Poland NECP Analysis

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Prepared for:

Carbon-Free Europe

Prepared by:

Evolved Energy Research

Agenda

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- Project Scope and Background
- Results
- Conclusions

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Project Scope and Background

Project Ambition

- Leverage modeling developed by Carbon-Free Europe to comment on Poland’s NECP
- Analyze multiple scenarios and sensitivities to develop additional understanding and intuition for Poland’s role in a broader regional and EU context
- Provide analysis and technical report that can be leveraged publicly to influence energy-sector decision-making. Provide outputs that can be used by Princeton to downscale energy sector infrastructure.

Background

- Leveraged updated ADP 2024 framework for underlying data and assumptions (technologies, fuel prices, European emissions prices, etc.)
- Re-configured the model topography and developed Poland-specific emissions targets
- Scenarios developed to represent varied futures for future Polish energy system with a focus on pathways to 2050

Background on Evolved Energy Research

EER addresses key policy and strategy questions raised by a transformation of our energy system to meet greenhouse gas emission goals

Annual Decarbonization Perspectives U.S. and Europe

NGOs

NRDC, TNC, SDSN, GridLab, Sierra Club, CETI, OCT, UCS, EDF, CATF, BPC, Third Way, RMI, and others

State & Local Energy Offices

Massachusetts, Washington, New Jersey, Maine

Utilities

PGE, DTE, Hydro Quebec, and others

Others

Princeton University, University of Queensland, Breakthrough Energy, Inter-American Development Bank, DOE, NREL, UVA

Methodology: Modeling Tools

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ENERGY PATHWAYS

<u>Demand-side tool</u>

- Produces bottom-up projection of final energy demand for all end-uses
- Incorporates scenario-based electrification and energy efficiency
- Characterizes rollover of stock over time
- Simulates the change in total energy demand and load shape for every end-use

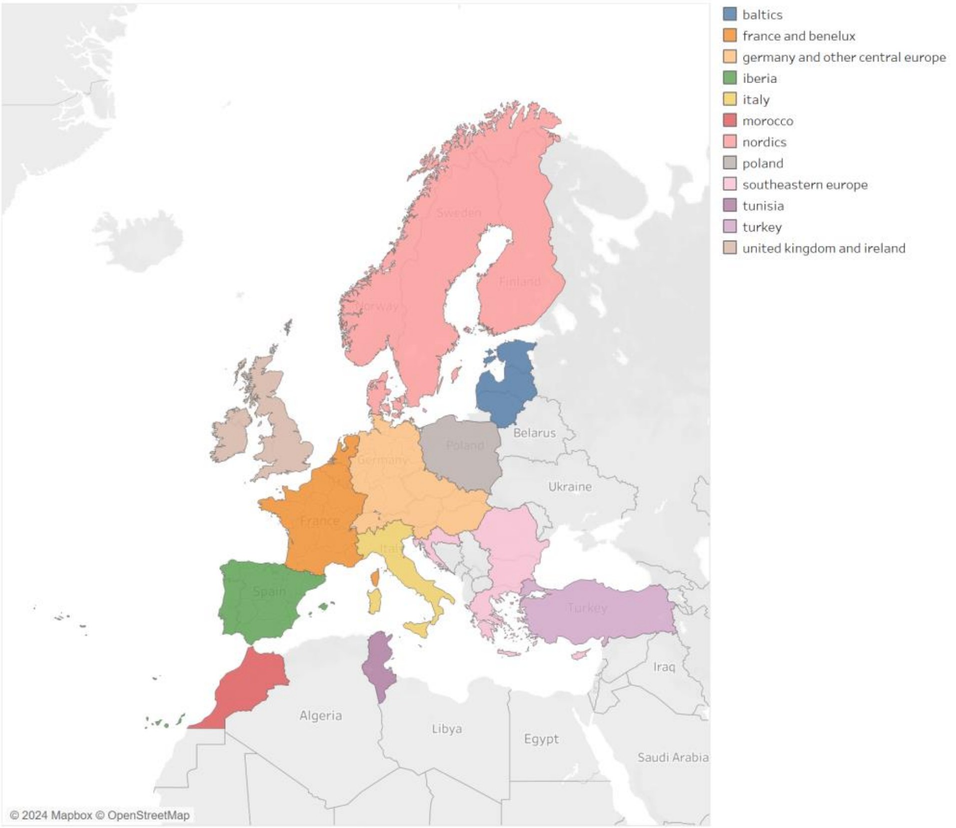
RIO

<u>Supply-side tool</u>

- Capacity expansion model produces cost-optimal energy supply
- Simulates hourly electricity operations and annual investment decisions
- Electricity and fuels are co-optimized to identify sector coupling opportunities
- State of charge of electricity and fuels storage tracked over the year
- Minimizes net present value of costs for a study horizon

Scenarios and Model Setup

Scenarios	Description
Core	Net-Zero RIO scenario for Poland (straight-line from 2022 to 2050) with standard resource availability, costs, etc. Based on a high-electrification demand scenario.
High Biomass	Expanded availability of biomass resources including forestry wastes and energy crops
High Coal w/CCS	Requirement to maintain at least 15 GWs of coal plants (with or without CCS) operating at least at 50% capacity factors. Coal w/CCS deployment optimal under that constraint.
High Nuclear Costs	Assumes a higher cost trajectory for new-build nuclear plants.
High Offshore Wind Costs	Standard assumption is supply curves based on aggressive long-term offshore wind cost declines. This uses supply curves for cost and performance based on more moderate cost and performance improvements (13-20% LCOE premium over Core assumptions)
No Additional Onshore Wind	No onshore wind able to be built in Poland past planned projects with a 2024 online date (caps overall onshore wind at 11.6 GW).
Slow Consumer Uptake	Net-Zero scenario with more limited contributions from electrification and fuel switching.
Reference	Scenario that combines the consumer behavior in **Slow Consumer Uptake** and hits emissions limits consistent with current Polish policy (35% reduction from 1990 levels by 2030)



Key Model Inputs

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Supply

Input	Unit	2030	2050
Nuclear LCOE	€/MWh	85/ 123	58/ 82
Offshore Wind LCOE	€/MWh	44-57/ 50-64	35-48/ 42-51
Onshore Wind LCOE	€/MWh	34 -45	32 - 43
Large Scale Solar - LCOE	€/MWh	40	37
Rooftop Solar - LCOE	€/MWh	50	41
Offshore Wind Resource Potential	GW	81	81
Onshore Wind Resource Potential	GW	28	28
Large Scale Solar Resource Potential	GW	29	29
Rooftop Solar Resource Potential	GW	91	91
Natural Gas Price	€/GJ	5.8	4.8
Coal Price	€/GJ	2.5	2
Lignite Price	€/GJ	1.8	1.8
Geologic Sequestration Annual Injection Potential	Mt CO2	18	18
Biomass Limit	Mtoe	15 / 38	16/ 41
Emissions Target	Mt CO2e	261/ 290	0/ 261

Demand

Input	Unit	2030	2050
Passenger EV Stock	Vehicles	8,500,000/ 1,900,000	19,300,000/ 15,400,000
Freight EV Stock	Vehicles	660,000/ 220,000	3,230,000/ 2,320,000
Freight FCV Stock	Vehicles	220,000/ 90,000	1,080,000/ 780,000
Residential Heat Pumps Stock Share	%	16%/ 3%	45%/ 31%
Tertiary Heat Pump Stock Share	%	50%/ 42%	75%/ 67%

- All Other Scenarios
- High Nuclear Costs
- High Offshore Wind Costs
- High Biomass
- Reference
- Slow Consumer Uptake

