ARIZONA TRANSPORTATION STUDY
TECHNICAL APPENDIX

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Prepared by:

Evolved Energy Research

Prepared for:

GridLab and WRA

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PROJECT GOALS

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- **Questions WRA is interested in to inform policy discussion in Arizona:**
  - What should be the transportation goals within the state moving forward?
  - How do energy rules within the power sector impact state investments?
- **Highlighted project outcomes:**
  - Numbers for vehicle stocks and sales across transportation subsectors under different scenarios and comparative costs between scenarios
  - How fast do vehicles sales shares need to ramp up for lowest cost outcomes? What needs to happen by 2030?
  - If action is not taken, how will this impact decarbonization costs?

PROJECT SETUP

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- **Determine the impacts of various transportation electrification strategies on pathway to achieving carbon reductions in line with IPCC**
  - Currently no emissions target in Arizona, however most realistic target over a 30-year time frame is to align with IPCC and many other states in the West
  - We designed a set of 6 scenarios that best achieves this
    - Range of assumptions about actions taken in transportation to transition away from internal combustion
- **While all scenarios achieve emissions goals, the differences between them are instructive**
  - What are the differences in investments across sectors of the economy?
  - What size of clean fuels market will be required in AZ?
  - What are the relative costs of different strategies, and which is most favorable?

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KEY STUDY FINDINGS

THE TRANSPORTATION SECTOR

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- **Transitioning away from ICE vehicles is imperative to lowering energy costs**
  - Taking no action to transition vehicles to EVs and FCVs is $10b/yr in 2040 and $14b/yr in 2050 more expensive than when vehicle stocks transition fully to EVs and FCVs by 2050
  - Assumes a net zero emissions target by 2050
- **Rapid action to promote vehicle electrification is key to cost containment**
- **However, pushing too hard too soon has negligible economic benefits, and several potential challenges**
  - Potential challenges with equity between customer groups and limited policy options when meeting a 2030 100% EV sales target
  - Accelerating infrastructure requirements to establish charging networks to support larger EV stocks earlier may be challenging

THE TRANSPORTATION SECTOR (CONT.)

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- **Balance economic benefits and feasibility/achievability**
  - Electric light duty vehicle sales of 100% by 2035, and 100% clean vehicle sales in heavy duty vehicles by 2040 is a cost effective and more achievable middle ground with negligible cost difference to moving faster
  - Longer runway to establish charging infrastructure
  - Better vehicle economics in future years may require lighter policy interventions to achieve target sales outcomes
- **Delaying action has economic repercussions**
  - Delaying sales in light duty EVs past 2035 results in greater 2050 transport fuel demands because of the assumed 15-year lifetime of a vehicle. Remaining transport fuels in 2050 under a net zero emissions policy drives costs higher
  - Delaying 100% sales targets for clean vehicles to 2050 increases costs by $3b/yr in 2040 and $1b/yr in 2050 over the balanced case described above

TRANSPORTATION SECTOR SALES TARGETS

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- **The following vehicle sales assumptions strike the balance between economics and feasibility/achievability**

Vehicle Category	Sales Target
Transportation: Light-Duty Vehicles	100% electric sales by 2035
Transportation: Medium-Duty Vehicles	100% electric sales by 2040
Transportation: Heavy-Duty Vehicles	HDV short-haul: 100% electric sales by 2040 HDV long-haul: 50% electric, 50% hydrogen sales by 2040 Buses 100% electric sales by 2030

- **However, achieving earlier transition of medium and heavy-duty vehicles than 100% clean sales by 2040 may be desirable if feasibility/achievability issues are not a problem**

ELECTRICITY SECTOR EMISSIONS

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- **Rapid decarbonization of electricity key to reaching net zero economically**
  - **Emissions reductions of 78 – 91% by 2035 and 100% by 2050, depending on the scenario**
  - The study incorporated carbon emissions reductions of 50% by 2032 and 80% by 2050 in electricity below a 2016-2018 emissions baseline. However, the economics of meeting an economy wide emissions target drives electricity emissions reductions faster than this in all scenarios
- **66% of these emissions reductions from the baseline are achieved by 2050 from retirement of coal generation**
  - However, the study assumes 2.9 GW of coal in 2030 and 600 MW in 2035 are still operating as baseload. Gas generation must be reduced to meet economy-wide GHG targets
  - If possible, retiring coal earlier would be lower cost

ELECTRICITY SECTOR INVESTMENTS

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- **Investments reach 4.5x today's generating capacity to serve 2.3x the load, including increasing exports to the rest of the West and new electrolysis loads for fuels production**
  - Electrolysis better utilizes solar resource and produces H_2 for new vehicle hydrogen demand and clean fuels production
- **Arizona takes advantage of some of the best solar available in the US**
  - Rapid development of the solar fleet from 2030 through 2050, reaching 78 GW by 2050 in the most favorable vehicle policy scenario
- **Concurrent investment in electricity storage, reaching 35 GW by 2050**
- **Expansion of transmission to California from 3 GW to 9 GW by 2050**
  - Study capped new transmission at 6 GW. More would likely be selected without the cap
- **Challenges to achieving pace and scale of electricity sector expansion**
  - Will require detailed planning to implement

HOW DOES TRANSPORT POLICY IMPACT ELECTRICITY?

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- Electricity sector investment/operational differences across scenarios depend on two factors:
  - The pace of transition to clean vehicles on the demand side
  - Electricity policy on the supply side
- Scenarios that do not transition or transition more slowly to clean vehicles require a cleaner electricity sector earlier
  - **When no transition occurs, and liquid fuels continue to be used at close to today's levels in transportation, emissions reductions are most cheaply achieved by decarbonizing electricity faster**
  - **Similarly, delays in transition also drive greater electricity emissions reductions to compensate for retaining transport fuels**

Percent Electricity Emissions Reduction by Scenario over 2016-2018 Baseline	2020	2025	2030	2035	2040	2045	2050
Balanced transport policy (Clean Car and Truck)	13%	33%	55%	78%	84%	96%	99%
No action to transition transport (No Transport Action)	13%	36%	60%	91%	99%	100%	100%
Delayed transition to clean vehicles (Delayed Action)	13%	35%	59%	88%	97%	99%	99%

WHAT IS THE IMPACT OF ELECTRICITY POLICY?

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- The study also looked at more stringent electricity policy, including:
  - A 100% clean energy standard (CES) by 2040, applied to Arizona retail sales
  - A 100% CES and a requirement for all pipeline gas (including to non-electricity end uses) to be clean by 2040
- **A 100% CES by 2040 has no impact on costs**
  - As a large electricity exporter by 2040, Arizona substitutes exported renewables for gas in this case to meet retail load clean energy requirements. Gas continues to be burned and exported to regions without a 2040 CES
  - Economy wide emissions policy applied to emissions within AZ borders regardless of destination. Arizona has leeway under the emissions cap to continue to export gas
- **A 100% CES by 2040 with economy wide clean gas costs ~$1b/yr extra from 2040 to 2050**
  - Low gas demands across the economy from electrification limit the quantity of clean gas needed to meet this requirement
  - Emissions drop significantly, and well below the emissions policy cap in 2040, as Arizona is no longer able to export gas generation out of state

WHAT NEEDS TO HAPPEN BY 2030?

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- **Action is needed soon to achieve balanced vehicle sales outcomes in the future**
  - Lower energy consumption from cleaner vehicle fleets have benefits in all years going forward
  - Charging infrastructure is needed to support large electric vehicle fleets in the future
- **Investments in charging infrastructure is prudent not just in response to emissions policy now, but to the potential for policy in the future**
  - Stock rollover of vehicles and construction of charging networks/distribution system investments take time
  - Delay too long, and Arizona could run out of runway to avoid high decarbonization costs in the future
  - Required to build customer confidence in EVs
- **Electricity sector planning for long-term future growth is necessary to ensure successful transition**
  - Pace and scale will require grid and land use planning and coordination early
  - Long lead time assets like transmission may need lead times up to 10 years in advance to construct
  - Early feasibility studies will give Arizona a better picture of the challenges and give enough time to find solutions

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CLEAN ELECTRICITY AND ECONOMY-WIDE EMISSIONS TARGETS

SUMMARY OF ELECTRICITY AND EMISSIONS POLICY

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- The study examines the impact of varying adoption of EV and fuel cell vehicles under different electricity and emissions policy
- Clean electricity policy examined includes:
  - AZ clean electricity policy of 100% clean electricity by 2070, 50% reduction in carbon emissions by 2032, 80% reduction in carbon emissions by 2050
  - Accelerated policy achieving 100% clean electricity by 2040
- Economy-wide emissions policy is constant between all scenarios, representing action taken by 2050 in line with IPCC goals
  - 40% below 2016-2018 baseline levels by 2030, 100% below 2016-2018 baseline levels by 2050

ELECTRICITY TARGETS

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- Targets relative to 2016-2018 baseline:
  - 100% clean electricity by 2070
  - 50% reduction in carbon emissions by 2032
  - 80% reduction in carbon emissions by 2050

Year	Emissions (MMT)
2016-2018 Baseline	45.1
2032	22.5
2050	9.0
2070	0

- Implementation – translation to CES
  - Assume that coal emissions contribution at capacity factors provided by WRA
  - Assume remaining fossil emissions in electricity are from gas
- Baseline from EIA fossil emissions for electricity sector

COAL IMPLEMENTATION

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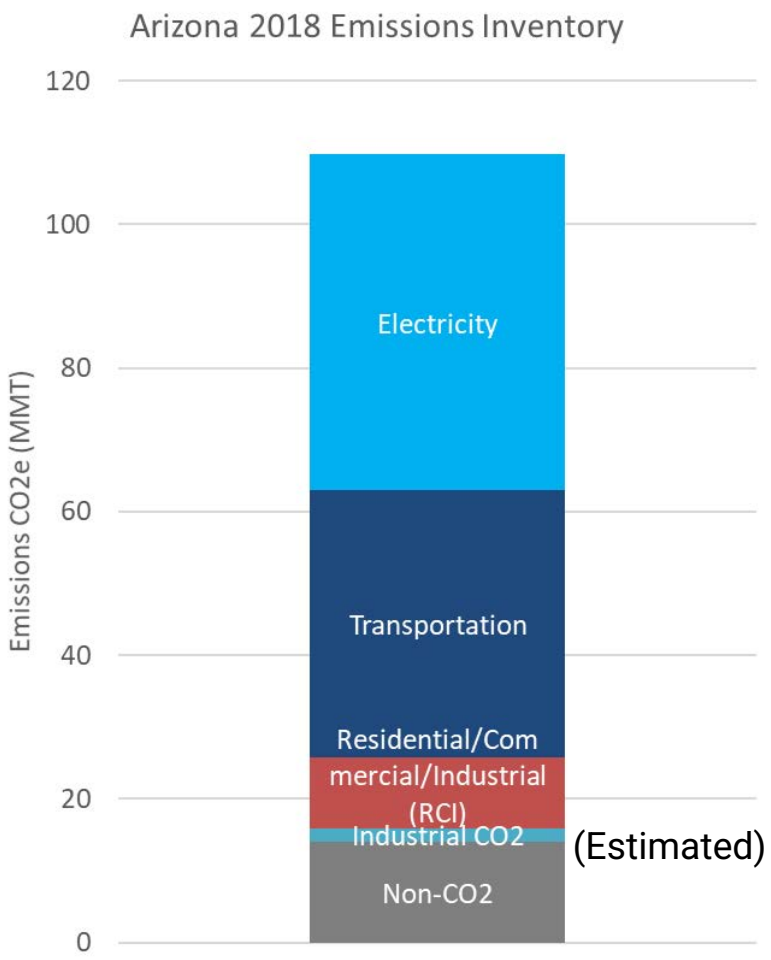
- The Project Team determined that near-term coal retirements or reductions in capacity factor were unrealistic
- Coal generators must stay online through their retirement dates in the model implementation, simulating near-term continued reliance on coal
- Minimum capacity factor from coal generation in Arizona set to ensure that coal remains baseload through to retirement
- For AZ owned shares of generators outside of AZ, these assumptions are also applied

Plant	Utility	Size (MW)	Utility's Share (MW)	Location
Apache 3	AEPCO	204	204	Cochise, AZ
Cholla 1	APS	113.6	113.6	Joseph City, AZ
Cholla 3	APS	312.3	312.3	Joseph City, AZ
Coronado	SRP	773	773	St. John, AZ
Craig 1	SRP	428	124	Craig, CO
Craig 2	SRP	428	124	Craig, CO
Four Corners 4 & 5	SRP/APS/TEP	1490	1296.3	Fruitland, NM
Hayden 2	SRP	262	131	Hayden, CO
San Juan	TEP	369	184.5	Waterflow, NM
Springerville 1	TEP	380	380	Springerville, AZ
Springerville 2	TEP	380	380	Springerville, AZ
Springerville 3	Tri-State	400	400	Springerville, AZ
Springerville 4	SRP	415	415	Springerville, AZ

ECONOMY-WIDE EMISSIONS TARGETS

- Targets:
  - 40% below 2016-2018 baseline by 2030
  - Net zero by 2050
- No state-wide AZ GHG emissions inventory
  - Using energy emissions from all sectors from EIA for baseline
  - Assume that non-energy emissions are offset by non-energy related emissions reductions action
    - E.g. increased land sink
  - Therefore, target 40% below 2016-2018 by 2030 and net zero by 2050 in energy emissions



AZ ENERGY AND INDUSTRY EMISSIONS ACCOUNTING

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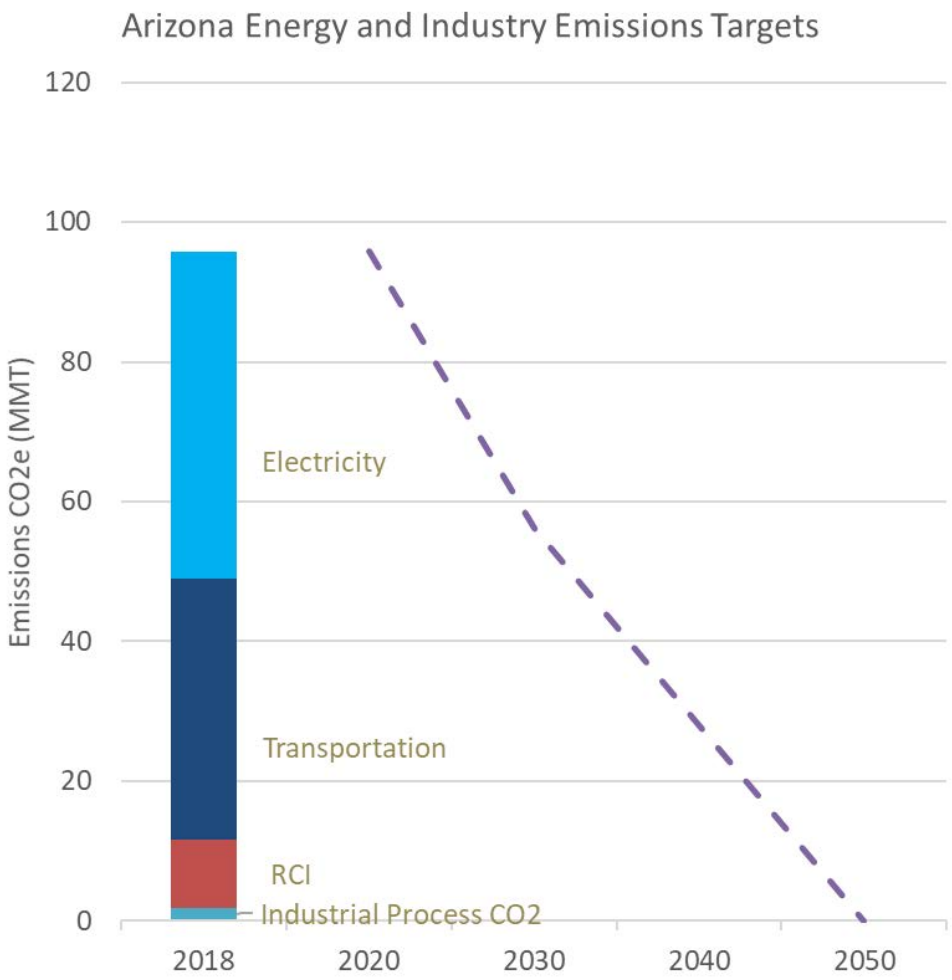
- Assuming all non-energy emissions reductions are attained with non-energy measures
- 40% and 100% targets applied to adjusted EIA 2016-2018 baseline
  - Adjustment includes cement and iron and steel emissions estimate

Year	Percent	Target MMT	Policy
2016-2018	Baseline	93.5	Adjusted to include emissions from cement and iron and steel
2030	40%	56.1	40% emissions reductions below 2016-2018 baseline by 2030
2050	100%	0	100% emissions reductions below baseline by 2050



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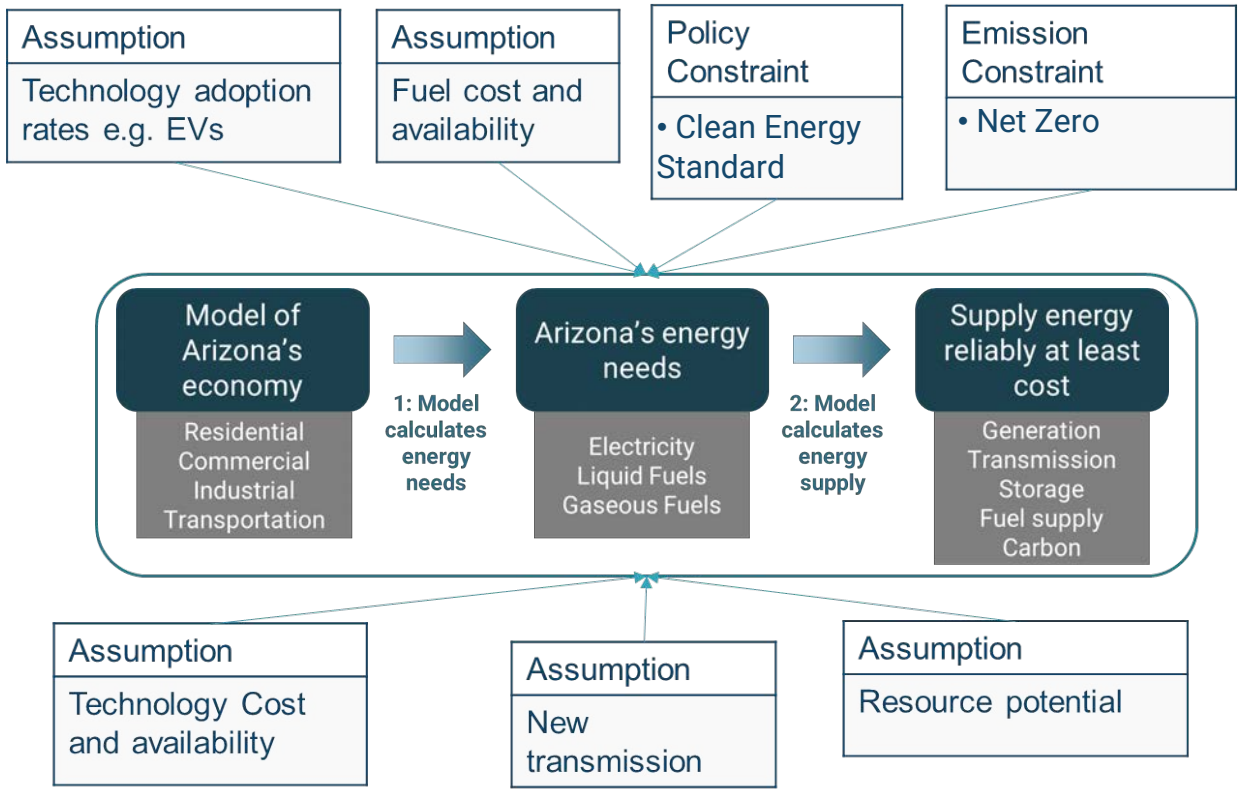
SCENARIO DEFINITIONS

SCENARIO DESIGN



- Determine the impacts of various transportation clean vehicle strategies and electricity policies on the pathway to achieving net zero carbon emissions
- Understanding the tradeoffs
  - How much does one pathway cost versus another?
    - Counterpoint for policymakers and stakeholders
  - Provides a target for near-term policy and action design
- Across 6 scenarios, what sets of assumptions/policies/constraints best capture the different futures we wish to investigate?

