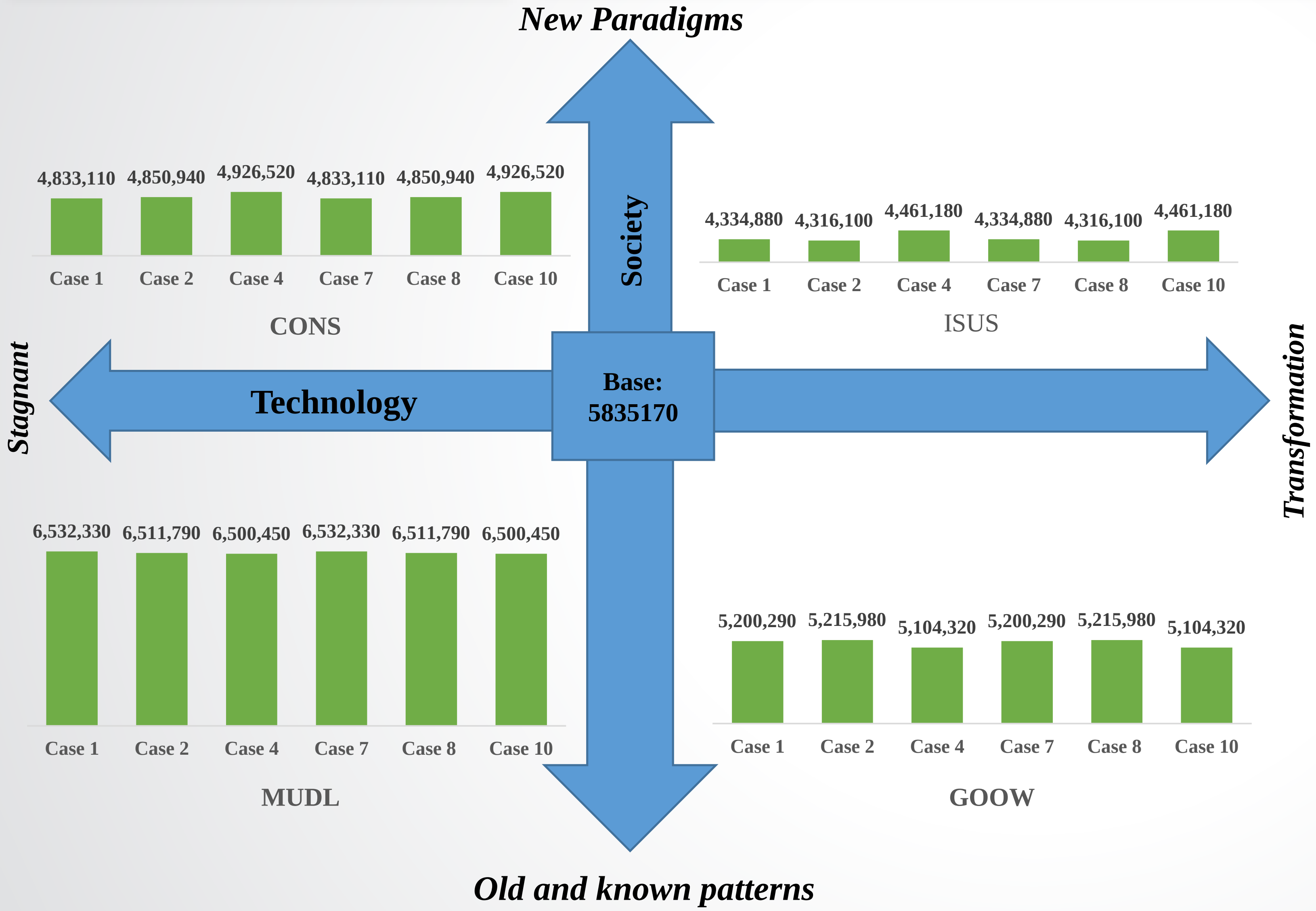
Base	2.3%	-	-	50

- The large difference in CH_4 emissions between Case 1 and Case 7 across all four energy futures is due to the CH_4 leakage rate assumption for NG-based electricity generation

- Absence of price spikes in NG results in an increase in CH_4 emissions – this increase is more noticeable for cases with high values of CH_4 leakage rate assumptions for NG-based electricity generation

Results: CO_2 Emissions



CO_2 emissions (kTonnes), 2045

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
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- CO_2 emissions are not impacted by methane leakage rate assumptions and these emissions are several orders of magnitude higher than methane
- System-wide Global Warming Potential (GWP) unaffected by methane leakage rate assumptions across cases in the same future

Summary of Results

- In addition to social paradigms and technological advancements, natural gas/oil price spikes and coal plant life extensions were found to be two major sources of additional uncertainty that could significantly impact:
  - Electric power generation mix
  - Electricity Prices
  - Water Consumption due to electric power generation
  - Emission levels