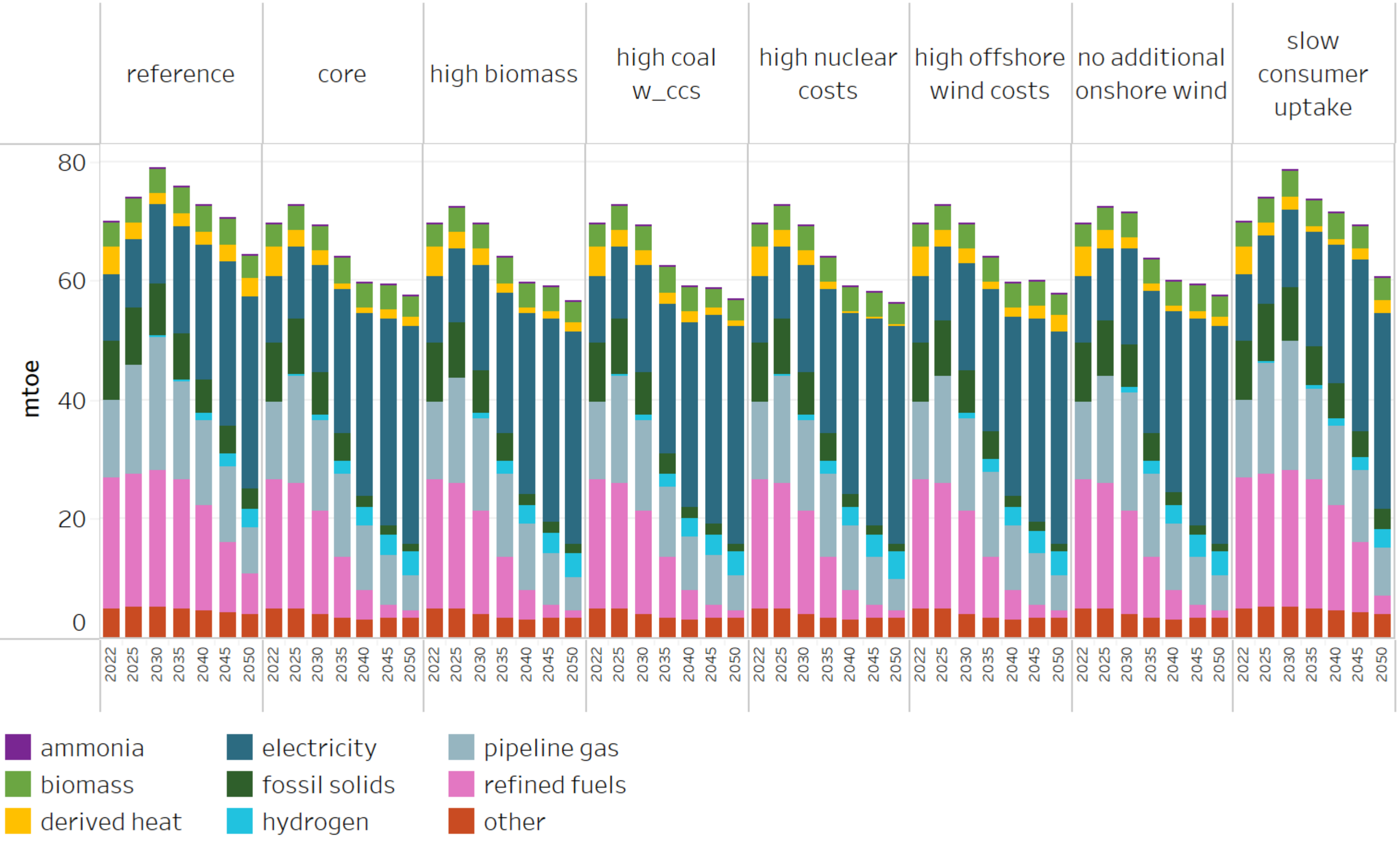
Results

Scenario Impacts

Scenarios	Description	High-Level Impact
Core	Net-Zero RIO scenario for Poland (straight-line from 2022 to 2050) with standard resource availability, costs, etc. Based on a high-electrification demand scenario.	
High Biomass	Expanded availability of biomass resources including forestry wastes and energy crops	Expansion of fuels production (hydrogen, e-fuels, and biofuels) as the biomass carbon becomes a high-value carrier of energy (e-fuels and biofuels) or valuable for sequestration.
High Coal w/CCS	Requirement to maintain at least 15 GWs of coal plants (with or without CCS) operating at least at 50% capacity factors. Coal w/CCS deployment optimal under that constraint.	Large increase in necessary inter-regional CO2 pipelines to store carbon (exports of ~100 Mt annually by 2050). Reduction in new nuclear electric capacity.
High Nuclear Costs	Assumes a higher cost trajectory for new-build nuclear plants.	Model chooses not to construct new nuclear facilities, replacing their energy principally with an expansion of offshore wind resources and their reliability contributions with a mix of battery storage and additional gas resources.
High Offshore Wind Costs	Standard assumption is supply curves based on aggressive long-term offshore wind cost declines. This uses supply curves for cost and performance based on more moderate cost and performance improvements (13-20% LCOE premium over Core assumptions)	Reduction from 45 GWs of offshore wind in Core scenario to 27 in High Offshore Wind Costs as higher offshore wind costs lowers its competitiveness against nuclear (Increase of 8 GWs of nuclear capacity).
No Additional Onshore Wind	No onshore wind able to be built in Poland past planned projects with a 2024 online date (caps overall onshore wind at 11.6 GW).	New onshore wind capacity is replaced almost completely by additional floating offshore wind.
Slow Consumer Uptake	Net-Zero scenario with more limited contributions from electrification and fuel switching.	Requires an accelerated retirement of existing coal generation to make up for more limited reductions from electrification of heating and transport. Coal generation not necessary to meet additional 2030 load growth seen in **Core.**
Reference	Scenario that combines the consumer behavior in **Slow Consumer Uptake** and hits emissions limits consistent with current Polish policy (35% reduction from 1990 levels by 2030)	Maintains coal generation through 2050. More limited deployment of clean energy technologies in electricity and more limited expansion of clean fuel sectors (hydrogen and biofuels).

Final Energy Demand

- Core scenario reduces 2030 demand approximately in line with 2030 NECP target
- Slower consumer uptake of efficiency and electrification increases final energy through 2030 before declining by 2050 with electrification