SCENARIO DESCRIPTIONS

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Scenario	Summary	Key Question
No Transportation Action	Investigates the challenge of meeting net zero emissions by 2050 if no action were taken to transition the vehicle fleet to EVs/FCVs. Conservative bookend using AEO Reference Case vehicle stocks through 2050	What is the cost of taking no action to transition vehicle stocks to electric and fuel cell?
Maximum Feasible Adoption Rate	Investigates the opposite bookend to No Transportation Action: Maximum feasible adoption rates of EVs/FCVs, representing aggressive action taken to transition vehicle stocks	What investments are needed and how much would it cost to meet net zero emissions with rapid electrification of the vehicle fleet? Note this determines only physical infrastructure costs, and not the potential distributional impacts of policy to achieve rapid transition
Clean Car and Truck	Investigates vehicle transition policy in line with California Air Resources Board (CARB) vehicle sales targets.	What is the cost of achieving net zero when adopting CARB policy?
Delayed Action	Investigates the challenge of achieving net zero emissions by 2050 when EVs and FCVs are adopted more slowly than in the Clean Car and Truck scenario	How are decarbonization costs impacted by slower policy or unforeseen challenges that prevent faster adoption on EVs and FCVs?
2040 CES	Investigates the challenge of achieving net zero emissions by 2050 and 100% CES by 2040	What investments are needed and how much would it cost to reach a more stringent 100% CES on retail sales by 2040 target?
2040 CES + Clean Gas	Investigates the impact of restricting pipeline gas to coming from only clean sources in 2040 and beyond	How costly is it to achieve a 100% CES in 2040 and restrict pipeline gas to only clean alternatives?

SCENARIO ASSUMPTIONS

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Scenario Assumptions	1. No Transportation Action	2. Maximum Feasible EV Adoption Rate	3. Clean Car and Truck	4. Delayed Action	5. 2040 CES	6. 2040 CES + Clean Gas
Clean Electricity Policy	100% clean electricity by 2070, 50% reduction in carbon emissions by 2032, 80% reduction in carbon emissions by 2050 below an emissions baseline averaging 2016-2018 emissions				100% clean by 2040 80% clean by 2030	Same as 1,2,3,4
Economy-Wide GHG Policy	40% below 2016-2018 baseline levels by 2030, 100% below 2016-2018 baseline levels by 2050					
Clean Resource Qualification	Constrained only by transmission limits (clean energy can be imported from out of state if cost effective)					
Buildings: Electrification	Fully electrified appliance sales by 2035					
Buildings: Energy Efficiency	Sales of high efficiency tech: 100% in 2035					
Transportation: Light-Duty Vehicles	AEO Reference Forecast	100% electric sales by 2030, 50% by 2025	100% electric sales by 2035	Slower transition, 15-year delay to full electric sales by 2050	Same as 3	
Transportation: Medium-Duty Vehicles	AEO Reference Forecast	100% electric sales by 2035	100% electric sales by 2040	Slower transition, 10-year delay to full electric sales by 2050	Same as 3	
Transportation: Heavy-Duty Vehicles	AEO Reference Forecast	HDV short-haul: 100% electric sales by 2035 HDV long-haul: 50% electric by 2035, 50% hydrogen sales by 2035	HDV short-haul: 100% electric sales by 2040 HDV long-haul: 50% electric, 50% hydrogen sales by 2040 Buses 100% electric sales by 2030	HDV short-haul: 100% electric sales by 2050 HDV long-haul: 50% electric, 50% hydrogen sales by 2050	Same as 3	
Industry	Generic efficiency improvements over Reference of 1% a year; fuel switching measures; 80% decrease in refining and mining to reflect reduced demand					
Resource Availability	NREL resource potential; 6 GW of additional transmission potential per path; 2x REEDS Tx Costs; SMRs not permitted.					
Fuels	AEO Reference fuel prices; no sequestration potential (NETL Injection Potential Study); clean fuels have zero emissions associated with them, so sequestration credit is left in state of origin					Same as 5, but clean gas required by 2040

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DEMAND SIDE RESULTS

DEMAND SIDE SCENARIOS

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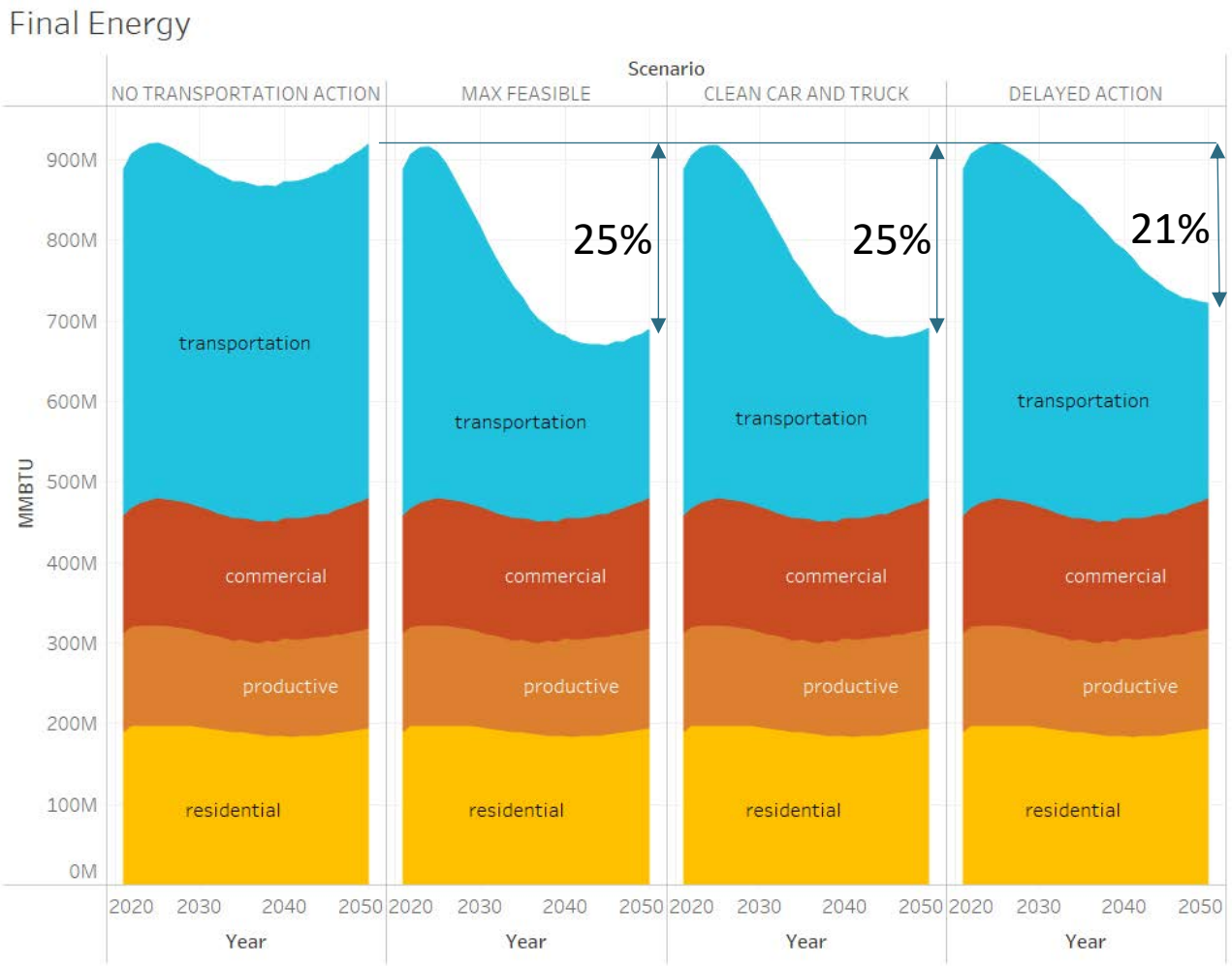
- Differences between scenarios on the demand side are designed to investigate differences in transportation policy or uncertainty in vehicle adoptions over time
  - Four unique demand side scenarios
    - No Transportation Action
    - Max Feasible
    - Clean Car and Truck
    - Sales Delay
  - The remaining scenarios share the same demand side assumptions as the Clean Car and Truck scenario
- Demand side assumptions in other sectors are held constant across scenarios

DEMAND SIDE EVOLUTION – FINAL ENERGY

- Max Feasible and Clean Car and Truck scenarios have 25% less final energy demand in 2050
  - Increase in electrification but decrease in overall energy requirement
  - 25% reduction from peak final energy demand occurring in 2023
- Sales Delay reaches 21% reduction by 2050 with significantly higher energy use in interim years



DEMAND SIDE EVOLUTION – FINAL ENERGY

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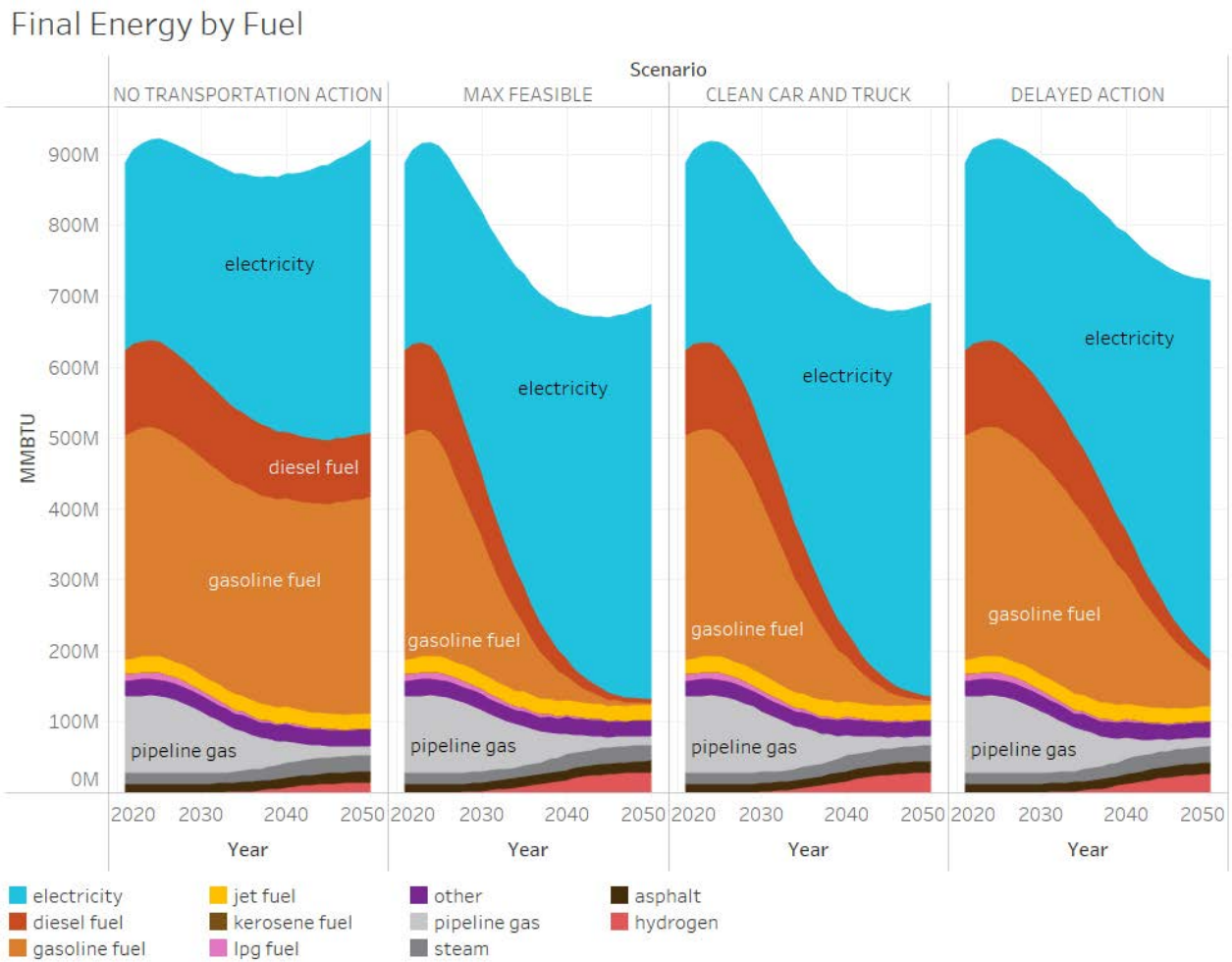
- Electricity growth displacing primary fuel use in the economy
  - Greater efficiency of electric vehicles and appliances
- Differences in rate and volume of displacement between cases
- Evolution of pipeline gas and non transport fuels constant between cases
- Electricity growth by 2050 over 2021 levels by scenario:
  - 55% in No Transportation Action
  - 110% in Max Feasible and Clean Car and Truck
  - 102% in Sales Delay



VARYING TRANSPORTATION SECTOR ASSUMPTIONS

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- Demand side scenarios vary by transportation sector sales share assumption, as detailed in the previous section
- These sales share assumptions are inputs to a stock rollover model that represents the stocks of demand side equipment across the economy, including light, medium, and heavy-duty vehicles
  - Vehicles have assumed lifetimes based on the literature and are replaced when they come to the end of their useful life
  - The stock of light duty vehicles, for example, becomes almost fully electric 15 years after a policy of 100% EV sales is adopted based on a 15-year lifetime assumption
  - Cost and efficiency varies by vehicle vintage based on forecasted improvements in technology
- **The following slides show the evolution of vehicle sales share, stocks, and energy demand over time in each scenario**

LIGHT DUTY VEHICLE SALES, STOCK, ENERGY

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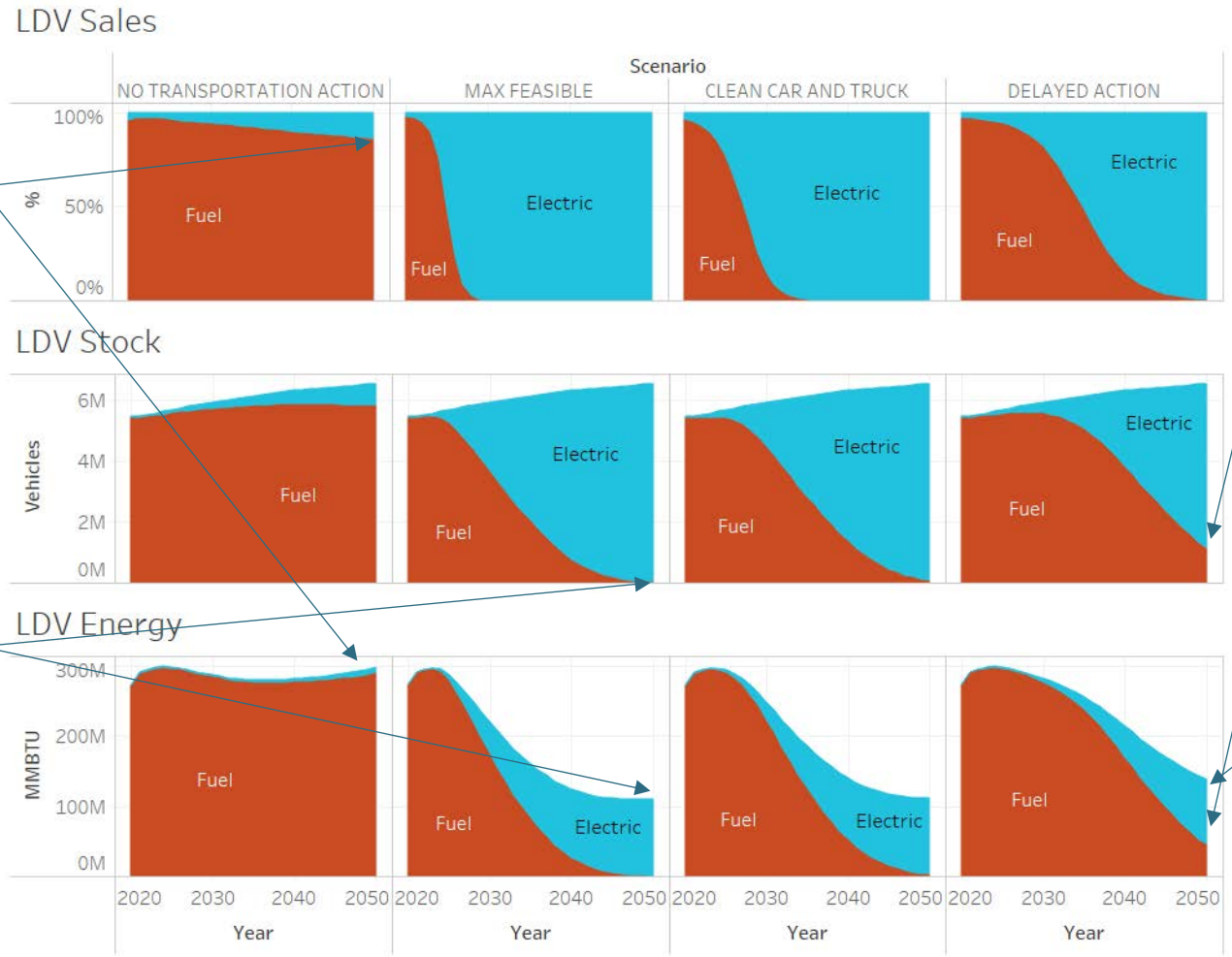
Conservative sales of EVs in AEO Reference Case (14% by 2050) leads to similar energy demand to today in 2050

Max Feasible and Clean Car and Truck scenarios reach ~100% EV stock by 2050 resulting in ~62% reduction in energy demand