- Large system-wide CH_4 emission changes are observed by comparing cases with widely different CH_4 leakage rates from Natural Gas based electricity generation
  - However, the overall impact on the system-wide Global Warming Potential (GWP) is minimal since the magnitude of CH_4 emissions is several orders of magnitude lower than CO_2: a major contributor to system-wide GWP

- Change in Natural Gas exports at a national level are not found to be very impactful
  - Scenarios considering changes in regional export levels are currently being modeled as a next step

Next Steps

- Analysis for assessment of impacts of additional sources of uncertainty at a regional level
    - Apply the four energy future scenarios and additional sources of uncertainty to two given regions to compare and contrast the impacts at a regional scale
- Assess the resilience of the regional energy grid
    - Based on assessment of impacts of additional sources of uncertainty at a regional level
- Explore the applicability of system dynamic techniques to resilience studies based on the diverse regional energy infrastructure portfolios obtained from previous analysis

Disclaimer

The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

Questions?

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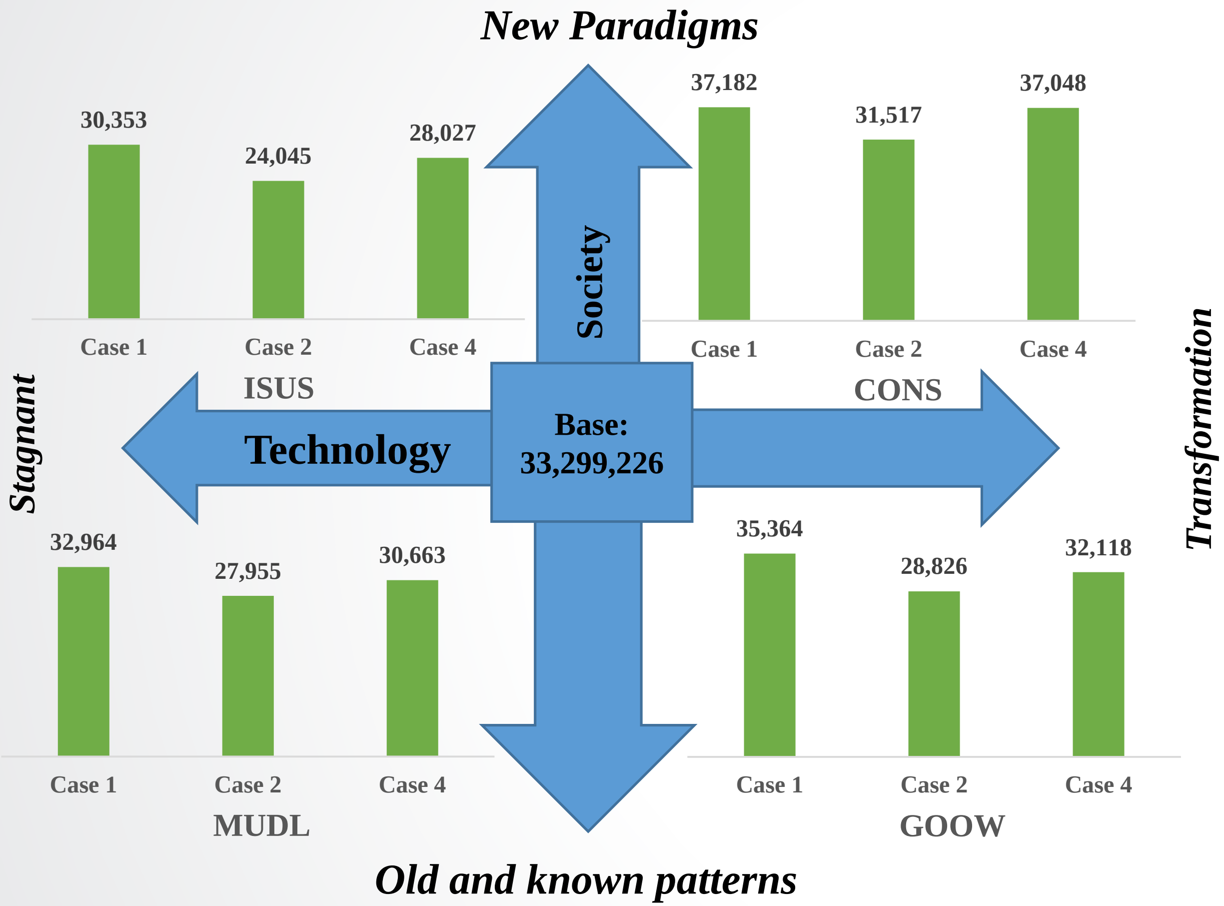
Backup slide: Water withdrawn in the electricity sector



Water withdrawn (billion gallons), 2045

MARKAL Case	% CH_4 emissions, NG-based electricity	% Price spike – NG and Oil	% NG exports	Coal plant life (years)
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- Water withdrawn is the water diverted from water bodies (such as rivers, lakes, reservoirs etc.) by electric power plants. Most of the withdrawn water is returned after being used for cooling purposes etc. by the power plant

- Graph indicates the difference in trends of water use among energy futures when considering different metrics: water consumption vs water withdrawn

(back)