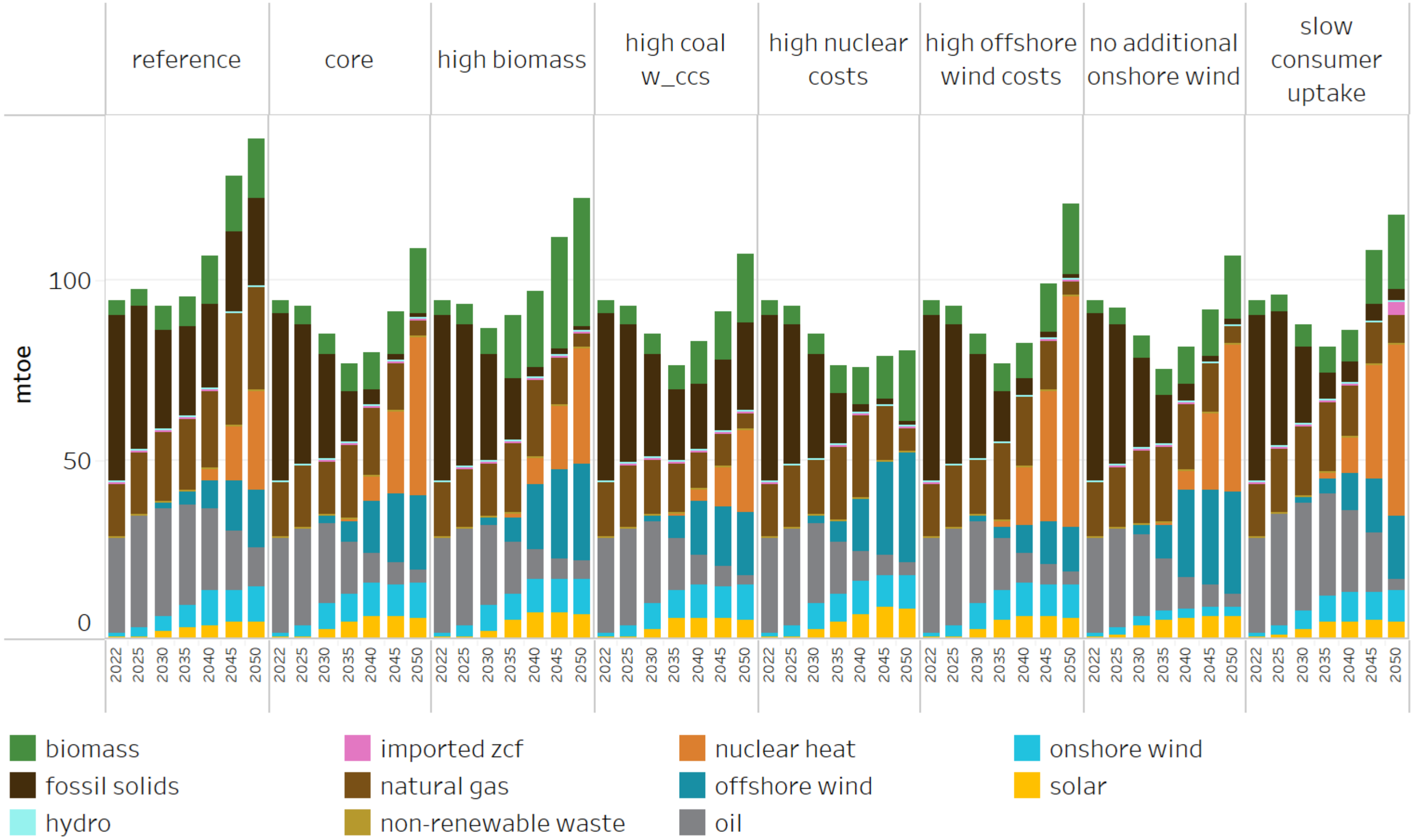
Final Energy Demand by End-Use

Core

- Significant final energy efficiency in space heating (transition from boilers to heat pumps along with building envelope improvements) as well as on-road vehicles (ICE to EV transition)
- Continued growth in industrial demand offset by some efficiency gains

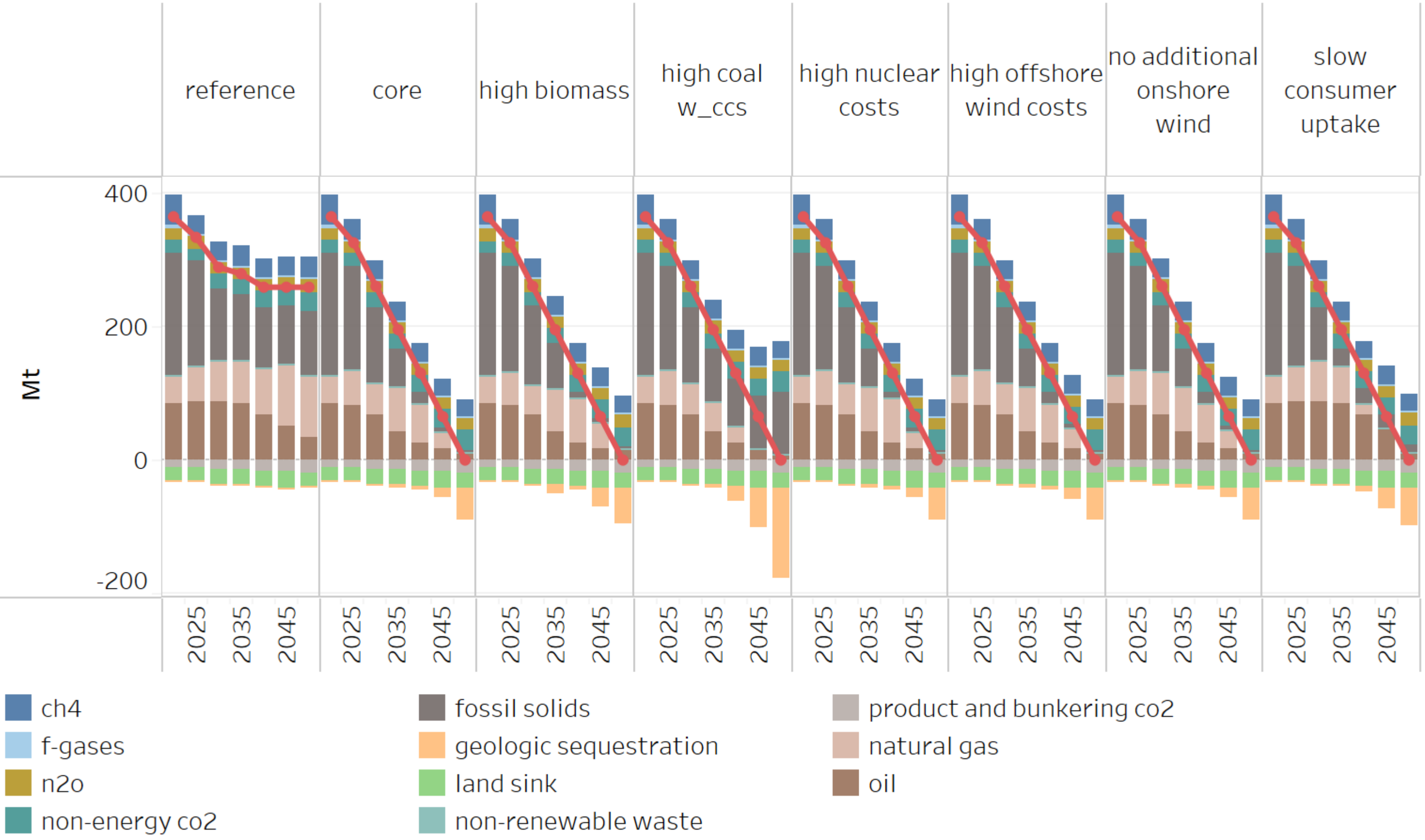
Primary Energy Demand

- Primary energy results can vary widely depending on electricity resource selection and hydrogen production processes as well as the achieved level of electrification
- High Offshore Wind Costs (resulting in more nuclear) our and High Coal w/CCS both increase primary energy; High biomass availability also increases primary energy use (given the conversion efficiency of biofuels production)