15% of vehicle stocks remain ICEs in the Sales Delay scenario by 2050

33% of energy demand is gasoline in 2050

Overall 53% reduction in energy demand versus No Transportation Action

LDV AUTOS & TRUCKS SALES, STOCK, ENERGY

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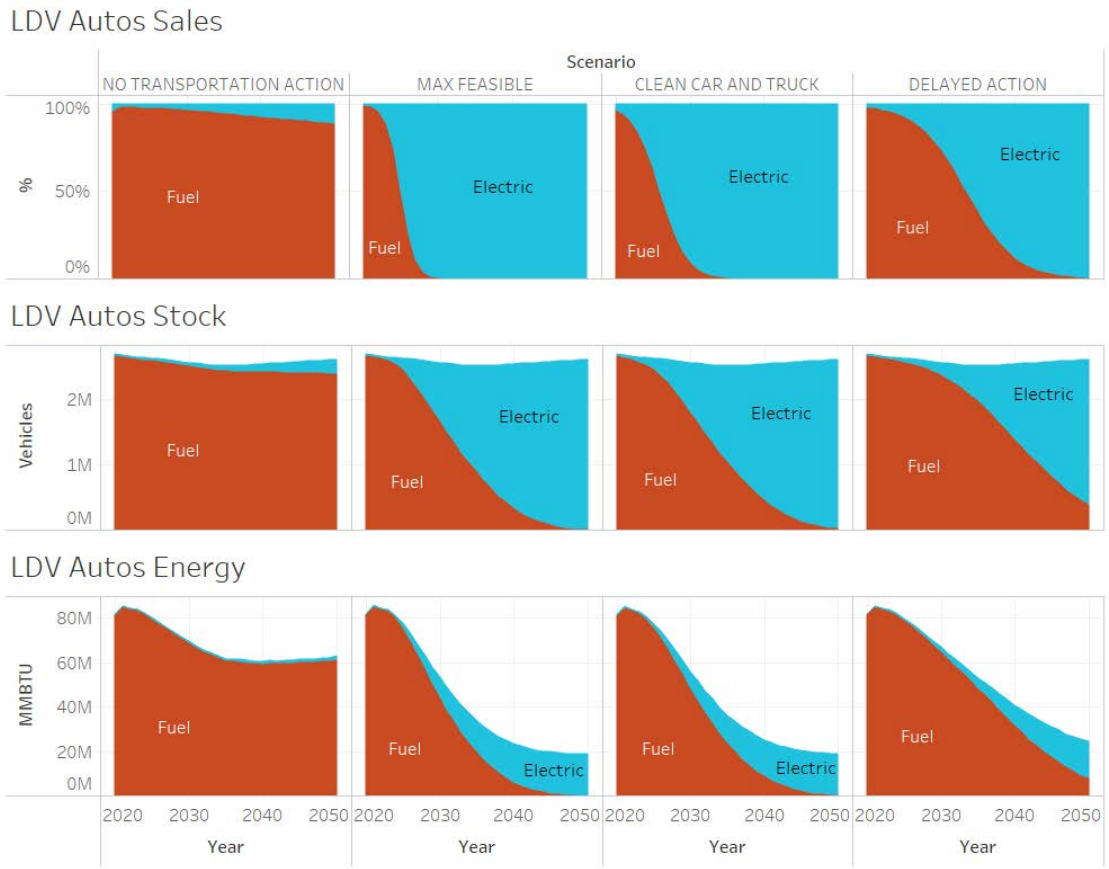
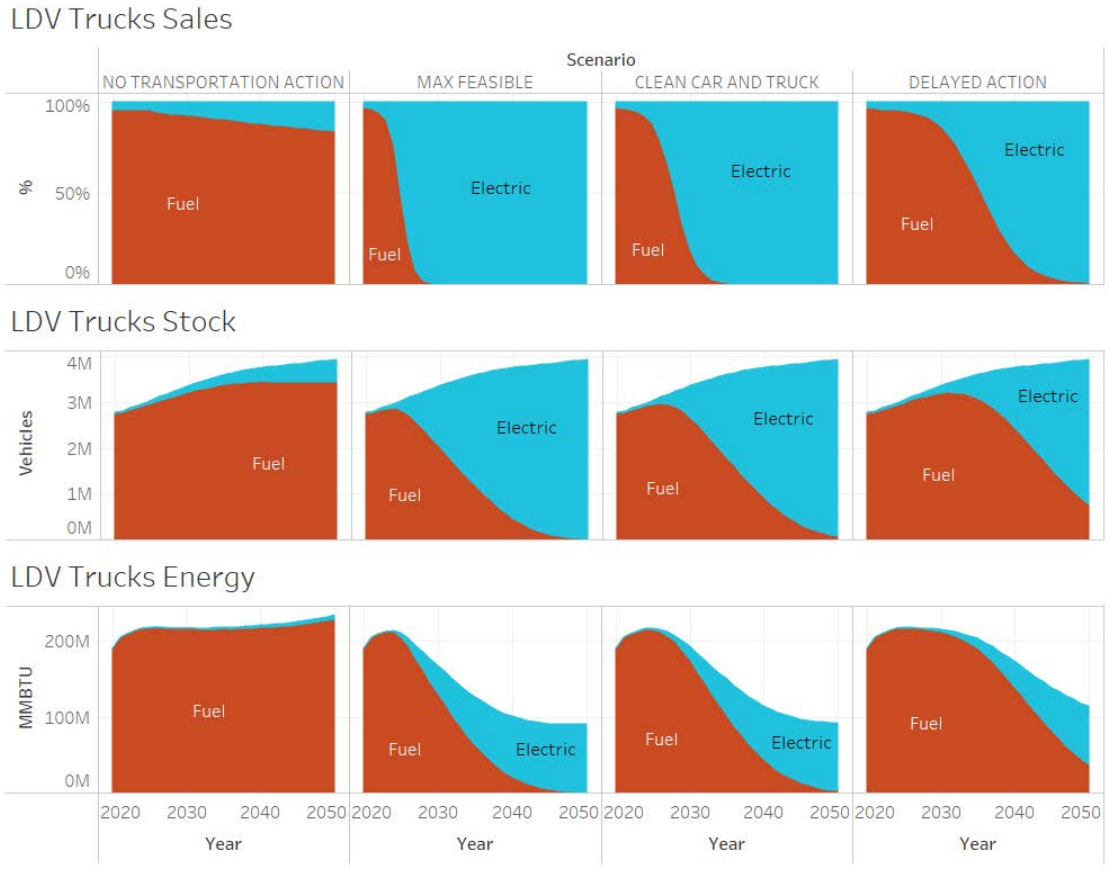
Decomposing LDVs into autos and trucks, auto stocks stagnate while truck stocks grow. The percentage share of energy demand in LDVs from trucks grows over time, as the overall demand from LDVs drops significantly





MEDIUM DUTY VEHICLE SALES, STOCK, ENERGY

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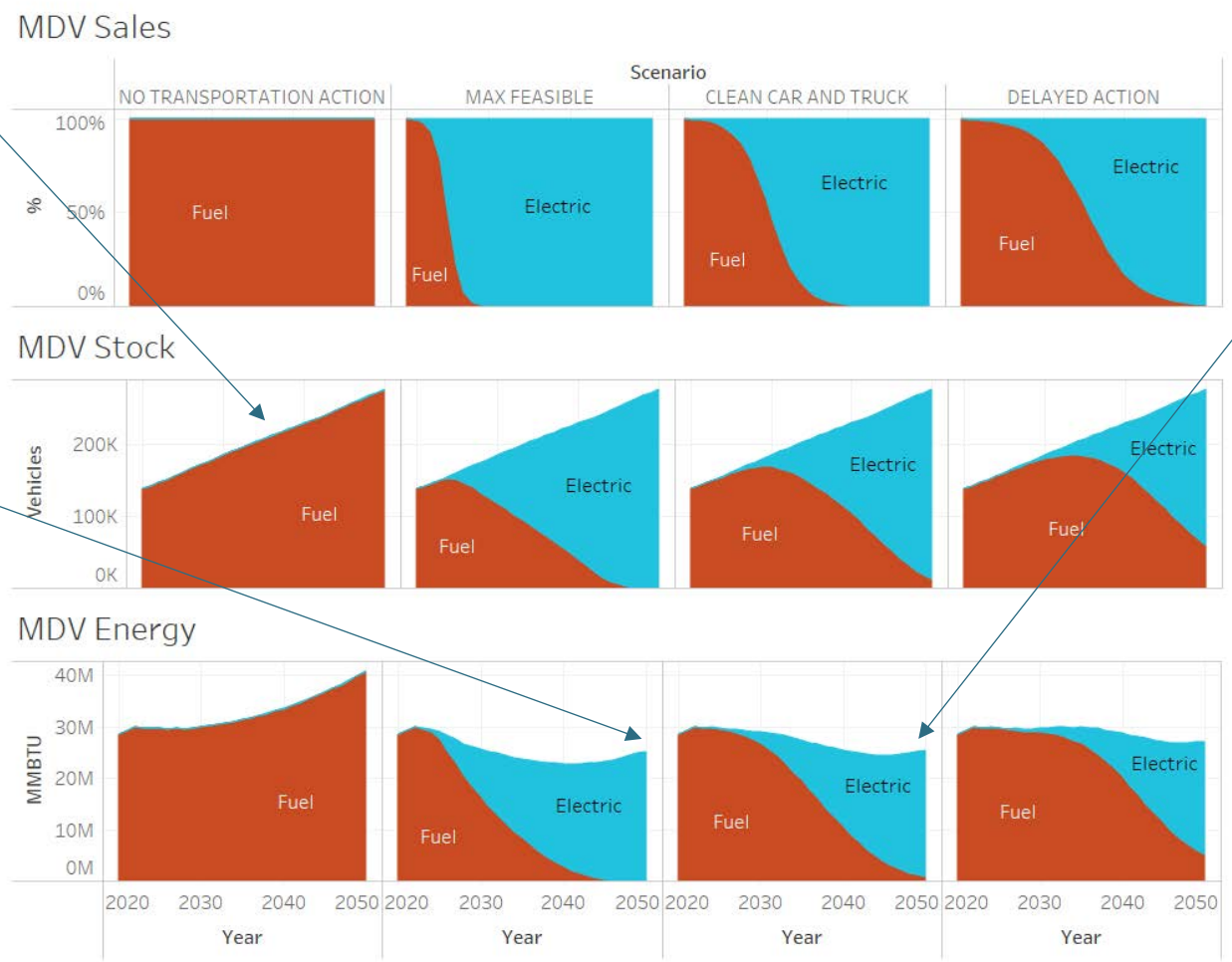
Rapid growth of the medium duty vehicle sector in AEO forecast

100% stock of EVs in Max Feasible Scenario results in 38% reduction in energy use over No Transportation Action



38% reduction and 34% reduction in energy use over No Transportation Action scenario in Clean Car and Truck and Sales Delay scenarios, respectively

HEAVY DUTY LONG-HAUL VEHICLE SALES, STOCK, ENERGY

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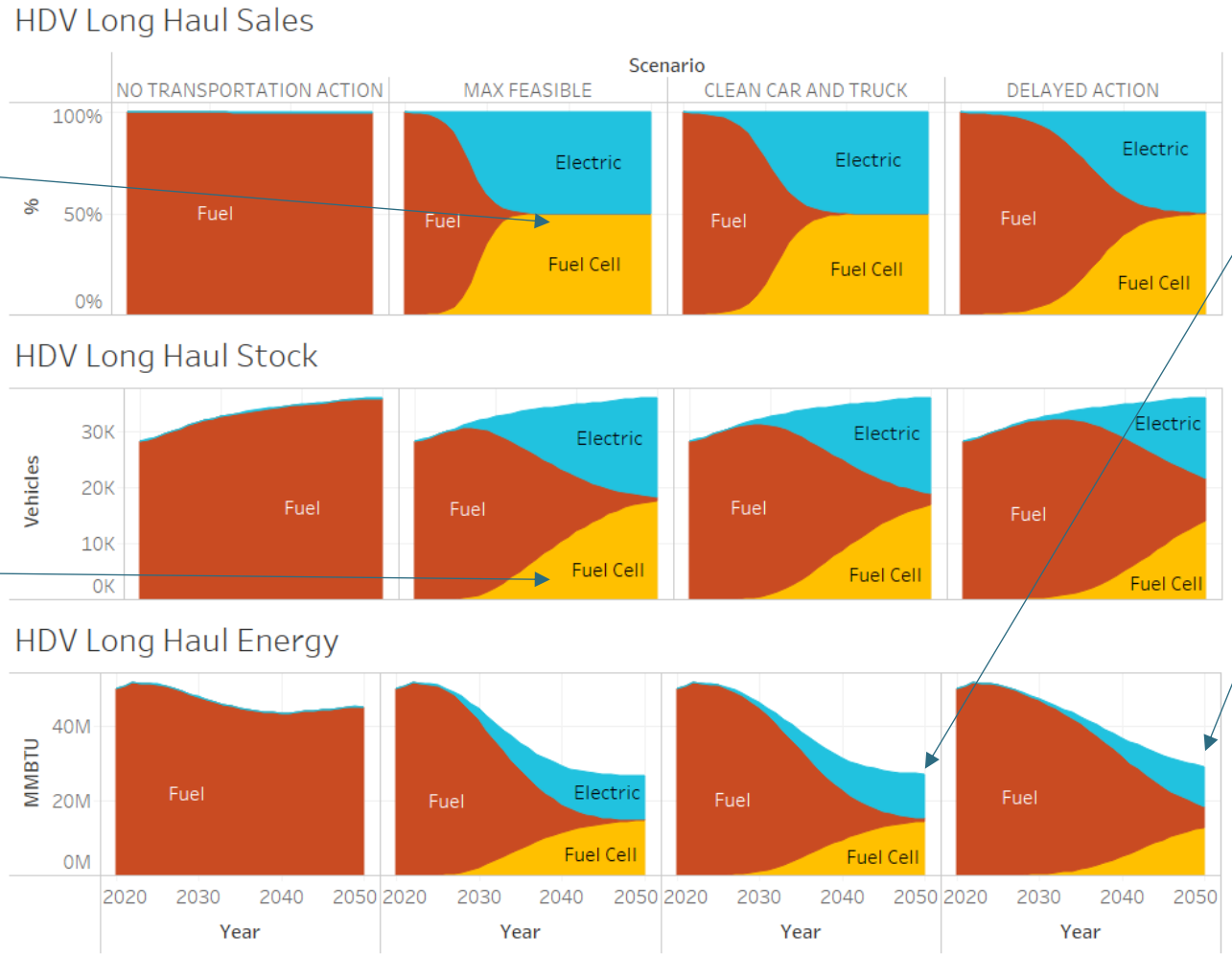
Competition between EV and FCV vehicles in long-haul applications. Uncertain which will win out: assume 50/50 split in sales

Max Feasible scenario sees early fuel cell deployment. Dependent on rapid infrastructure development



Clean Car and Truck and Max Feasible scenarios ~41% lower in energy demand than No Transportation Action by 2050

Sales Delay has 36% lower energy demand by 2050 than No Transportation Action

HEAVY DUTY SHORT-HAUL VEHICLE SALES, STOCK, ENERGY

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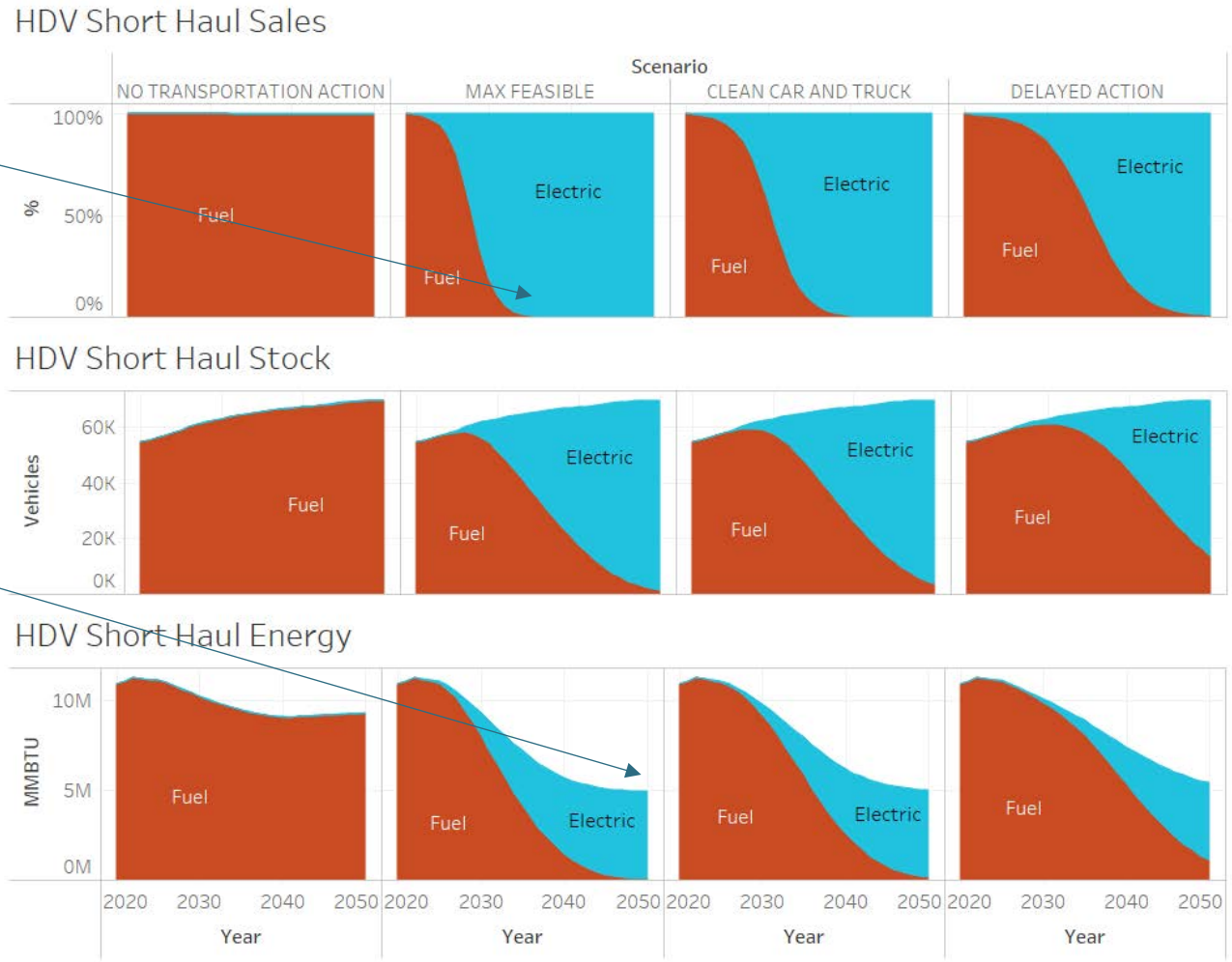
Sales inputs assume EVs are more competitive for short haul trucking that FCVs

Both Max Feasible and Clean Car and Truck achieve close to 100% EV stocks by 2050 resulting in significant energy savings



DEMAND SIDE DISCUSSION

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- **Action taken in the transportation sector significantly impacts economy-wide energy demand**
  - The difference between No Transportation Action, and the Max Feasible and Clean Car and Truck scenarios is a 25% reduction by 2050
  - The 25% reduction in energy demand significantly reduces supply side investments necessary to serve that demand, as shown in the next section
- **Adoption of EVs and FCVs results in significant growth in electricity demand over 2021 levels**
  - 110% in Clean Car and Truck versus only 55% in No Transportation Action
  - Greater simultaneous reductions of MMBTUs of gasoline and diesel demand due to the greater efficiency of EVs
- **While energy demand is reduced overall, electrification will drive significant changes in the way energy is produced and consumed**
  - New opportunities and challenges in shifting modes of energy consumption across economic sectors
  - Risks to electrifying too quickly as well as too slowly

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SUPPLY SIDE RESULTS

SUPPLY SIDE OVERVIEW

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- This section answers the question "**How do we serve the energy demands of the economy at least cost?**"
  - Subject to the constraints defined for each scenario, such as electricity policy, emissions policy, resource availability etc.
- It is concerned with investments in physical infrastructure and system operating costs
  - How many MWs of solar/batteries/transmission/conversion technologies etc. should we invest in?
  - How much fuel should we purchase?
- It does not answer questions about distributional impacts of investments
  - E.g. what rate do customers pay for electricity for their electric vehicles?
  - However, it does aim to minimize the size of the total cost pie that must be distributed among customers – a strong basis for further work in policy design

ECONOMY-WIDE EMISSIONS

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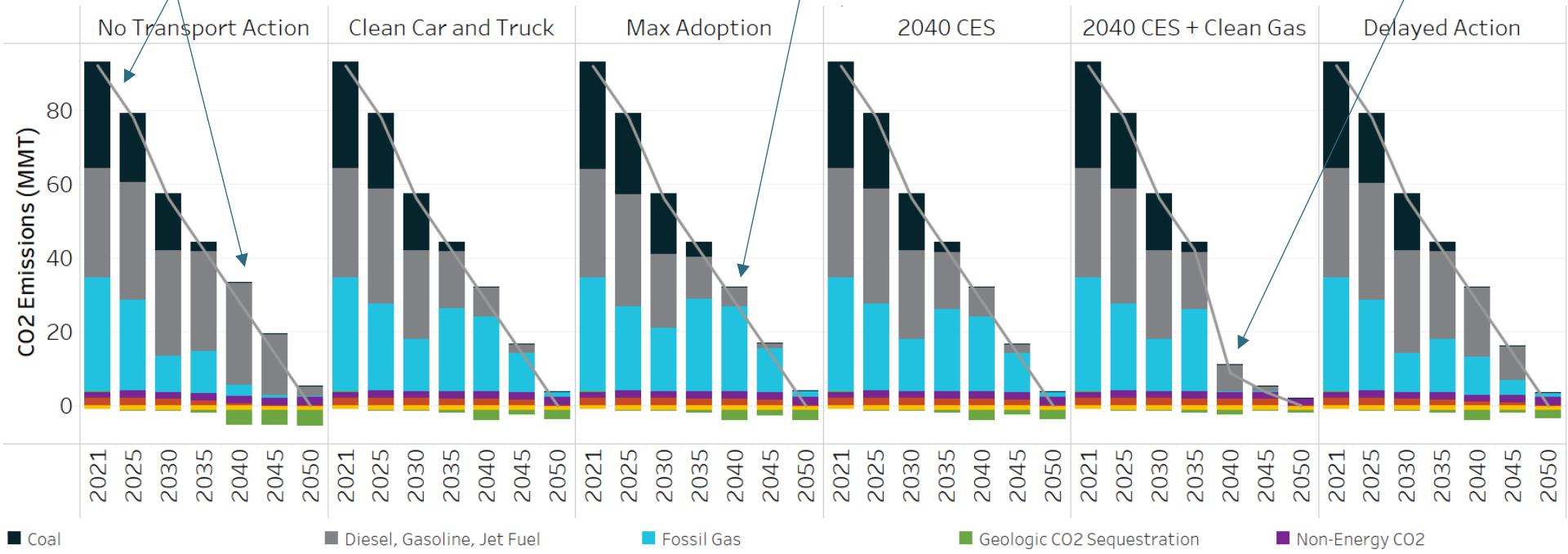
~30% of emissions from coal in 2021. Assumed retirement schedule of coal generation removes coal from emissions by 2040 for significant emissions reductions

In scenarios with aggressive EV adoption, low vehicle fuel emissions and no coal leaves room for emissions from additional gas burn in 2040

Clean gas policy is more restrictive on emissions than GHG policy resulting in significant reductions over Clean Car and Truck by 2040

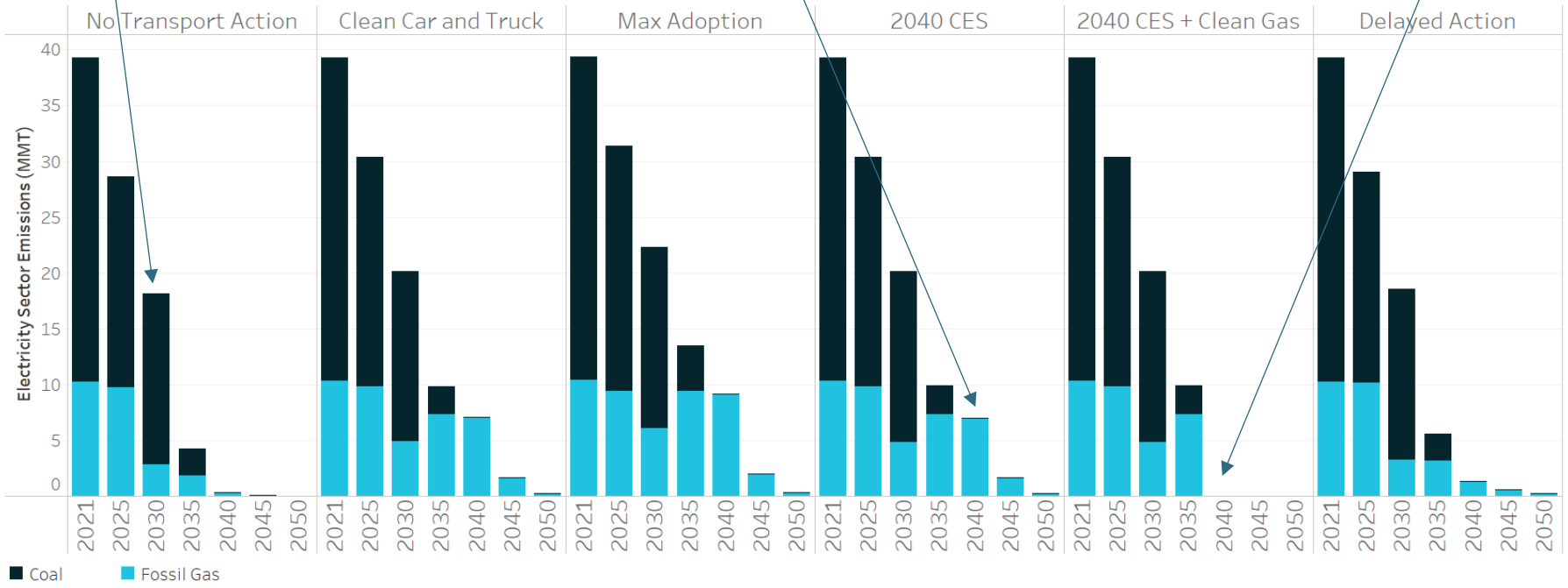


ELECTRICITY SECTOR EMISSIONS

When taking no action or delaying vehicle transition, faster electricity sector reductions are economic, offsetting greater emissions from vehicle fuels

Retail sales are served with 100% clean energy by 2040 in CES scenario, however AZ has room under emissions cap to export gas out of state to places without CES

Clean gas policy achieves 100% clean electricity sector in 2040, driving lower economy wide emissions than other scenarios



ELECTRICITY GENERATION AND DEMAND

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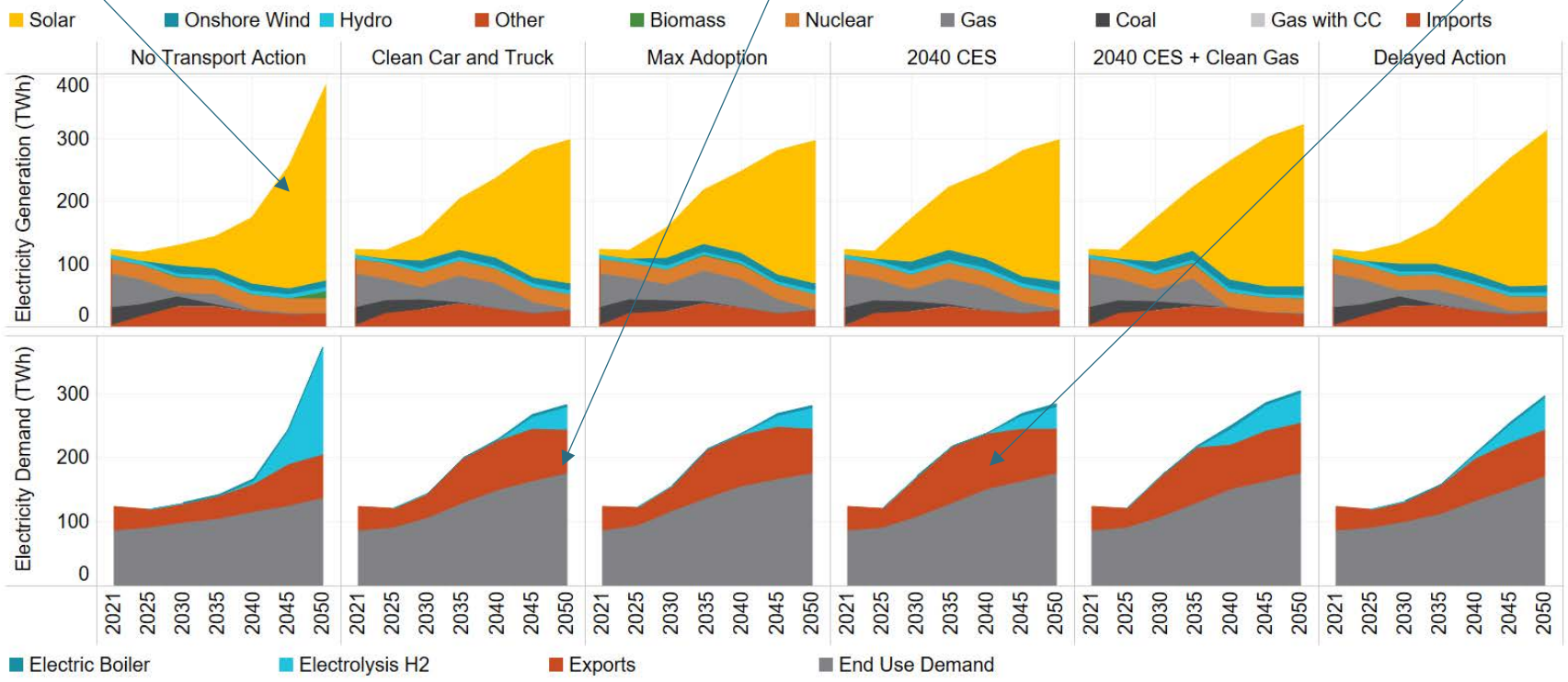
Excellent Arizona solar resource is the dominant source of energy by 2050 with rapid growth from 2030 onwards

130% growth in demand from 2021 to 2050 including demand side load growth, growing export market, and new electrolysis loads

2040 CES applied to retail sales drives increased export market and sends gas generation out of state in 2040 and beyond



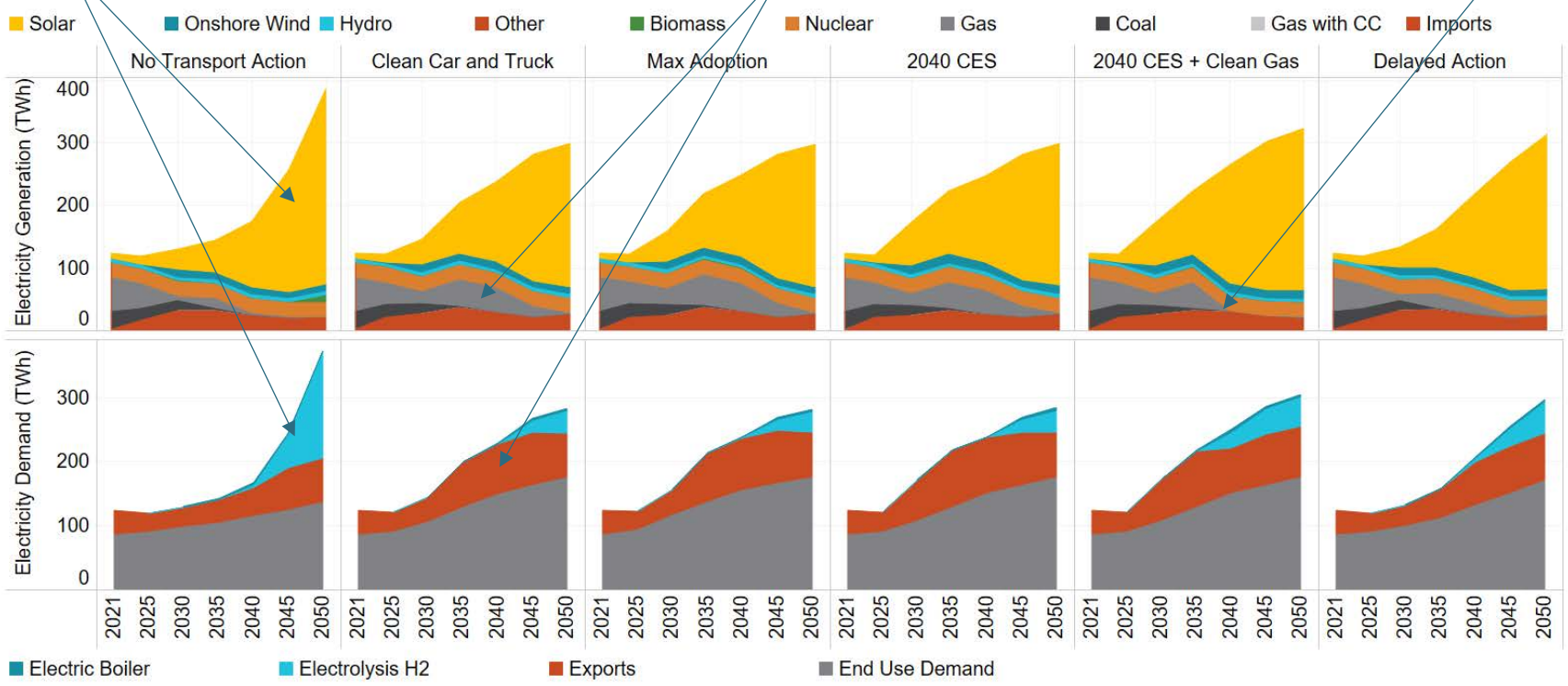
ELECTRICITY GENERATION AND DEMAND (CONT.)

EVOLVED ENERGY RESEARCH

No Transport Action has highest energy and clean fuel demands resulting in largest electricity and hydrogen sectors

Growth in gas and exports. Room for emissions in AZ in 2040 increases gas generation and drives higher clean energy exports out of state

Clean gas requirement leads to minimal gas usage in 2040 and beyond, reducing exports and driving larger investments in solar



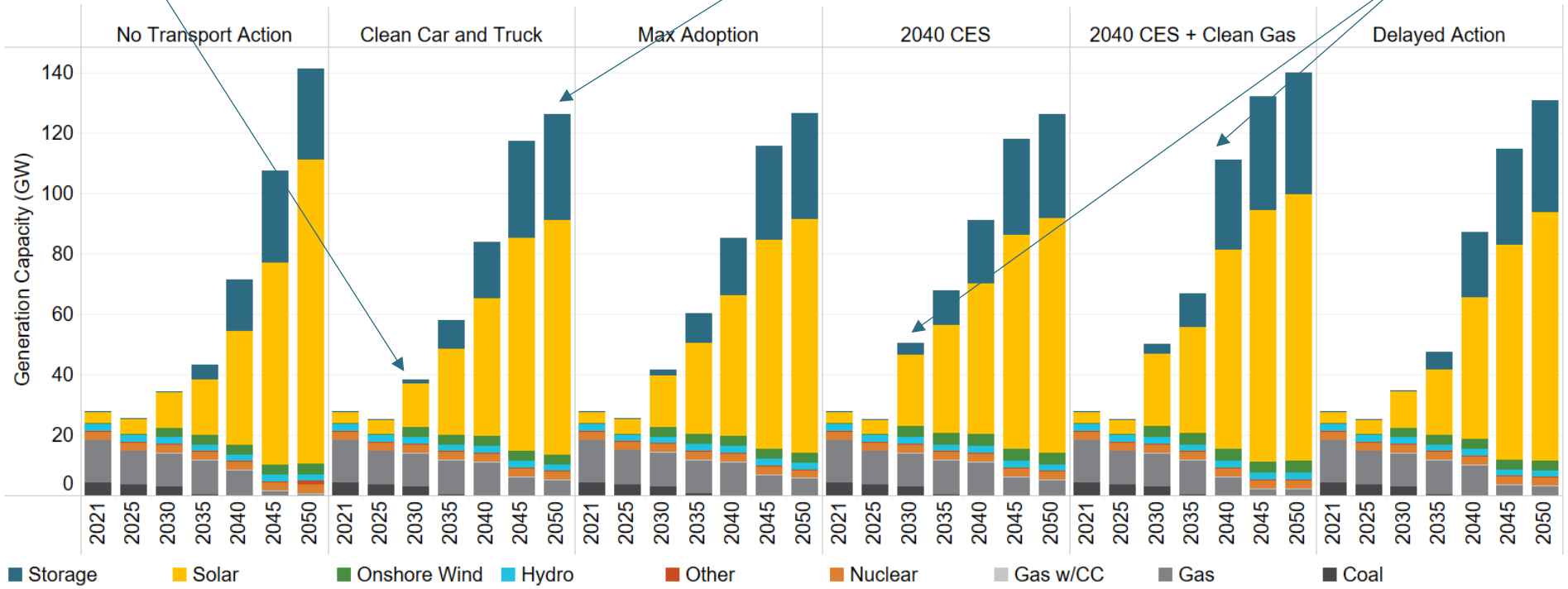
ELECTRICITY CAPACITY

EVOLVED ENERGY RESEARCH

Rapid increase in solar and storage investments from 2030 onwards with associated investments in T&D will require early planning to achieve

4.5x 2021 capacity by 2050 to support 2.3x the load, including 35 GW of storage to balance solar production

Both 2040 CES and Clean Gas scenarios require even faster deployment of solar and storage investments, including in 2030



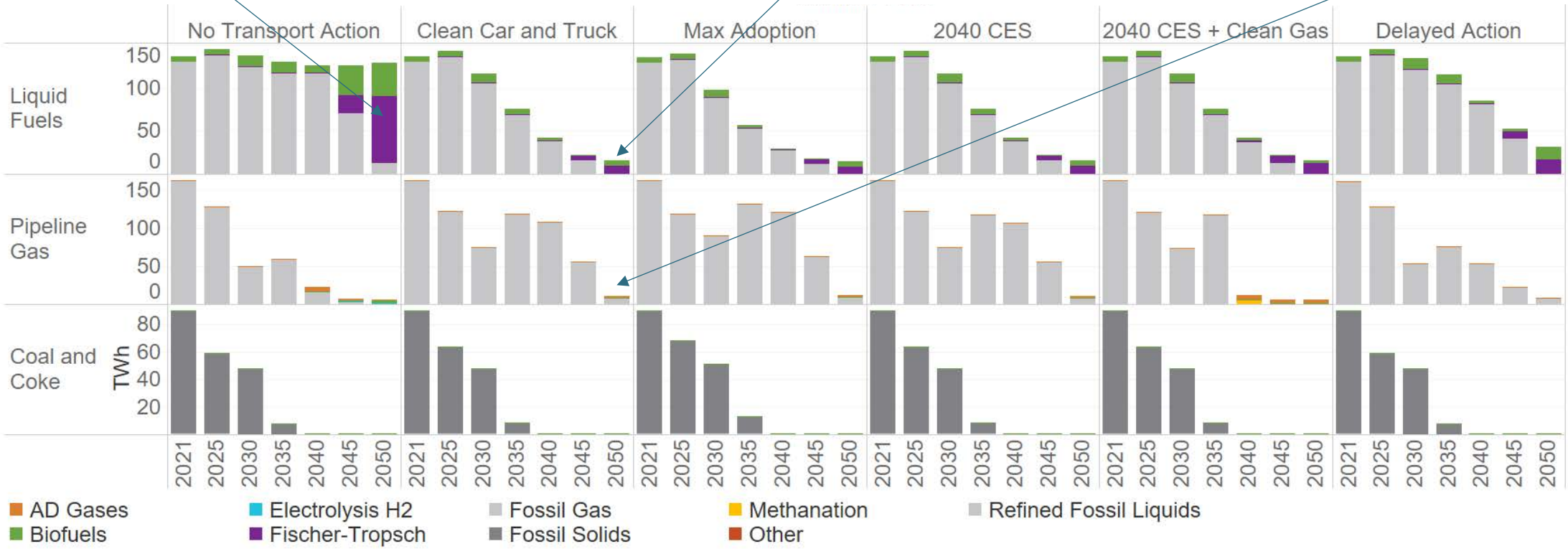
MAJOR FUELS

EVOLVED ENERGY RESEARCH

No Transport Action retains fuel use in vehicles, requiring infrastructure to produce clean fuel alternatives to reach emissions goals

Remaining liquids in other scenarios also decarbonized with clean fuels at lower volumes, including biofuels and synthetic fuels from hydrogen

Pipeline gas is lower cost than liquid fuels and has fewer emissions than coal, therefore it is the last to be decarbonized economically

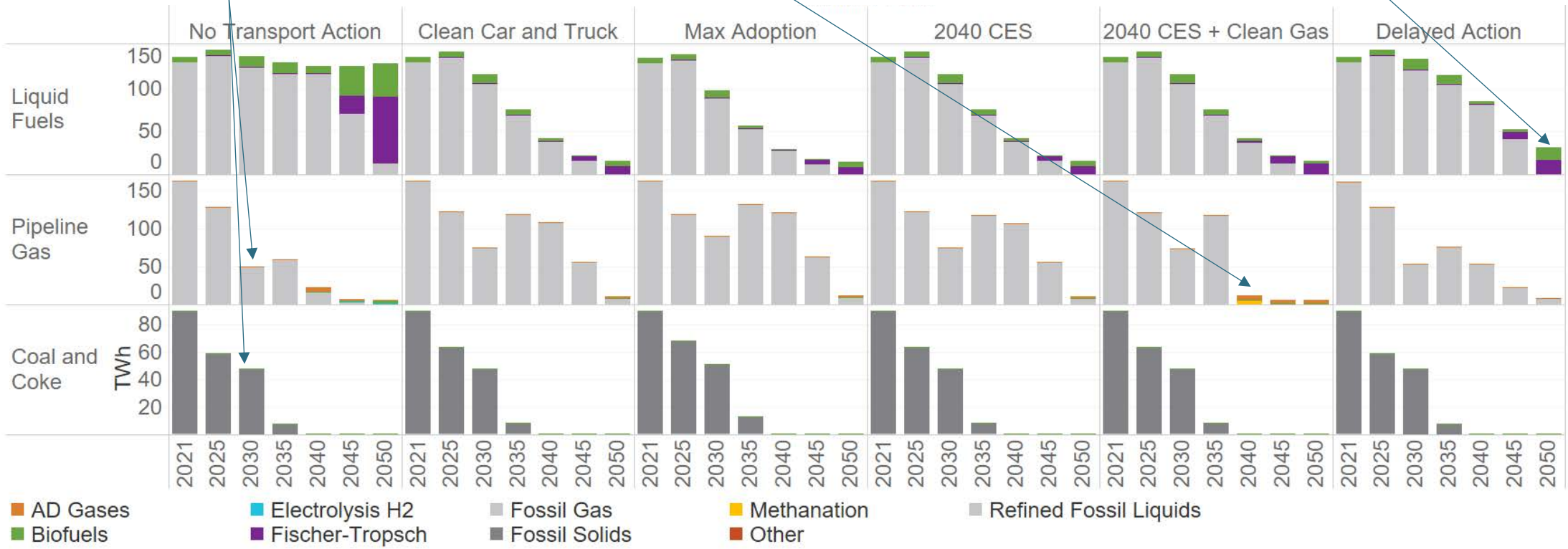


MAJOR FUELS (CONT.)