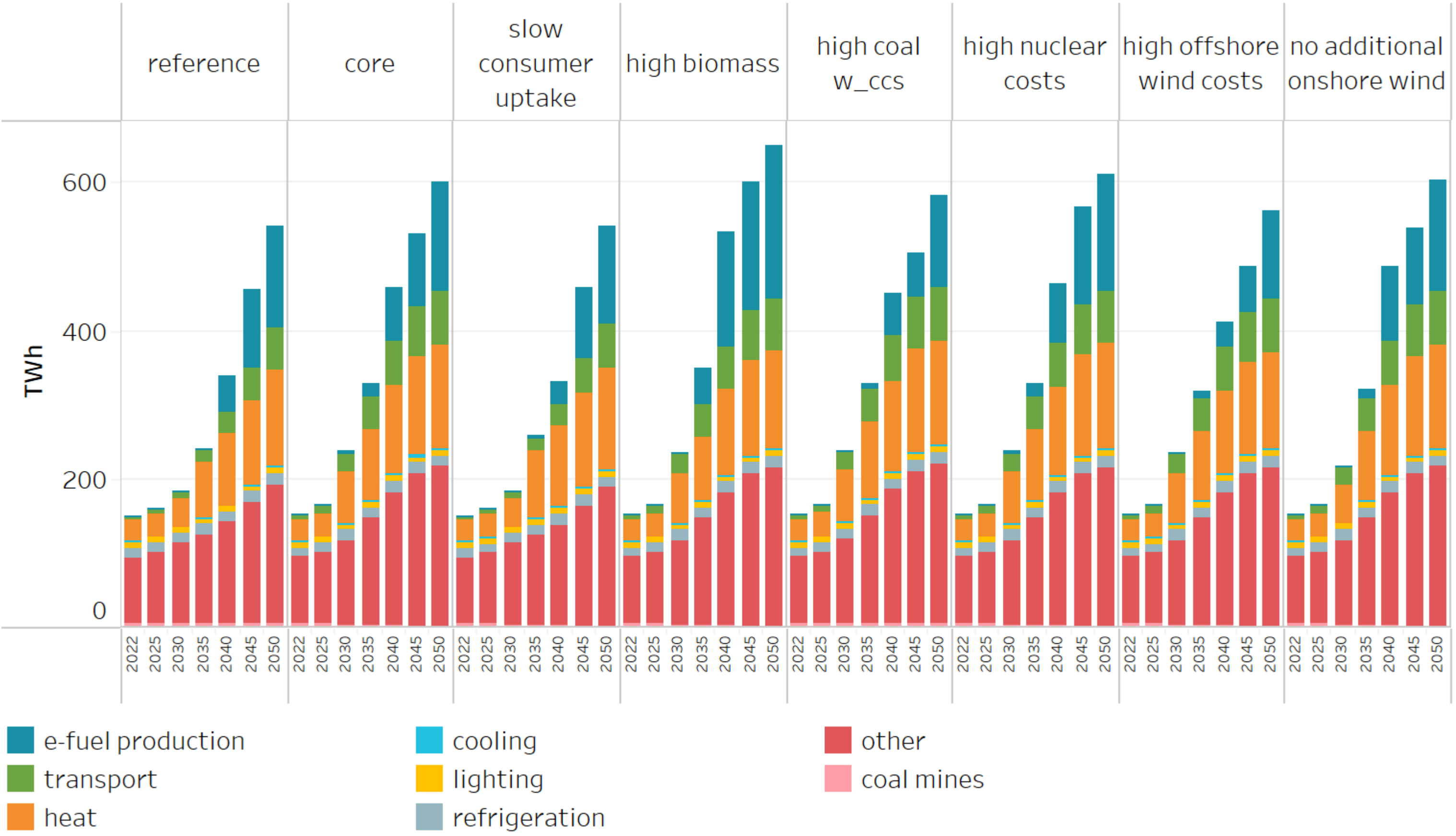
Emissions

- Early emissions reductions driven by replacement of coal in electricity
- Core case also sees declines in oil use through electrification of transport
- Long-term emissions reductions from continued electrification and displacement of gas in buildings, industry, and power



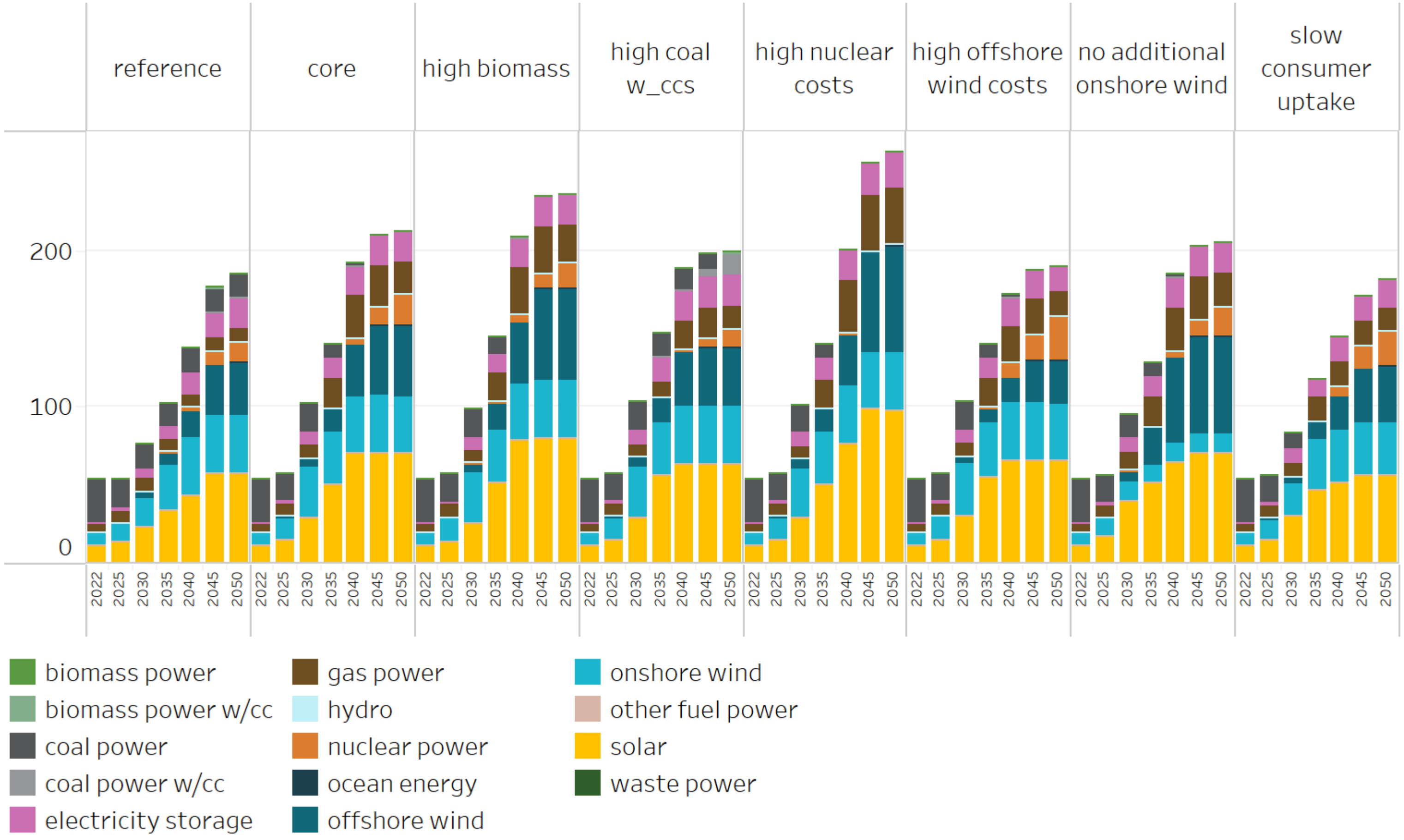
Electricity Sector - Load

- Large increase in overall electricity demand in all cases
- Largest increases in heat, transport, and e-fuel production (electrolysis). Many of these loads are different than current electric loads in terms of voltage and potential location (i.e. electrolysis loads can be collocated with generation resources) so it doesn't imply a commensurate increase in grid capacity
- The necessity to plan, invest, and deploy a large amount of new capital in the electric sector is obvious given precipitous increases in load