Coal retirements in power follow a set schedule with must run baseload requirements. This drives gas out of power in 2030 to meet GHG targets

Pipeline gas decarbonized completely by 2040 in Clean Gas scenario. Volumes significantly lower because of the higher price

Delayed Action scenario has slower stock turnover in vehicles, driving greater need for clean fuels in 2050



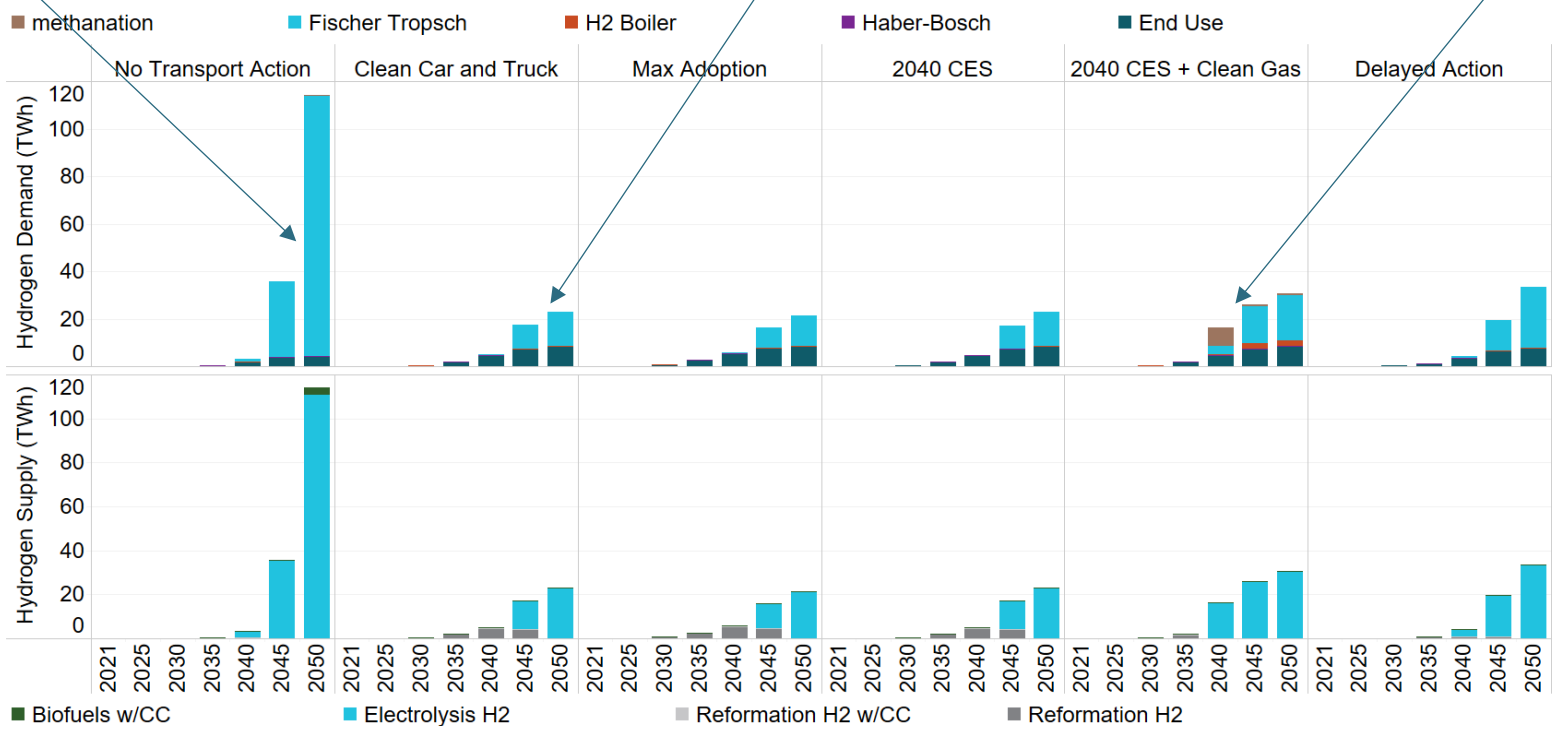
HYDROGEN DEMAND AND SUPPLY

EVOLVED ENERGY RESEARCH

Hydrogen demand for Fischer Tropsch liquids production in No Transport Action drives investment in a larger electricity sector

Clean Car and Truck scenario produces hydrogen from electrolysis to meet transport and industrial end uses, and fuels production demand

Additional hydrogen demand in 2040 in Clean Gas scenario to displace fossil gas with a clean alternative



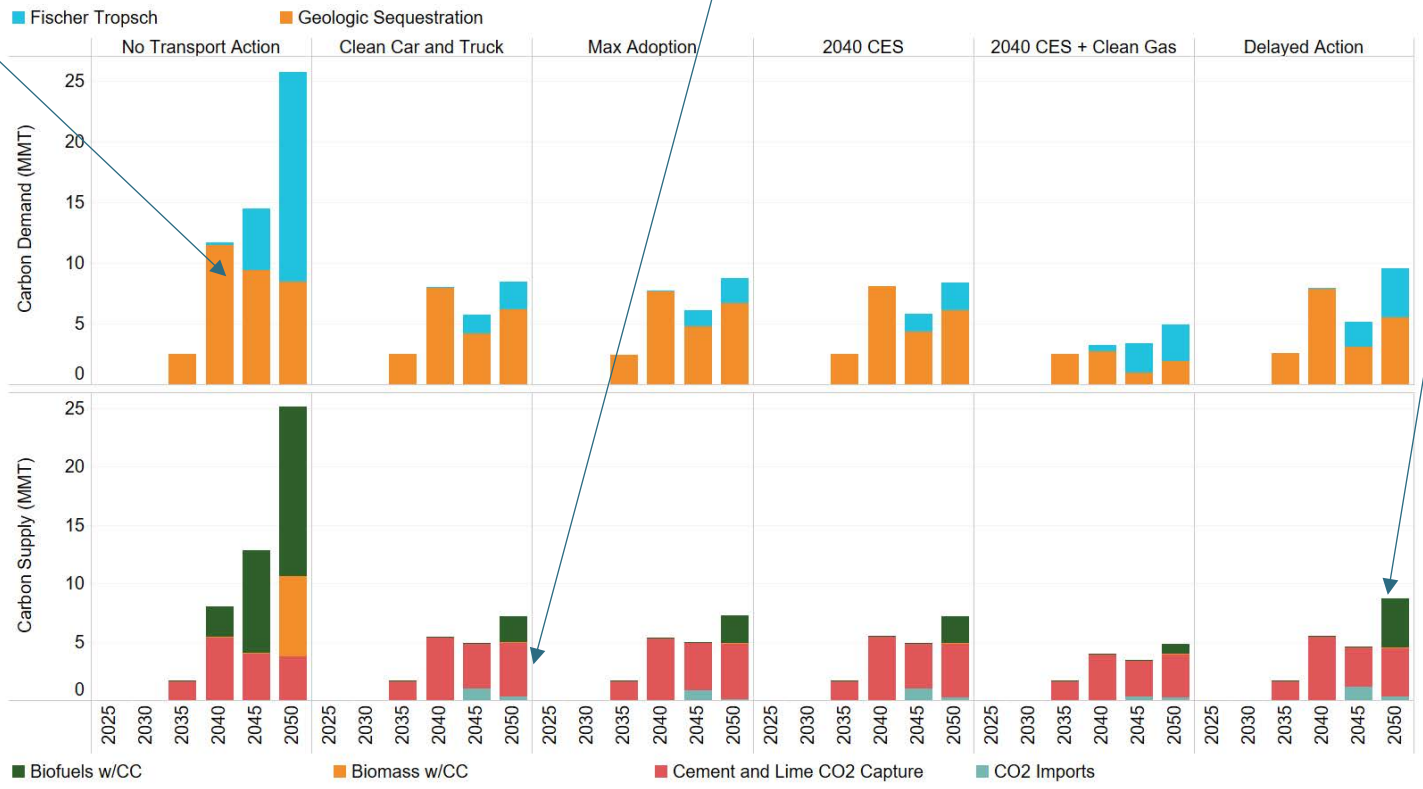
CARBON DEMAND AND SUPPLY

EVOLVED ENERGY RESEARCH

Carbon either sequestered or combined with hydrogen to produce fuels. Greatest carbon demand in No Transport Action

Carbon sourced from industrial CO2 capture. However, supply is limited, and biomass sources provide the remainder

Cases with higher primary fuel demand in transportation require greater investments in biomass and biomass processing equipment



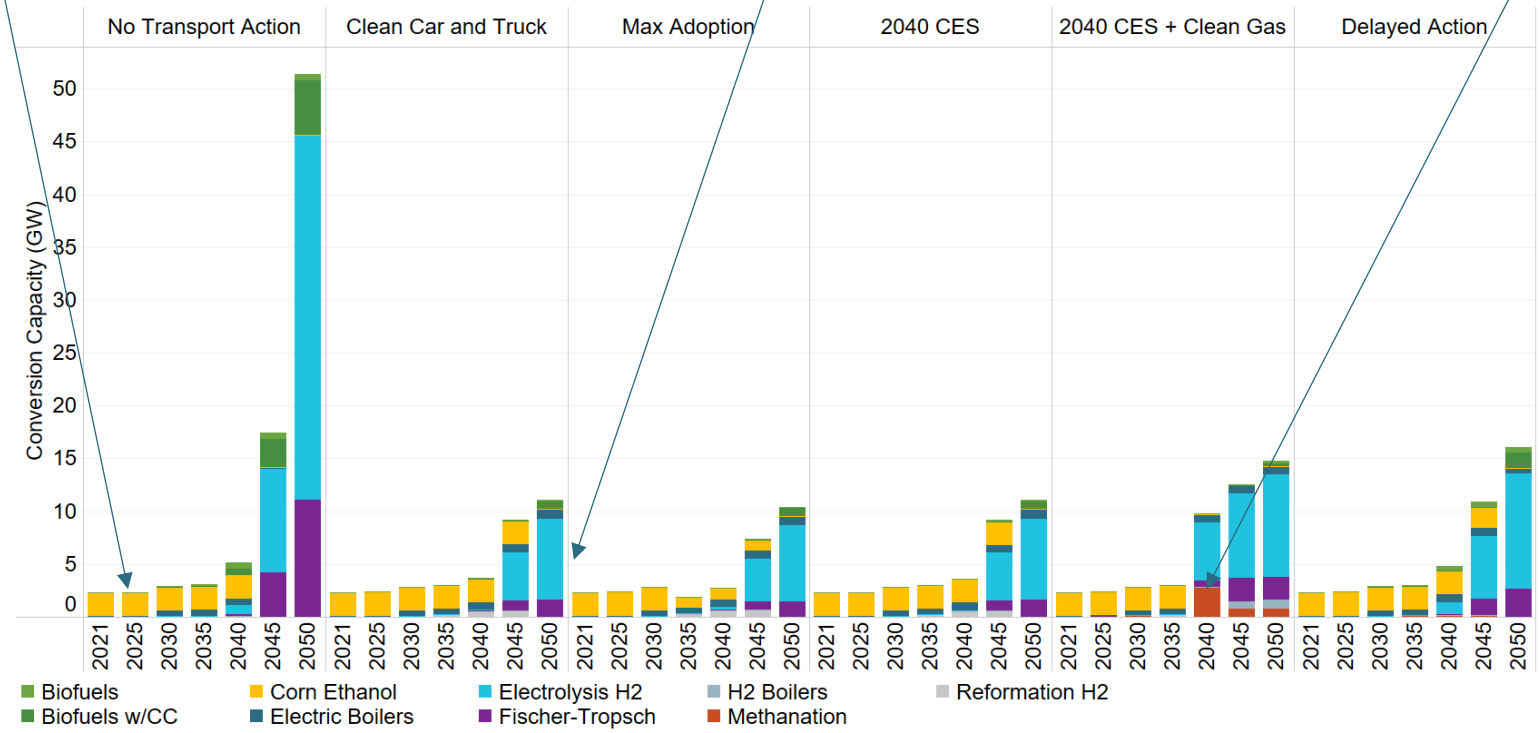
CONVERSION CAPACITY

EVOLVED ENERGY RESEARCH

Existing corn ethanol processing infrastructure to produce present day gasoline blends across first 20 years of the modeled time period

Transition away from gasoline in vehicles to clean fuel alternatives in 2045/2050 reflected in electrolysis and Fischer-Tropsch investments

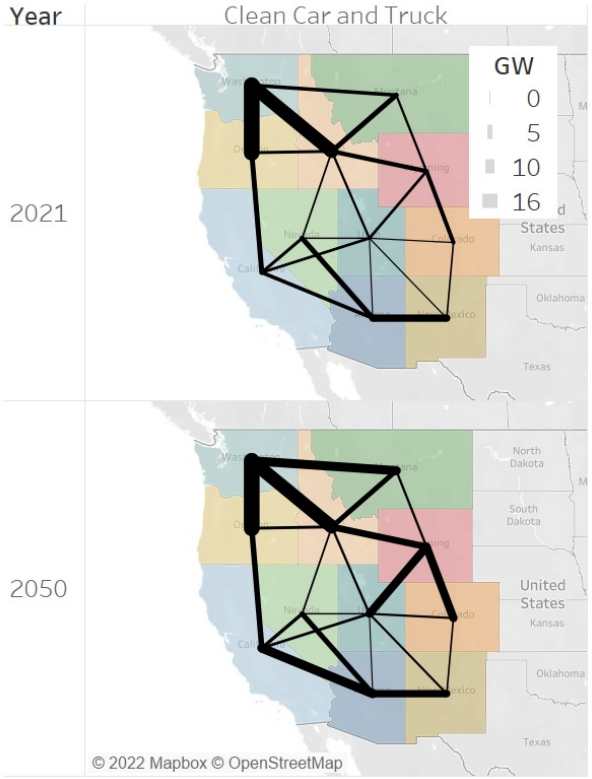
Methanation to produce synthetic methane from hydrogen in Clean Gas scenario beginning in 2040

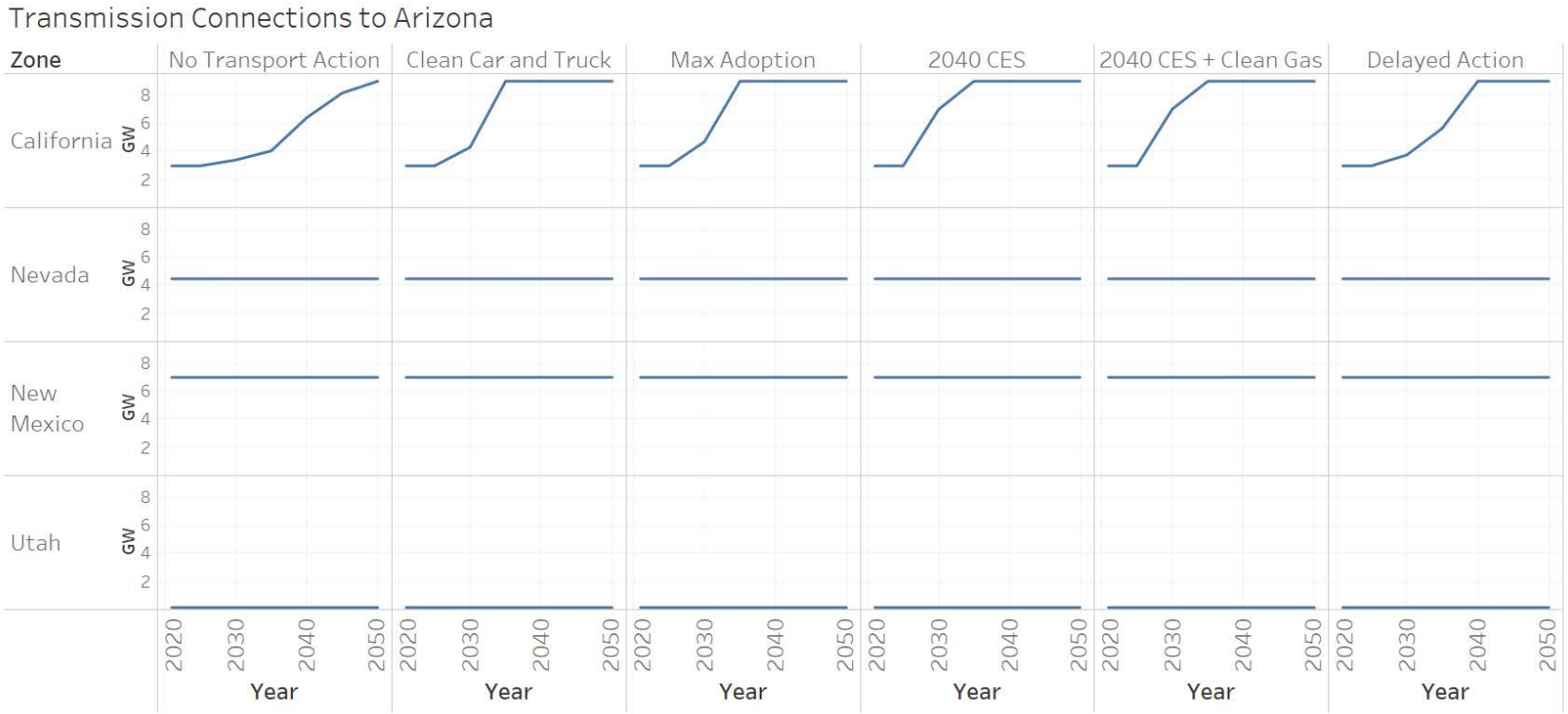


TRANSMISSION

Strengthening of transmission across the West takes advantage of renewable resource diversity

In all scenarios, transmission between Arizona and California is increased by the maximum additional 6 GW per corridor by 2050, facilitating greater exports and resource sharing





SUPPLY SIDE DISCUSSION

EVOLVED ENERGY RESEARCH

- **Arizona becomes a large exporter of energy as high quality solar is built out**
  - Relies on 6 GW expansion of transmission to California
  - Rate of solar and storage deployment from 2030 to 2050 will require detailed planning
- **Impact of slower transition to clean vehicles include:**
  - Faster reductions in emissions from coal and gas in electricity
  - Reliance on clean fuels to decarbonize to net zero
  - Larger investments in electrolysis and fischer tropsch drive larger loads and electricity sector investment, and larger investments in biofuels conversion processes
- **Impact of accelerated CES:**
  - 2040 CES: Requiring retail sales to be 100% clean by 2040 sends all gas generation to exports and slightly increases investment in solar in 2040. The 80% clean by 2030 requirement drives significantly more solar investment in the near-term
  - 2040 CES + Clean Gas: Drops electricity emissions to zero and drives greater investment in solar and storage over 2040 CES case
    - Reliability benefits of gas become more expensive in clean gas scenario because of the higher cost of clean gas, and more renewables are built to reduce the use of clean gas

SUPPLY SIDE DISCUSSION

EVOLVED ENERGY RESEARCH

- **New markets for hydrogen and carbon as clean fuels production ramps up to decarbonize remaining fuel use in 2045 and 2050**
  - Majority of carbon comes from industrial carbon capture. However, more is needed in the No Transport Action scenario, taken from biomass sources
  - Hydrogen is primarily sourced from electrolysis
- **Carbon sequestration is used between 2040 and 2050 to offset emissions. These are piped out of state to locations with sequestration potential**
  - Remaining process emissions must be offset to reach the net zero target. Sequestration is the economic solution to achieve that
- **6 GW of new electricity transmission is built to California to export electricity generation and take advantage of regional diversity and balancing**
  - Model limited to 6 GW of additional transmission. More would have likely been economic