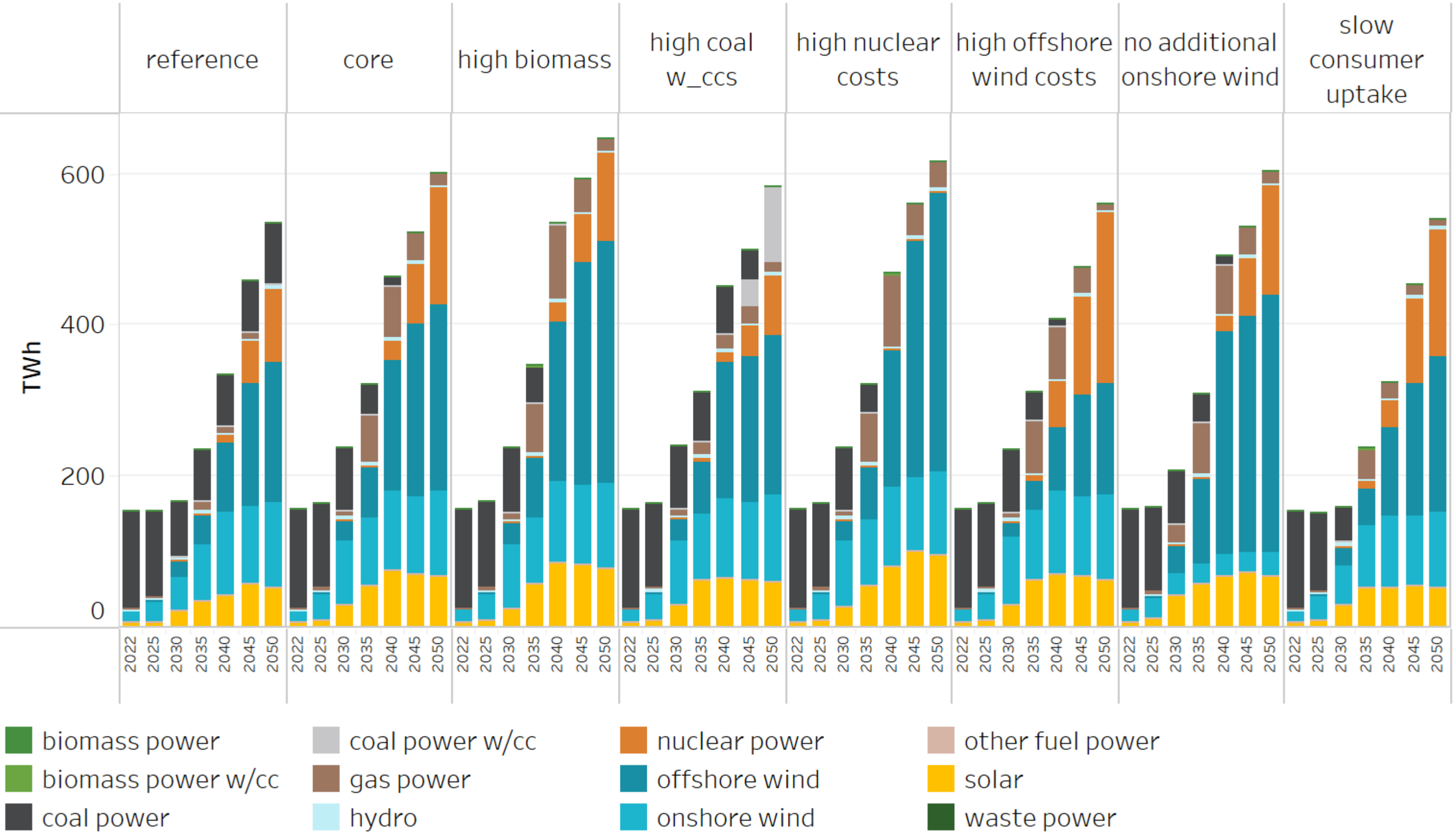
Electricity Sector - Capacity

- Economic onshore wind deployment is consistent across cases except where restricted (**No Additional Onshore Wind**)
- **High Nuclear Costs** results in a significant increase in renewable capacity deployed (offshore wind and solar) as well as the largest increase in gas and electricity storage to provide reliability
- **High Coal w/CCS** sees over 13 GWs of coal CCS capacity



Electricity Sector - Generation

- Significant increases in electricity demand means that there is a dual challenge of phasing out coal in a growth environment
- Technology deployment in the this analysis is very sensitive to anticipated resource costs; some scenarios have heavily nuclear portfolios while high anticipated costs prevents optimal build altogether.
- Suggests a balanced future might be appropriate to hedge risk of single technology being too large a part of the portfolio.