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COSTS

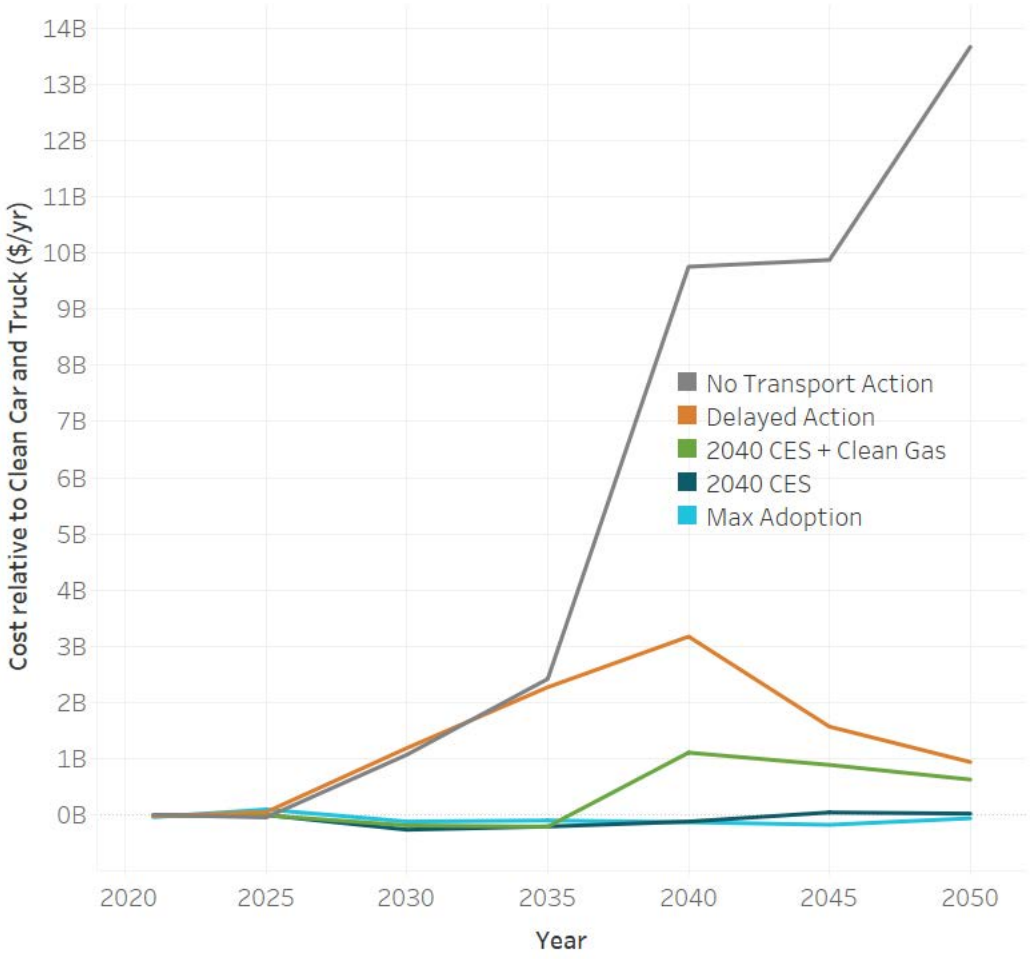
COST OVERVIEW

EVOLVED ENERGY RESEARCH

- Net costs are annualized, akin to a revenue requirement for energy across the economy
  - Annualized capital costs + operating costs
- We present the costs as relative to Clean Car and Truck to show the differences between scenarios
- These costs are based on forecasts from publicly available data sources. How these costs will manifest in the future is uncertain, and the uncertainty grows the further into the future we go

NET COSTS RELATIVE TO CLEAN CAR AND TRUCK CASE

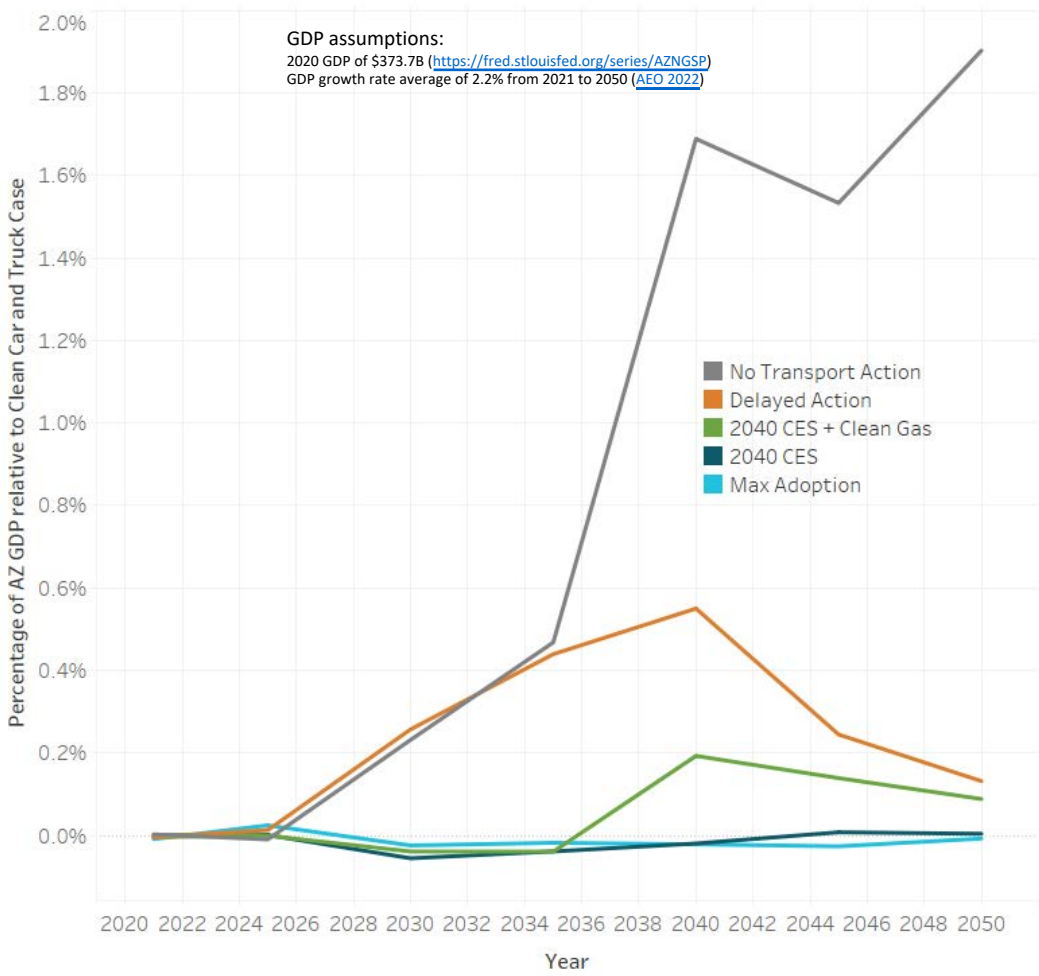
- The annual costs are relative to the Clean Car and Truck scenario
  - How much more or less costly are the policies in these other scenarios relative to Clean Car and Truck?
- No Transport Action drives costs up as ICE vehicles become more costly than EVs on a lifecycle basis early and clean fuels are required later
  - Delayed Action sees this same trend on a reduced scale
- 2040 CES + Clean Gas requires a larger, more costly electricity sector
- 2040 CES drives earlier renewable investment, but costs are similar
- Max Adoption has no cost benefits over Clean Car and Truck and potentially significantly more challenges to implement



NET COSTS RELATIVE TO CLEAN CAR AND TRUCK: GDP

EVOLVED ENERGY RESEARCH

- Converting the relative costs to a percentage of forecasted Arizona GDP puts them in perspective
  - What is the difference in energy spending in GDP terms versus the Clean Car and Truck case?
- Max Adoption and the 2040 CES cases have low impact on energy spending in GDP terms
- Delayed Action spending is higher than Clean Car and Truck by up to 0.55% of GDP in 2040
  - Corresponds to ~$3B/yr additional energy spending in 2040
- No Transportation Action reaches 1.9% of GDP greater energy spending than Clean Car and Truck by 2050
  - Corresponds to $13.7B/yr additional energy spending in 2050



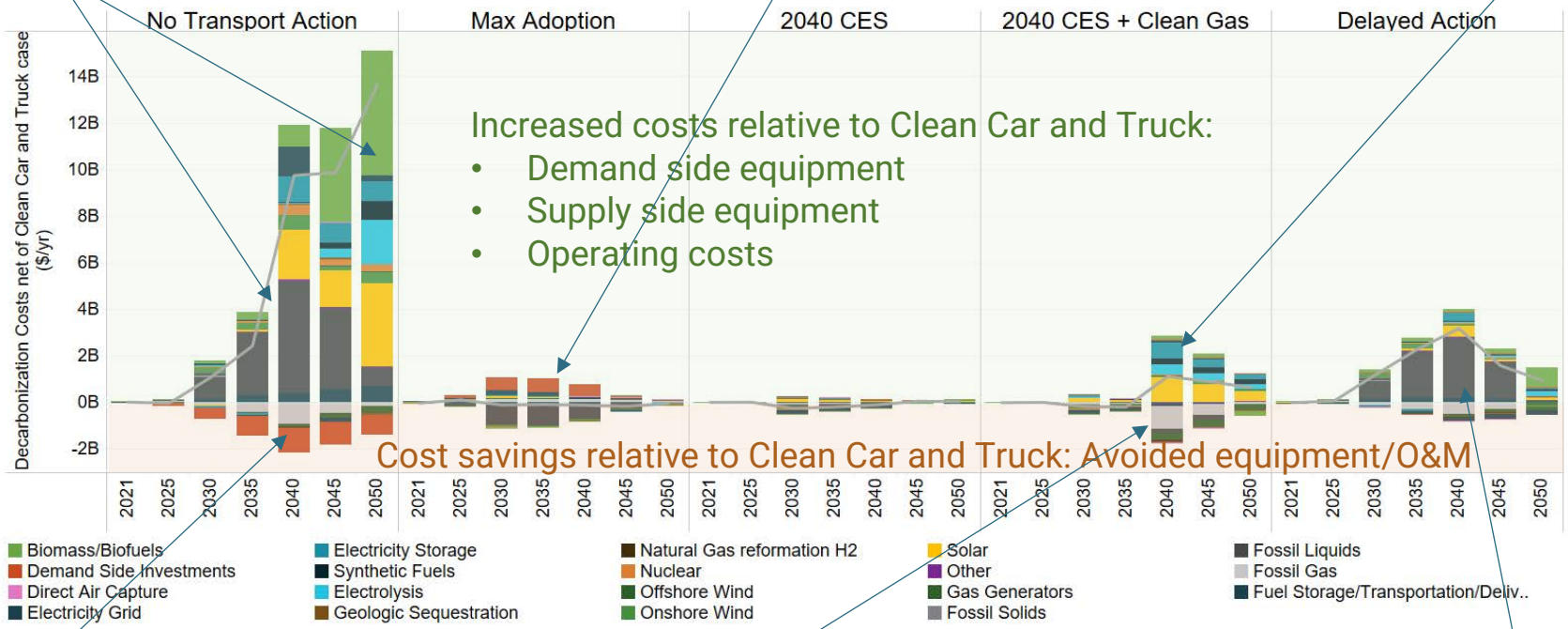
NET COSTS RELATIVE TO CLEAN CAR AND TRUCK CASE

EVOLVED ENERGY RESEARCH

No Transport Action increased fossil costs early, then larger electricity sector and clean fuels costs later

Max adoption offsetting increased demand side costs with decreased gasoline and diesel costs

Clean Gas drives additional investment in solar, storage, and electrolysis



Decreased fossil gas and demand side equipment investments

Clean gas avoids gas and gas generator costs in 2040 and after

Delayed Action avoids some gas but fossil and clean fuels drive up costs

COST DISCUSSION

EVOLVED ENERGY RESEARCH

- Dramatic cost increases over Clean Car and Truck (1.9% of GDP) in the No Transport Action scenario show that not adopting EVs/FCVs while going to net zero is not an option
  - Costs of serving an economy-wide energy demand 33% larger and large clean fuel demands
- Max Adoption has no economic benefit – cost savings in fuel are offset by increased demand side costs
  - Clean Car and Truck EV adoption occurs at lower price points later and has extra runway for policy action and infrastructure investment
- 2040 CES has little impact on costs because AZ can redistribute renewable resources and exports and solar is low cost
- Delayed Action shows that some of the challenges of No Transportation Action hit when stocks of ICE vehicles remain in 2050

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KEY ACTIONS BY DECADE

KEY ACTIONS IN THE 2020s

EVOLVED ENERGY RESEARCH

- **Electrification** of transport and other economic sectors
  - Early action required to achieve stock rollover of demand side technologies
  - Early development of policy initiatives to support electrification: how best to promote the shift to electrified end uses? How to minimize the adverse impacts of doing so?
- **Retirement of coal** is Arizona's most impactful near-term path to significant emissions reductions
  - Easiest win in emissions reductions is tapering coal power generation
  - Policy development: Are there ways to accelerate coal retirements?
- **Planning for load growth** is essential to meet new loads and support future electric vehicle charging
  - Investments in high quality Arizona solar and onshore wind
  - Avoid public and private charging requirements becoming a bottleneck to accelerated electric vehicle adoption
  - What initiatives can best support growth of the electricity sector and vehicle charging infrastructure?

KEY ACTIONS IN THE 2030s

EVOLVED ENERGY RESEARCH

- **Solar energy and battery** investments accelerated; coal retired
- **100% electrification sales by 2035** across light duty transport and building appliances
  - Early electrification key to avoiding large decarbonization costs in the future
- **100% clean vehicle sales by 2040** in medium and heavy-duty vehicles
- **Transmission expansion** to facilitate greater regional balancing
- **Greater regional coordination** to facilitate clean energy transfers across the West/US

KEY ACTIONS IN THE 2040s

EVOLVED ENERGY RESEARCH

- **Electrolysis** ramping up to support clean fuels production and provide balancing to the grid
  - Clean fuels decarbonize remaining primary fuel use in the economy
- **Electrified and clean end uses** reach close to 100% penetration in transportation and many sectors of the economy
  - Vehicle energy demands primarily electricity, with hydrogen potentially playing a role depending on technological development
- **Carbon capture and sequestration** used to offset remaining emissions in the economy including non-energy CO2 emissions

THANK YOU

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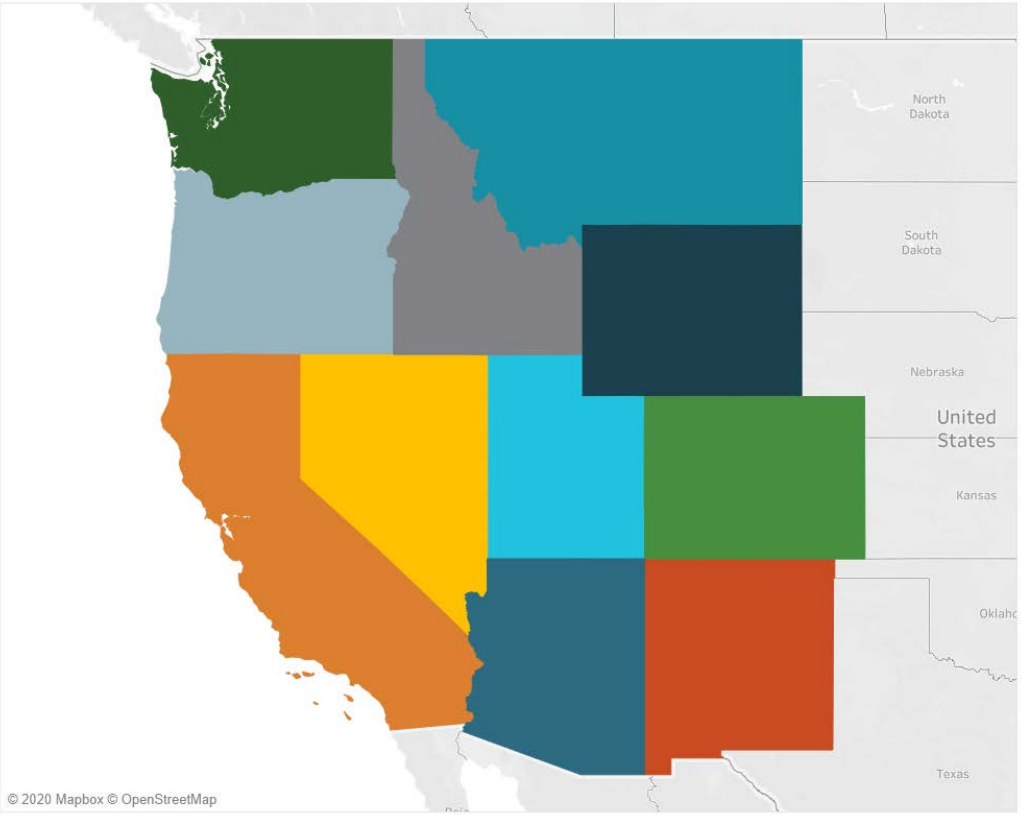
APPENDIX: MODELING APPROACH

OVERVIEW OF MODELING APPROACH

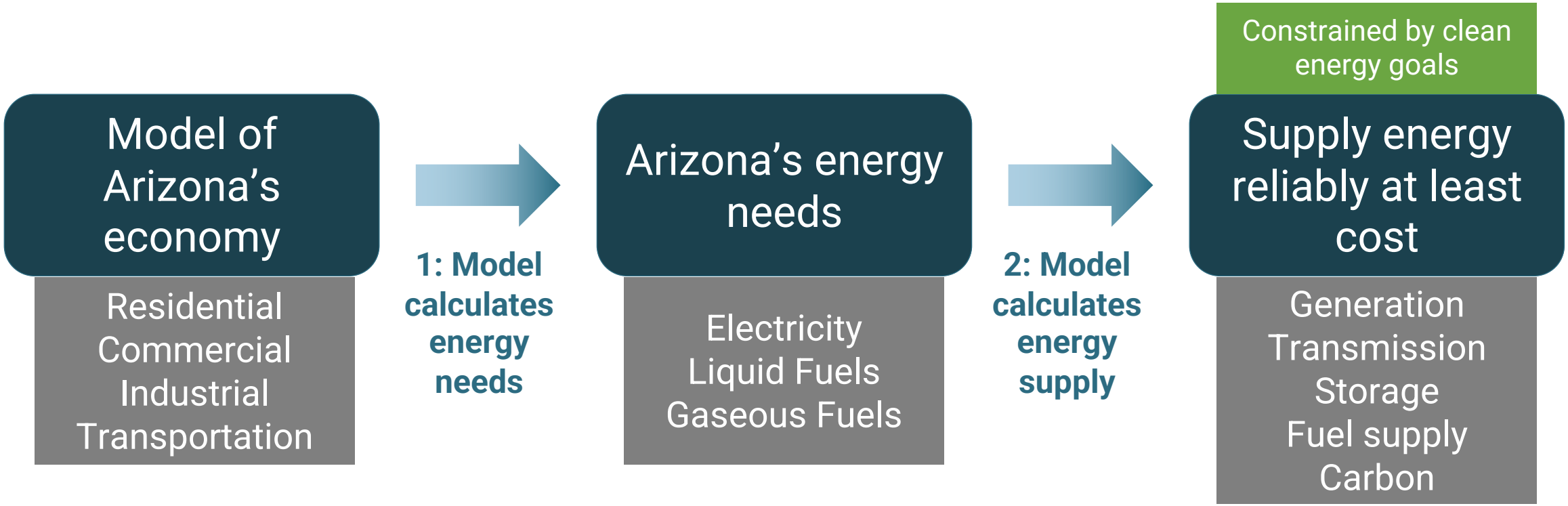


- **Explores** pathways to achieve net zero emissions in Arizona by considering the transition needed in all sectors of the economy
- **Modeling determines optimal investment** in resources, constrained by scenario definitions, investigating different potential state objectives or uncertainties
- **Decarbonizing the energy supply**—electricity, pipeline gas, liquid fuels
- **Conservative** assumptions about existing technologies and cost projections from public sources
- Models integrate electricity and fuels systems that extend beyond Arizona's borders to **capture regional opportunities and challenges**
    - Other states' actions will impact the availability and cost of solutions Arizona has to transition to clean energy