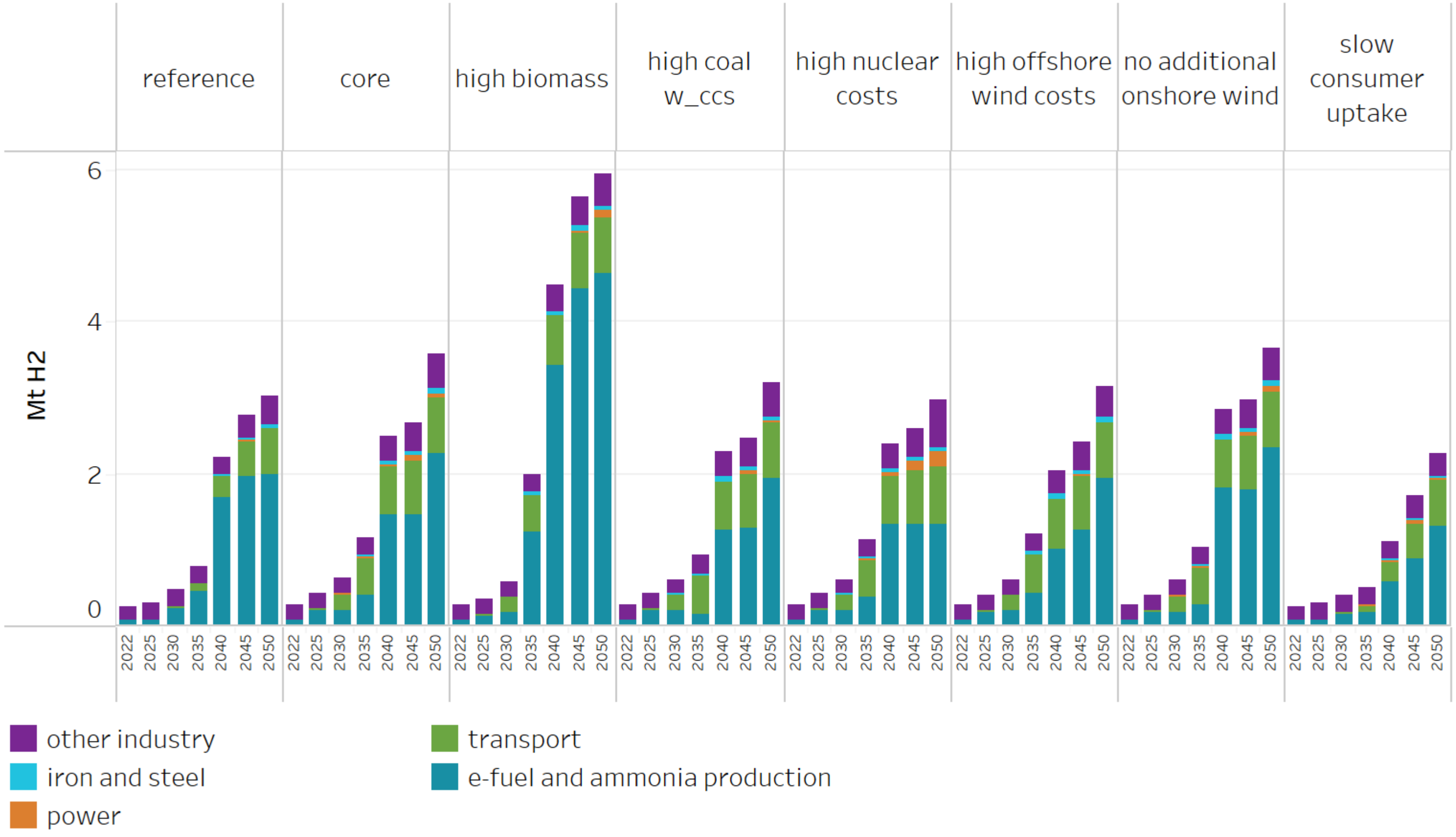


Storage Needs

- Highly renewable systems necessitate an economy-wide energy balancing strategy including electricity, heat, and hydrogen storage to mitigate overgeneration and undergeneration conditions
- The highest level of storage needs are in the **High Nuclear Costs** scenario, which includes a higher share of renewables in the electric sector.

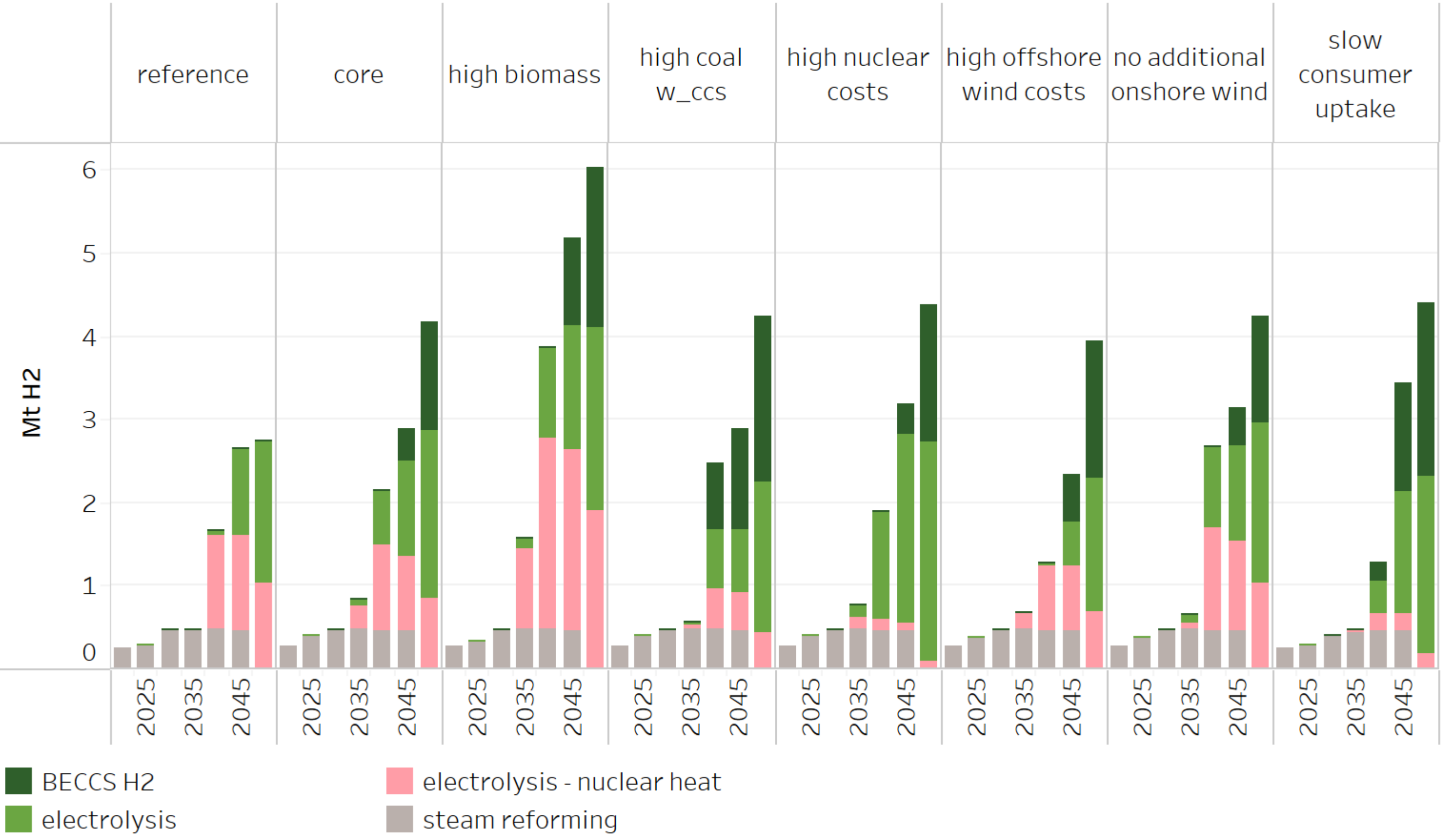
Hydrogen Demand

- Poland becomes a significant producer of e-fuels (ammonia; synthetic liquids) due to availability of electricity resources as well as potential carbon feedstocks (principally biomass capture). This is seen most clearly in the **High Biomass scenario**.
- Other scenarios are similar to each other in terms of hydrogen demand, with only **Slow Consumer Uptake and Reference** seeing less direct demand in transport and industry



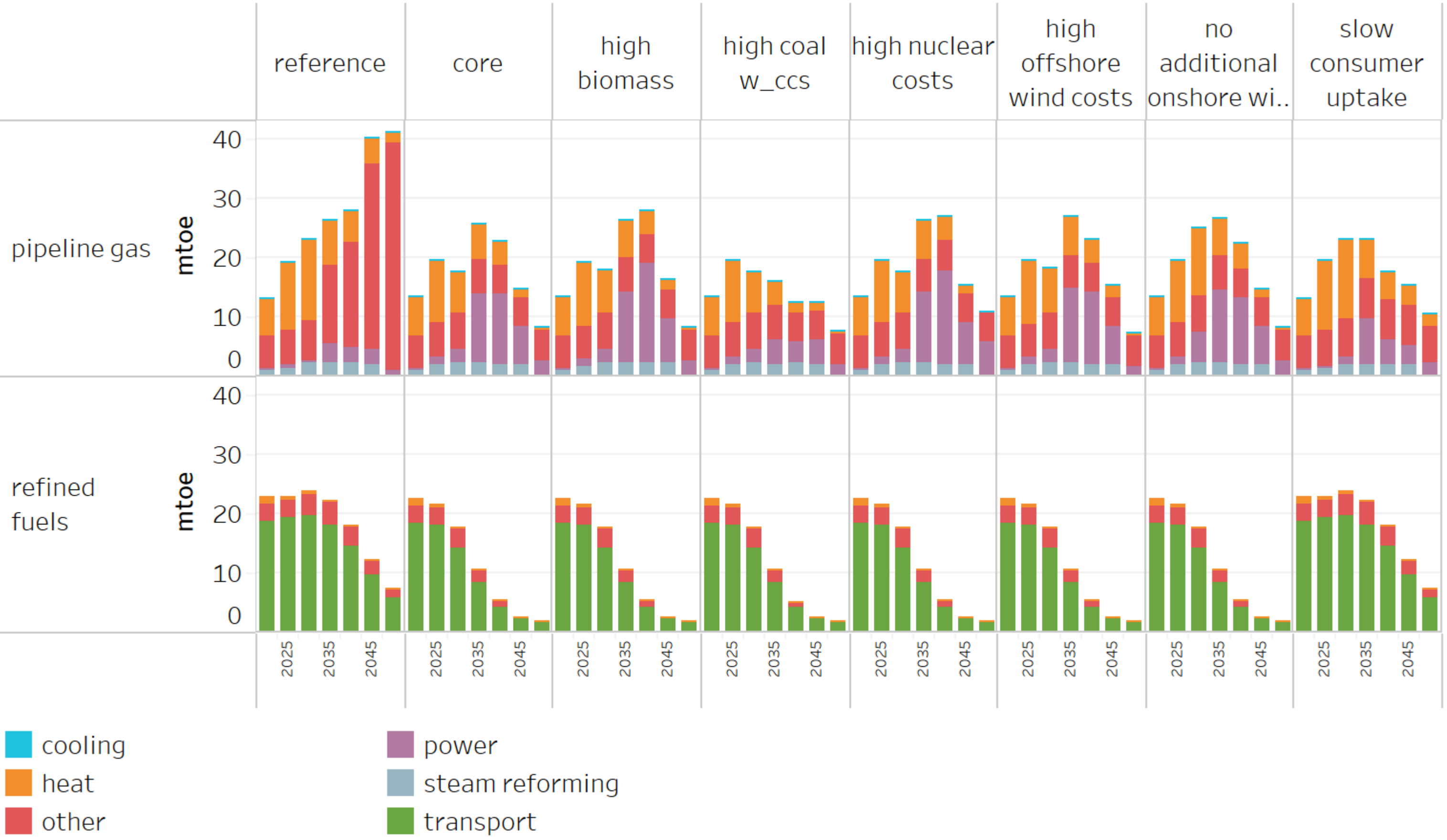
Hydrogen Production

- Poland leverages its nuclear, offshore wind, and biomass potential to become a large producer of hydrogen in the long-term
- In the near-medium term, electricity resources are devoted to decarbonizing electricity supply directly, and so domestic hydrogen production is slow to develop



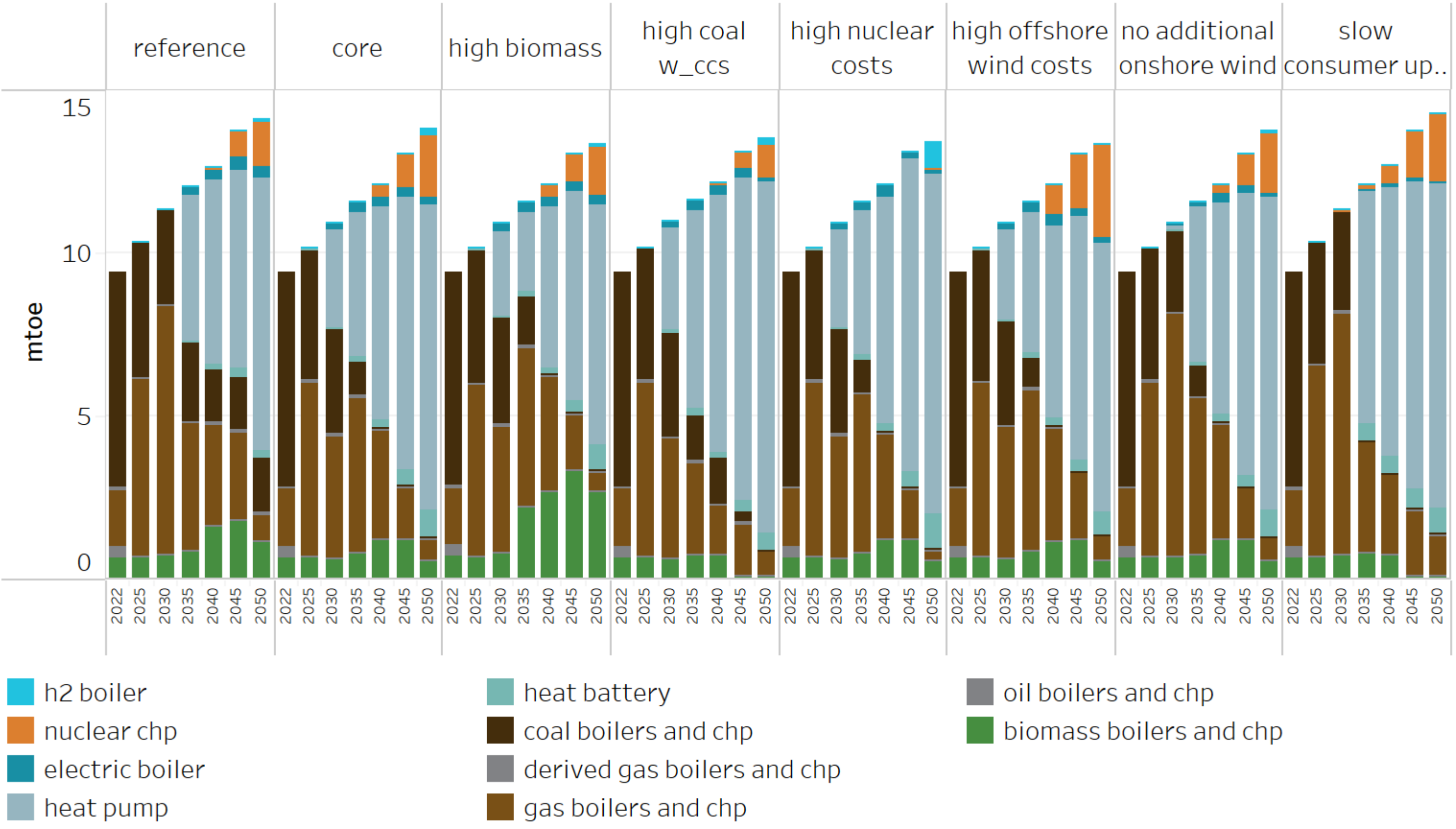
Other Fuels

- We see an increase in gas in many scenarios as coal is retired and displaced (principally with renewable) but also with some gas (for heating and power)
- Refined fuels demand is commensurate with the pace of electrification, with the **Slow Consumer Uptake** scenario seeing the slowest decline