HIGH LEVEL DESCRIPTION OF MODELING APPROACH

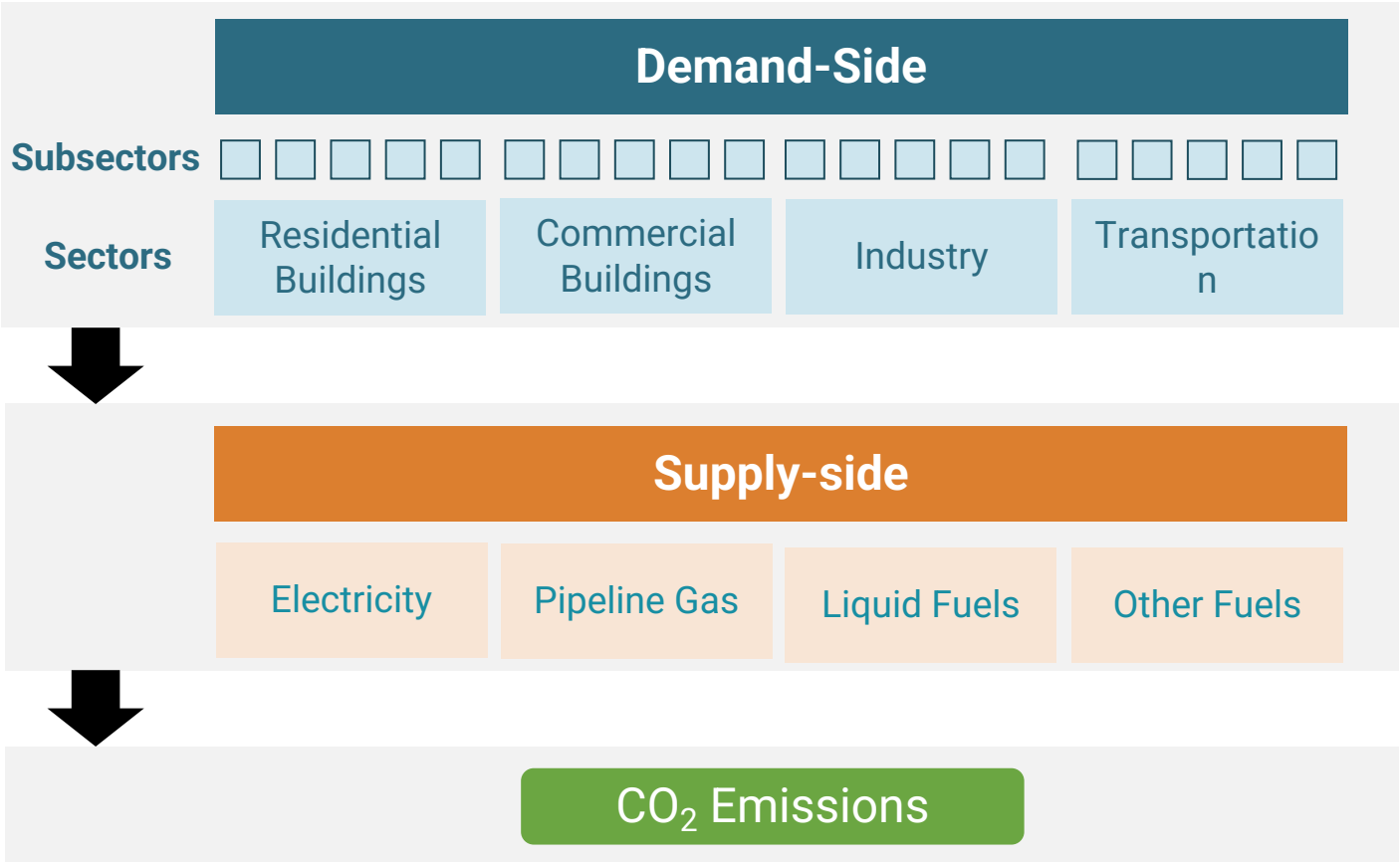
EVOLVED ENERGY RESEARCH

- Model calculates the energy needed to power Arizona's economy, and the least-cost way to provide that energy under clean electricity and emissions goals



ANALYSIS COVERS ARIZONA'S ENTIRE ENERGY SYSTEM

EVOLVED ENERGY RESEARCH



- **EnergyPATHWAYS** model used to develop demand-side cases
- Applied electrification and energy efficiency levers
- Strategies vary by sub-sector (residential space heating to heavy duty trucks)

- **Regional Investment and Operations (RIO)** model identifies cost-optimal energy supply
- Net-zero electricity systems
- Novel technology deployment (biofuels; hydrogen production; geologic sequestration)

DEMAND-SIDE MODELING

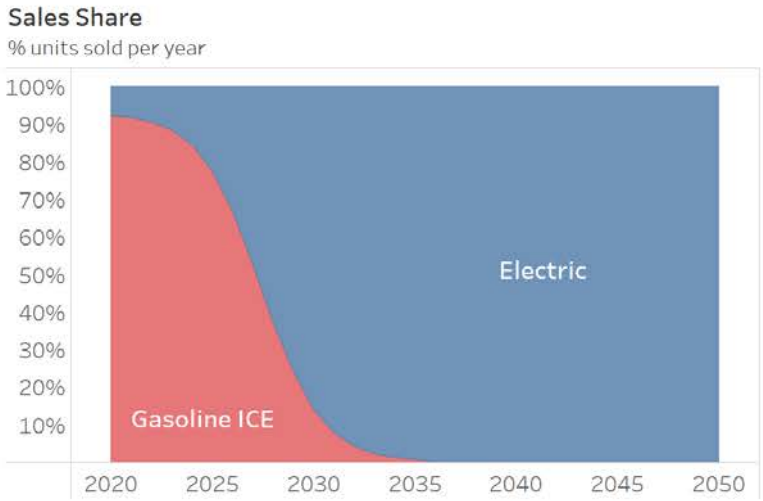
- Scenario-based, bottom-up energy model (not optimization-based)
- Characterizes rollover of stock over time
- Simulates the change in total energy demand and load shape for every end use

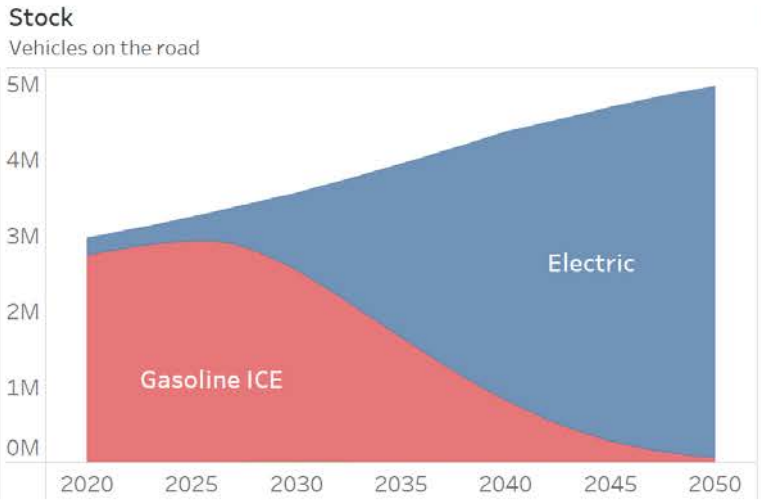
Illustration of model inputs and outputs for light-duty vehicles

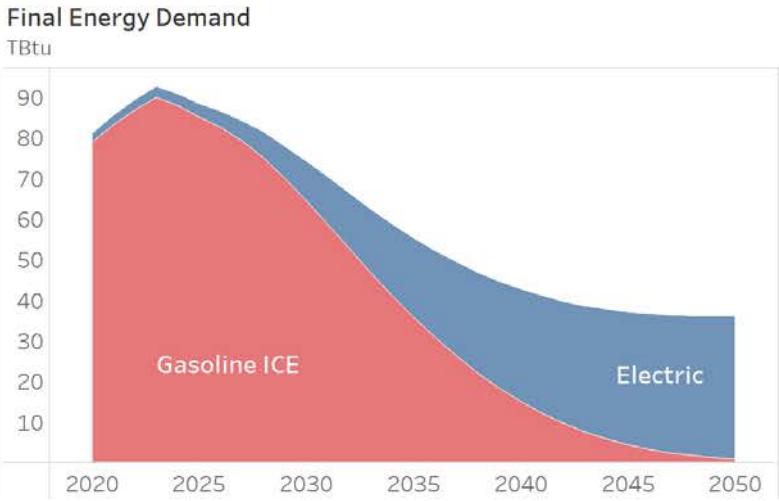
Input: Consumer Adoption
EV sales are 100% of consumer adoption by 2035 and thereafter

Output: Vehicle Stock
Stocks turn-over as vehicles age and retire

Output: Energy Demand
EV drive-train efficiency results in a drop in final-energy demand







END-USE SECTORS MODELED

- Approximately 70 demand sub-sectors represented
- The major energy consuming sub-sectors are listed below:

Key energy-consuming subsectors.

Residential Sector
- Air-conditioning
- Space heating
- Water heating
- Lighting
- Cooking
- Dishwashing
- Freezing
- Refrigeration
- Clothes washing
- Clothes drying

Commercial Sector
- Air-conditioning
- Space heating
- Water heating
- Ventilation
- Lighting
- Cooking
- Refrigeration

Industrial Sector
- Boilers
- Process heat
- Space heating
- Curing
- Drying
- Machine drives
- Additional subsectors (e.g., machinery, cement)

Transportation Sector
- Light-duty autos
- Light-duty trucks
- Medium-duty vehicles
- Heavy-duty vehicles
- Transit buses
- Aviation
- Marine vessels

Source: CETI, NWDDP, 2019

SUPPLY SIDE MODELING

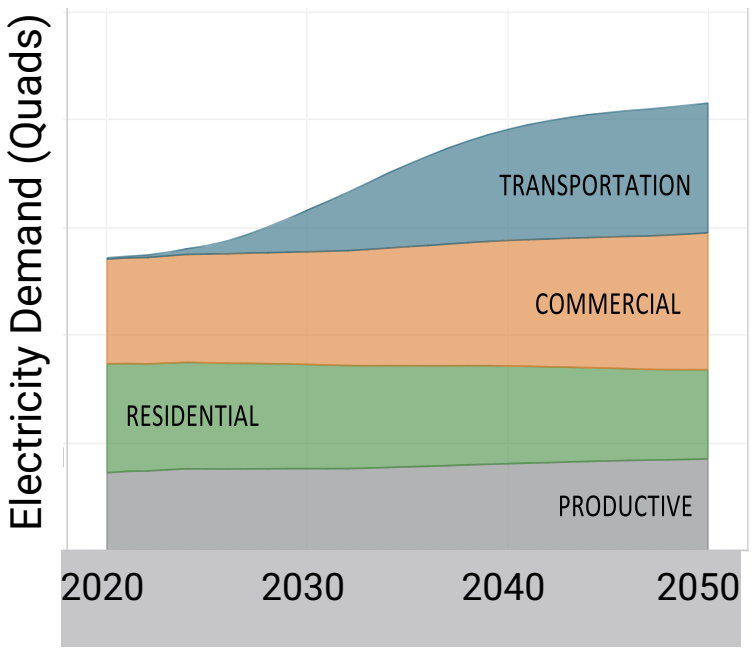
Optimized investments in energy infrastructure

EVOLVED ENERGY RESEARCH

Example: Electricity

Electricity includes all economic sectors

Model optimizes investments to meet demand, reliability, and emission targets



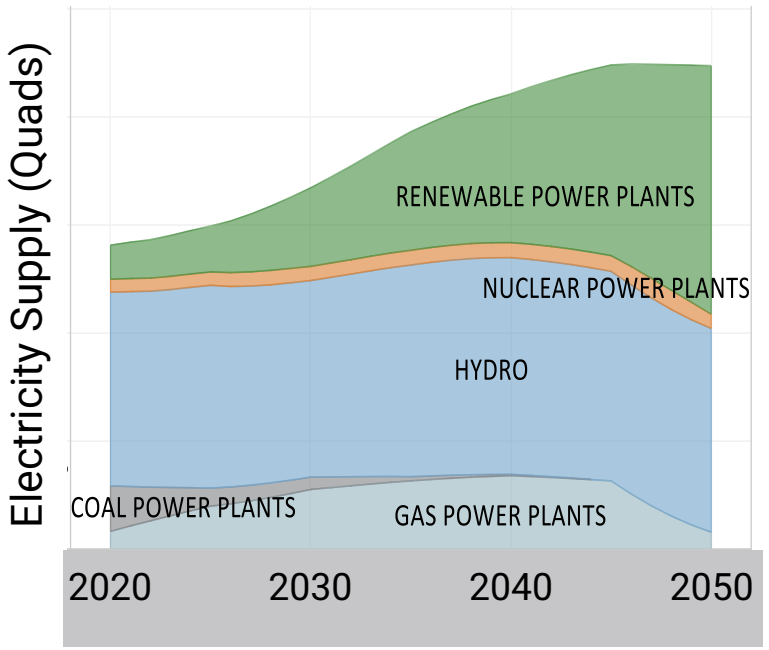
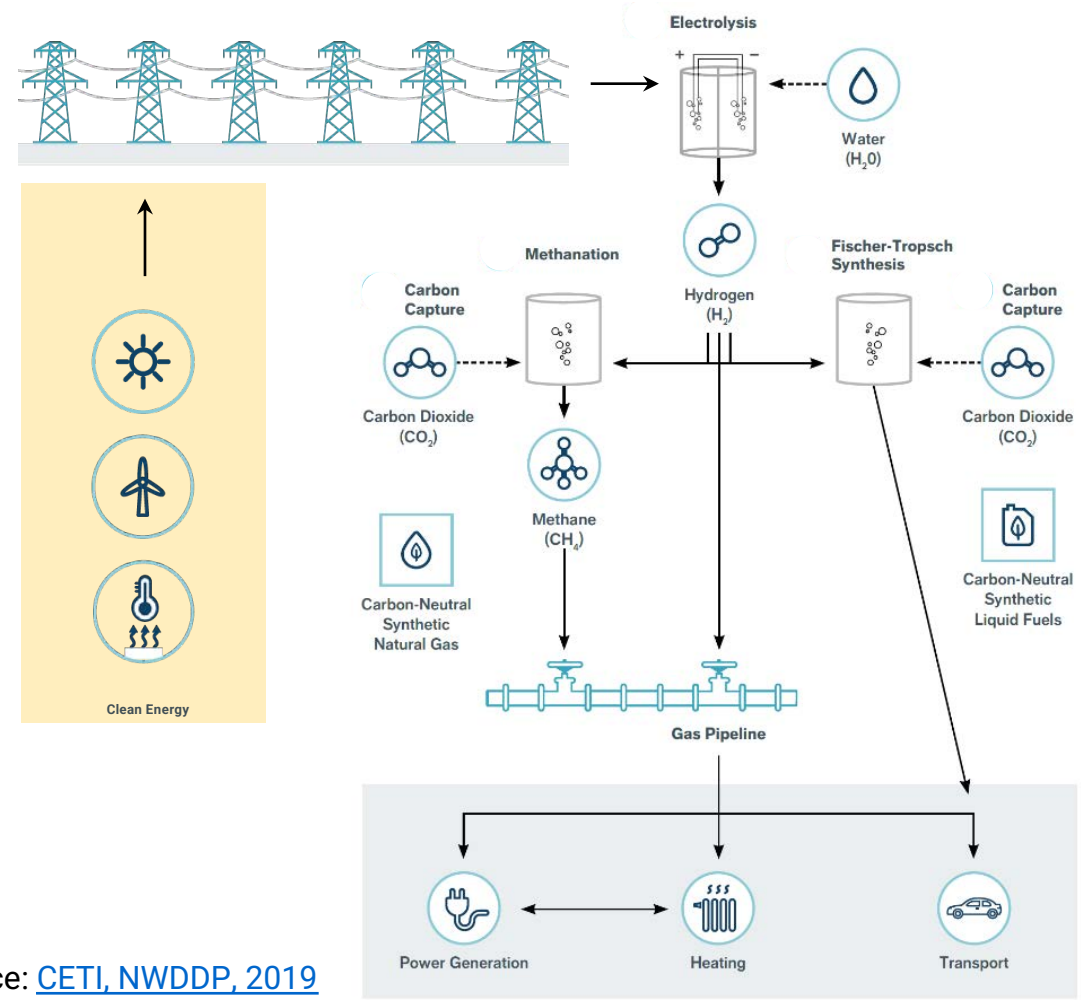


Figure for methodology illustration only

- **Reliability**: Model requires supply is met during rare, severe weather events, while maintaining reserve margin
- Fuel and electricity supply are optimized together
- Model uses best available public data

INTEGRATED SUPPLY SIDE: ELECTRICITY AND FUELS

- Conventional means of “balancing” may not be the most economic or meet clean energy goals
- New opportunities: Storage and flexible loads
- Fuels are another form of energy storage
- Large flexible loads from producing decarbonized fuels:
  - Electrolysis, synthetic fuels production



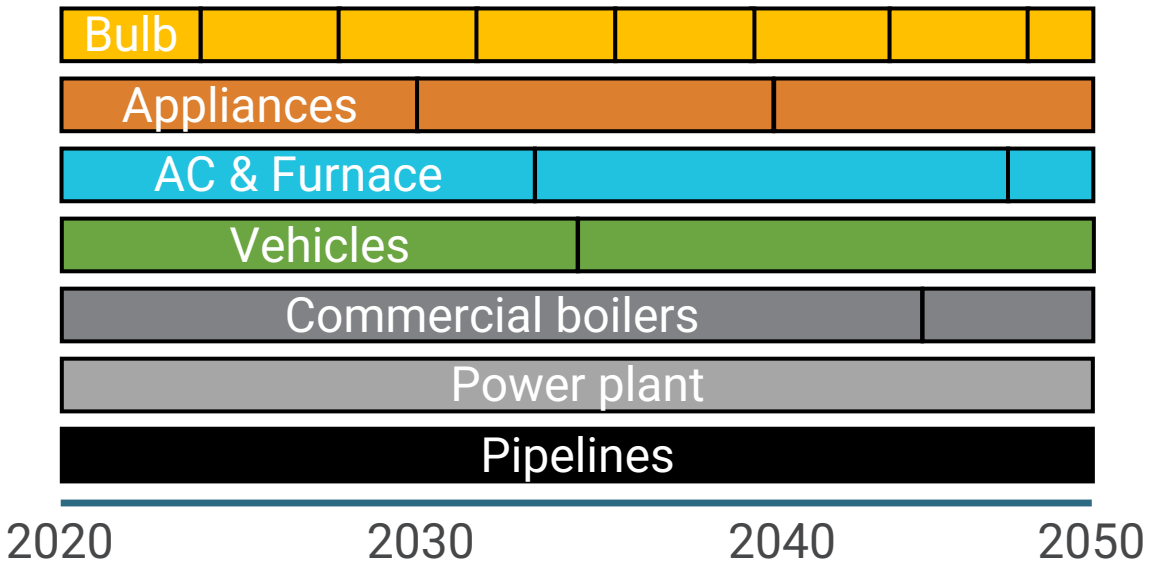
Source: CETI, NWDDP, 2019

NEAR-TERM FOCUS ON LONG-LIVED ASSETS

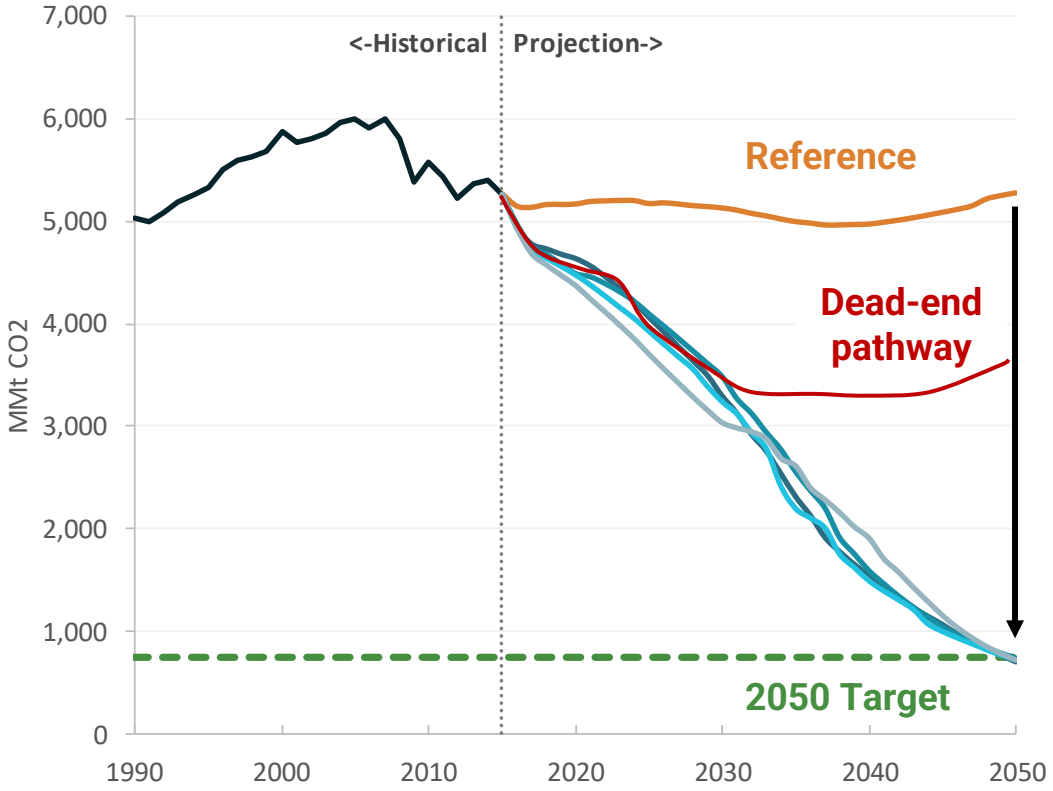
Long-lived infrastructure should be an early focus to avoid carbon lock-in or stranded assets

EVOLVED ENERGY RESEARCH

Stock replacement count before mid-century



U.S. Energy-related CO_2 Emissions

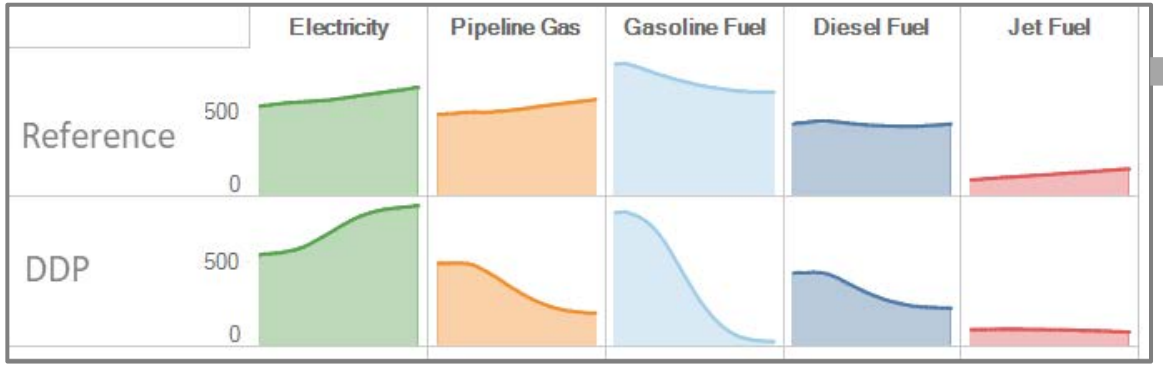


DEMAND AND SUPPLY-SIDE MODELING FRAMEWORK

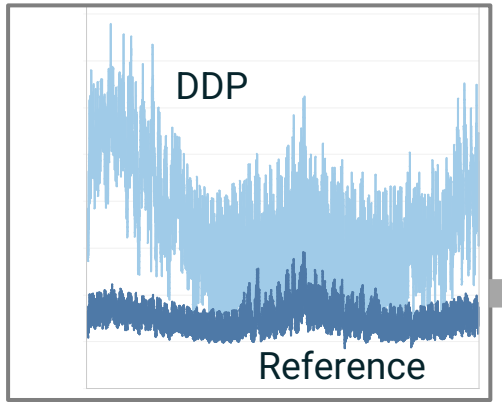
EVOLVED ENERGY RESEARCH

EnergyPATHWAYS (EP)

Annual End-Use Energy Demand



Hourly Load Shape



Regional Investment and Operations (RIO)

Inputs

- End-use energy demand
- System emissions constraints
- RPS or CES constraints
- Technology and fuel cost projections
- New resource constraints
- Biomass and CO_2 Sequestration costs
- Hourly load shape

Outputs

Electricity sector
- Wind/solar build
- Energy storage capacity/duration
- Capacity for reliability
- Curtailment
- Hourly operations

Hydrogen production

Synthetic electric fuel production (H2/SNG)

Biomass allocation

CO_2 sequestration

RIO OPTIMIZES ACROSS TIME-SCALES

EVOLVED ENERGY RESEARCH

Solution Constraints

- Carbon constraints
- RPS constraints
- CES constraints
- Build-rate constraints
- Renewable potential
- Geologic sequestration
- Biomass

365+ days

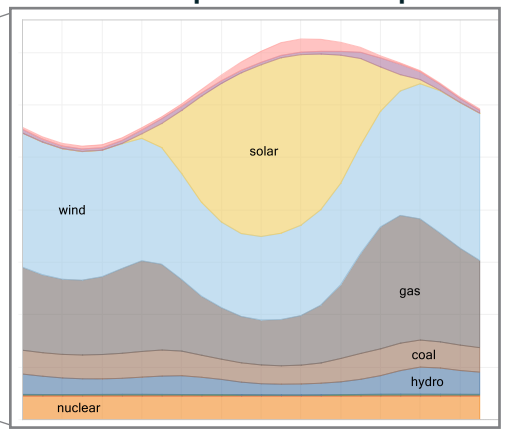
40-60 daily snapshots

2010

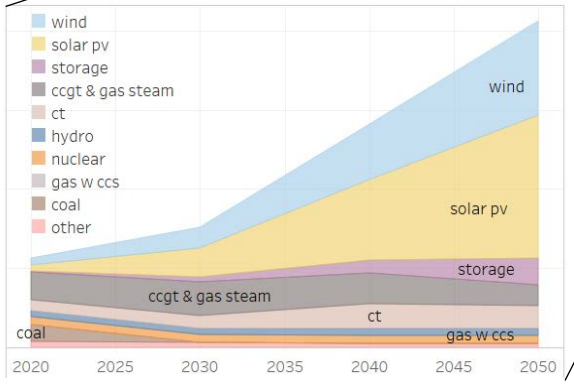
5-year timestep

2050

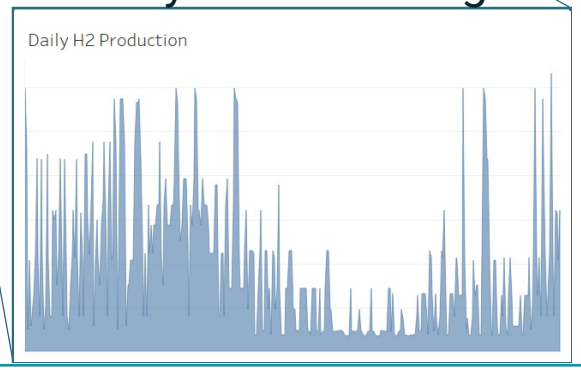
24-hr sequential dispatch



Capacity build



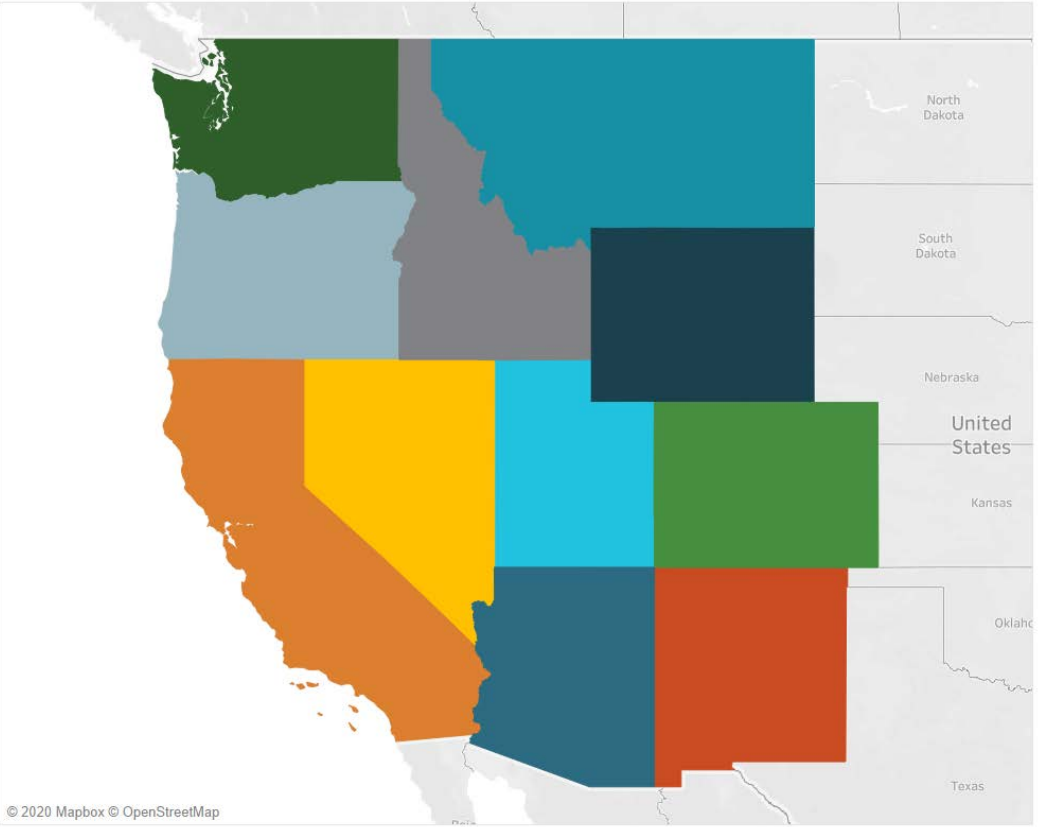
Daily fuels tracking



RIO OPTIMIZES ACROSS GEOGRAPHIC CONSTRAINTS

EVOLVED ENERGY RESEARCH

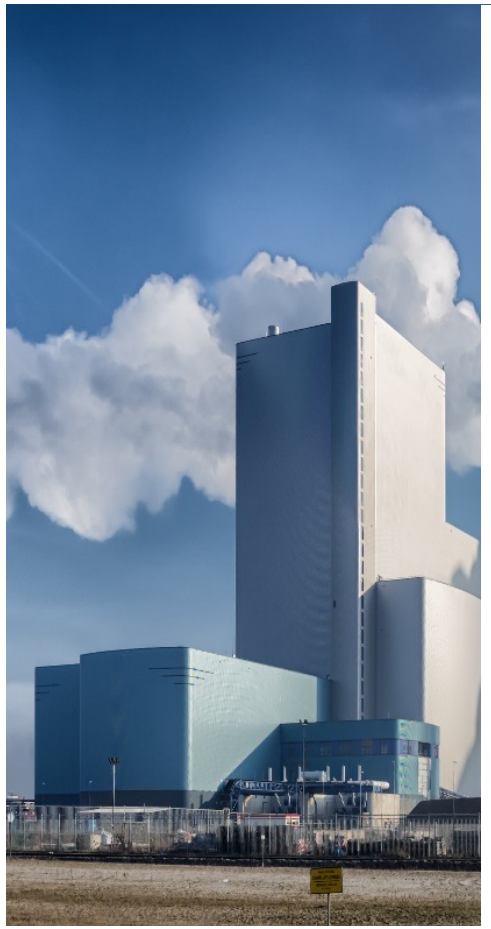
- Transmission constraints and potential between states
  - Model can optimally expand interties and fuels delivery infrastructure
- Loads, resources, and new resource potentials by state
  - Captures unique geographic advantages and local conditions by state
- Arizona is integrated into the West-wide/US- wide transmission network of electricity and fuels, and decarbonization solutions depend on this integration
  - Opportunity for coordination across states
- Arizona has limited potential for carbon sequestration
  - Model allows for CO2 pipeline construction for out-of-state sequestration

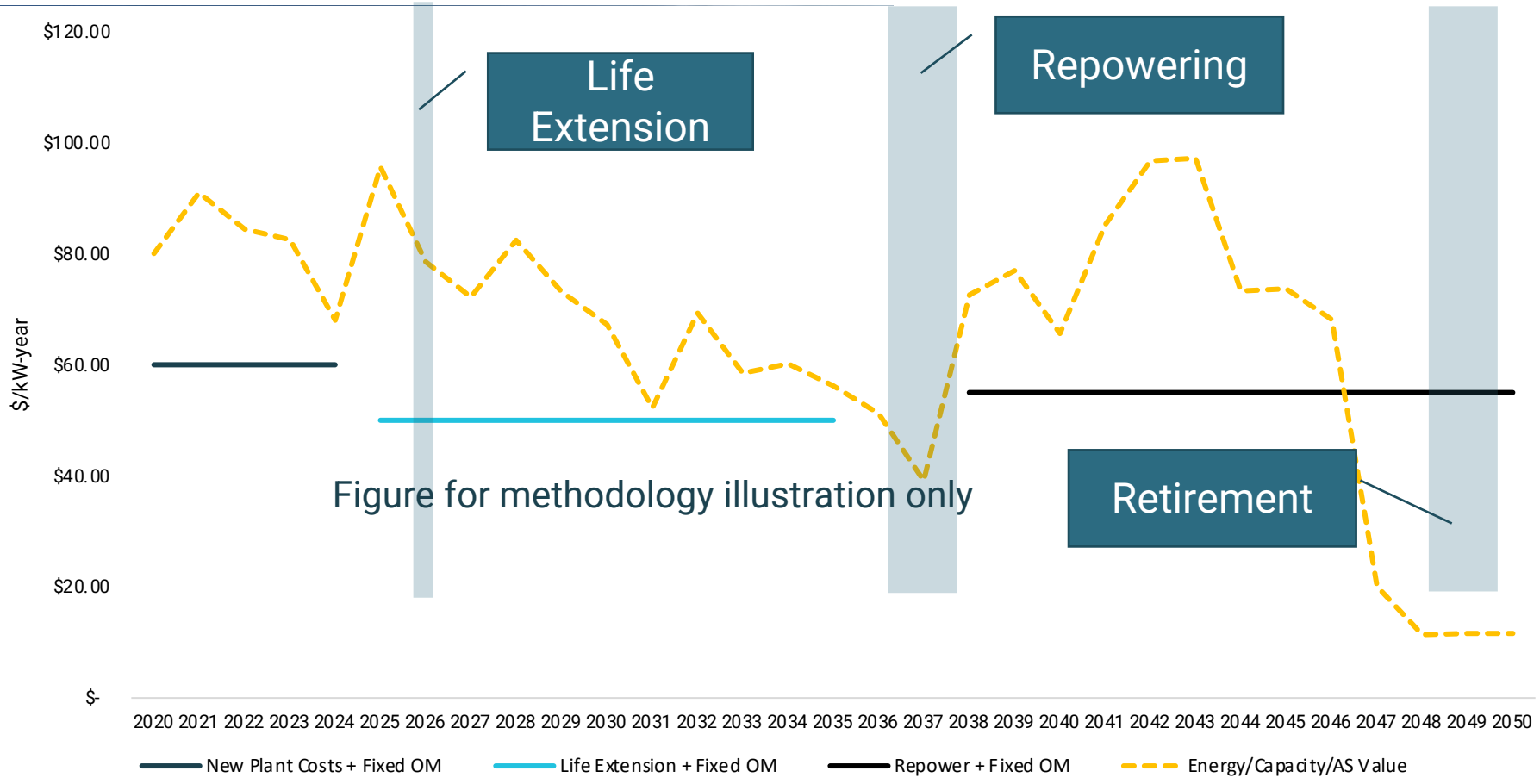


ECONOMIC GENERATOR LIFECYCLES

EVOLVED ENERGY RESEARCH

RIO optimizes plant investment decisions including life extensions, repowering, and retirements based on system value and ongoing costs





ELECTRICITY AND FUELS SECTOR INTEGRATION

EVOLVED ENERGY RESEARCH

- Traditional capacity expansion approaches have narrowly defined the problem in terms of the electric sector
- Decarbonization and pushes towards 100% renewables have revealed the inadequacy of that approach as both will require sectoral integration
- A key opportunity for sectoral integration is in the fuel-supply sector, as it may be counted on to provide low-carbon fuels for thermal generation/primary end uses and provide electricity balancing services to the grid
- Endogenizing decisions in both allows us to explore opportunities for sectoral integration that have escaped other modeling frameworks

HOW DOES RIO APPROACH RELIABILITY?

EVOLVED ENERGY RESEARCH

- Reliability is assessed across all modeled hours with explicit accounting for:
  - Demand side variations – higher gross load than sampled
  - Supply side availability – outage rates, renewable resource availability, energy availability risk, single largest contingencies
- Multiple years used in day sampling adds robustness
- Advantage over pre-computed reliability assessments because it accommodates changing load shapes and growing flexible load
  - Any pre-computed reliability assessment implicitly assumes a static load shape, which is not a realistic assumption
- No economic capacity expansion model can substitute fully for a LOLP study, but different models offer different levels of rigor

Hourly Reliability Snapshot

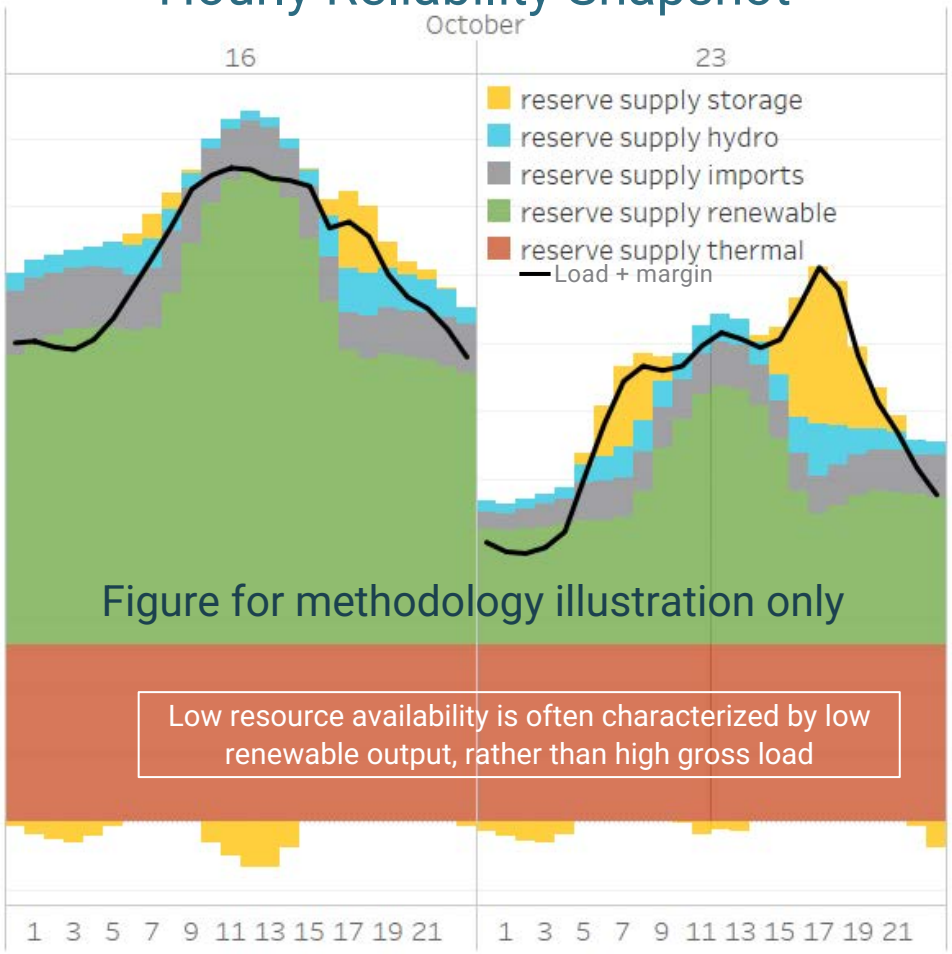


Figure for methodology illustration only

Low resource availability is often characterized by low renewable output, rather than high gross load

EVOLVED
ENERGY
RESEARCH

APPENDIX: VEHICLE CHARGER ASSUMPTIONS

VEHICLE CHARGER ASSUMPTIONS

EVOLVED ENERGY RESEARCH

- Numbers of vehicle chargers installed are based on assumptions from the NREL Electrification Futures Study about the ratios of different types of chargers per million vehicles
  - Total transportation costs include the cost of installing these chargers
- Light duty vehicle chargers installed per million vehicles are from (Melaina et al. 2016):

Charger Type	DC Fast Charger	Community Level 2	Community Level 1	Work Level 2	Work Level 1	Home Level 2	Home Level 1
Chargers per million vehicles (thousands)	0.47	11.11	0.43	166	166	328	559

- Medium and heavy-duty truck DC fast charger installations are based on assumptions on how many vehicles can be charged everyday by a charging complex
  - Calculated using coincident peak power output over 10-hour daily operations/vehicle battery size assuming 80% depth of discharge
  - Assumes 350kW for heavy duty and 50kW for medium duty

HOW MANY CHARGERS IN ARIZONA BY 2050?

EVOLVED ENERGY RESEARCH

- Total numbers of chargers assumed installed by 2050 are as follows:

Charger Type	DC Fast Charger	Community Level 2	Community Level 1	Work Level 2	Work Level 1	Home Level 2	Home Level 1
Total Chargers by 2050	152021	71463	2766	1067759	1067759	2109788	3595645

- These estimates are based on the NREL Electrification Futures Study for the purposes of estimating charger costs
  - However, charger installations in the future will depend on technological advances, vehicle battery sizes, and how customers and businesses utilize charging infrastructure to best fit their lifestyles or business activities
- One caveat to these numbers is that they reflect charging needs for vehicles registered in Arizona
  - Long-haul EV freight traffic passing through the state may increase charger capacity needs