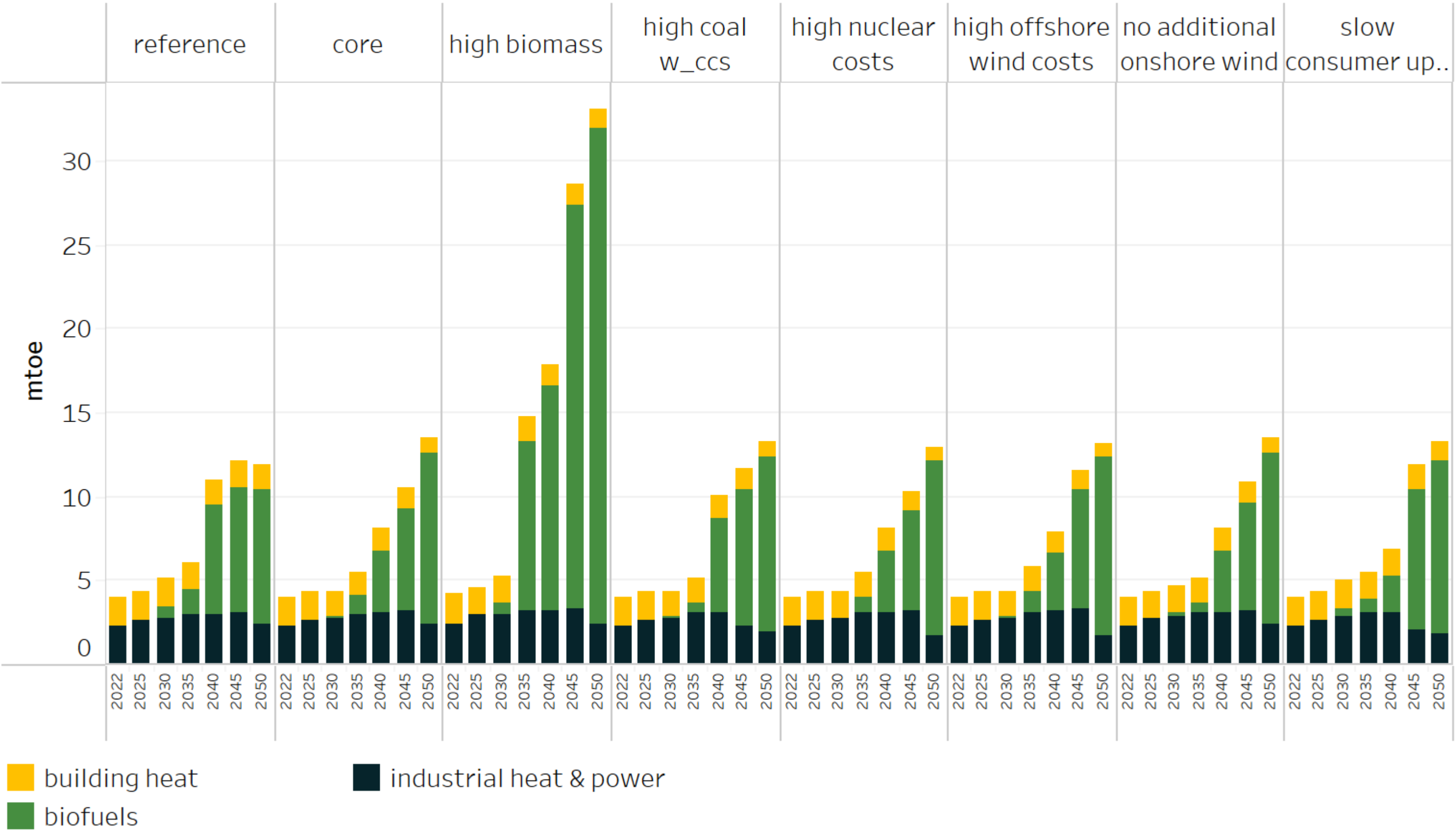
Steam Supply

- The coal phaseout happens in both power as well as steam production. In early years, coal provides the majority of steam in Poland.
- Heat pumps are deployed in the 2030s with continued decarbonization of electricity with electric and fuel boilers used to meet peak steam demands
- Some nuclear facilities in the long-term are integrated as CHP facilities similar to the role currently played by coal



Biomass Usage

- Biomass use in buildings declines in the long-term with deployment of heat pumps and improvement in building envelopes
- Industrial heat provision is consistent
- Growth is almost entirely in biofuels production (BECCS H2 or BECCS liquid fuels)



Carbon Management

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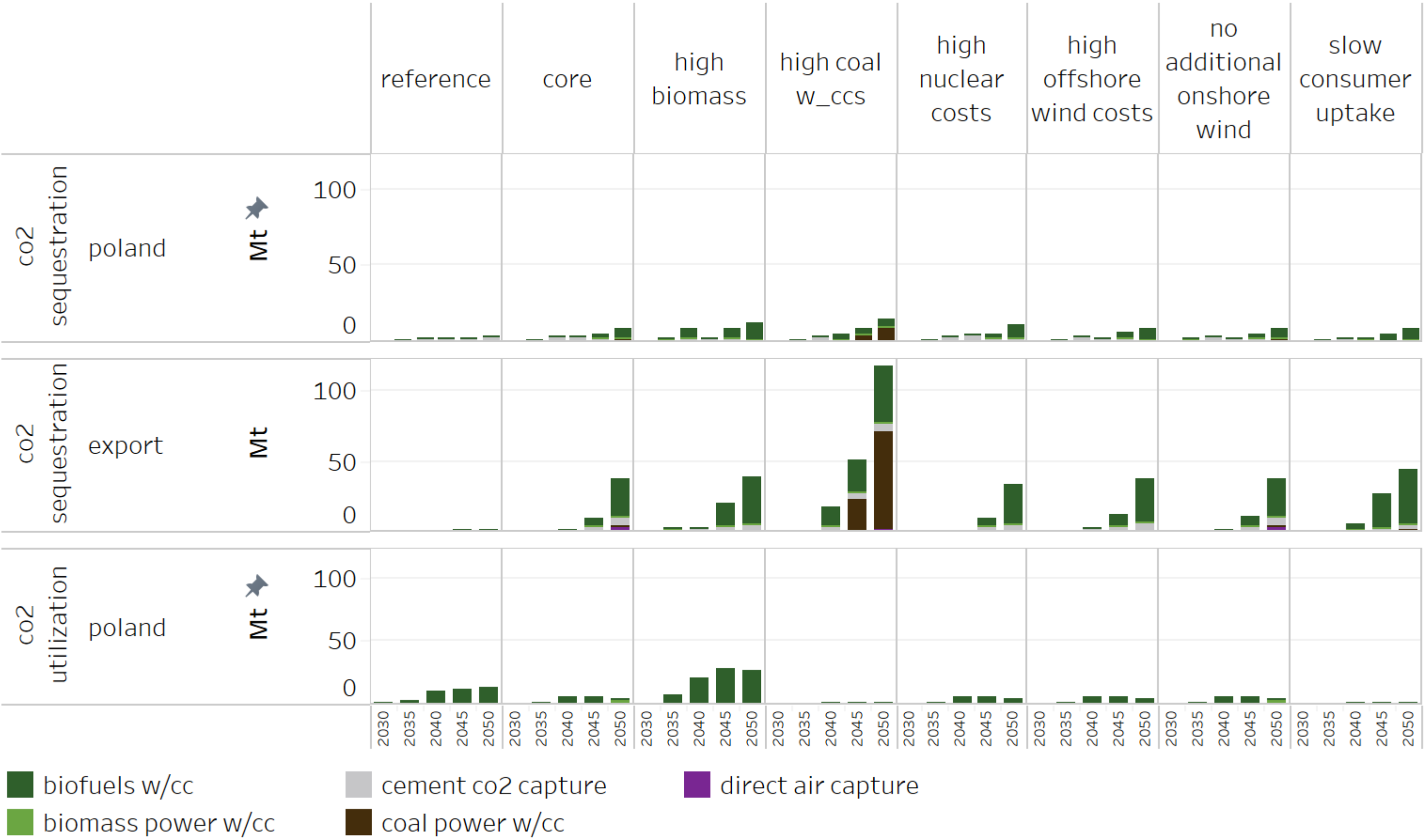
- Poland becomes a net exporter of CO2 in almost all cases through constructed pipelines to other countries with more attractive sequestration opportunities. This is seen most starkly in the **High Coal w/CCS** scenario.
- CO_2 utilization from capture at biofuels facilities allows for additional synthetic fuel production with the highest amount of utilization occurring in the **High Biomass** scenario.

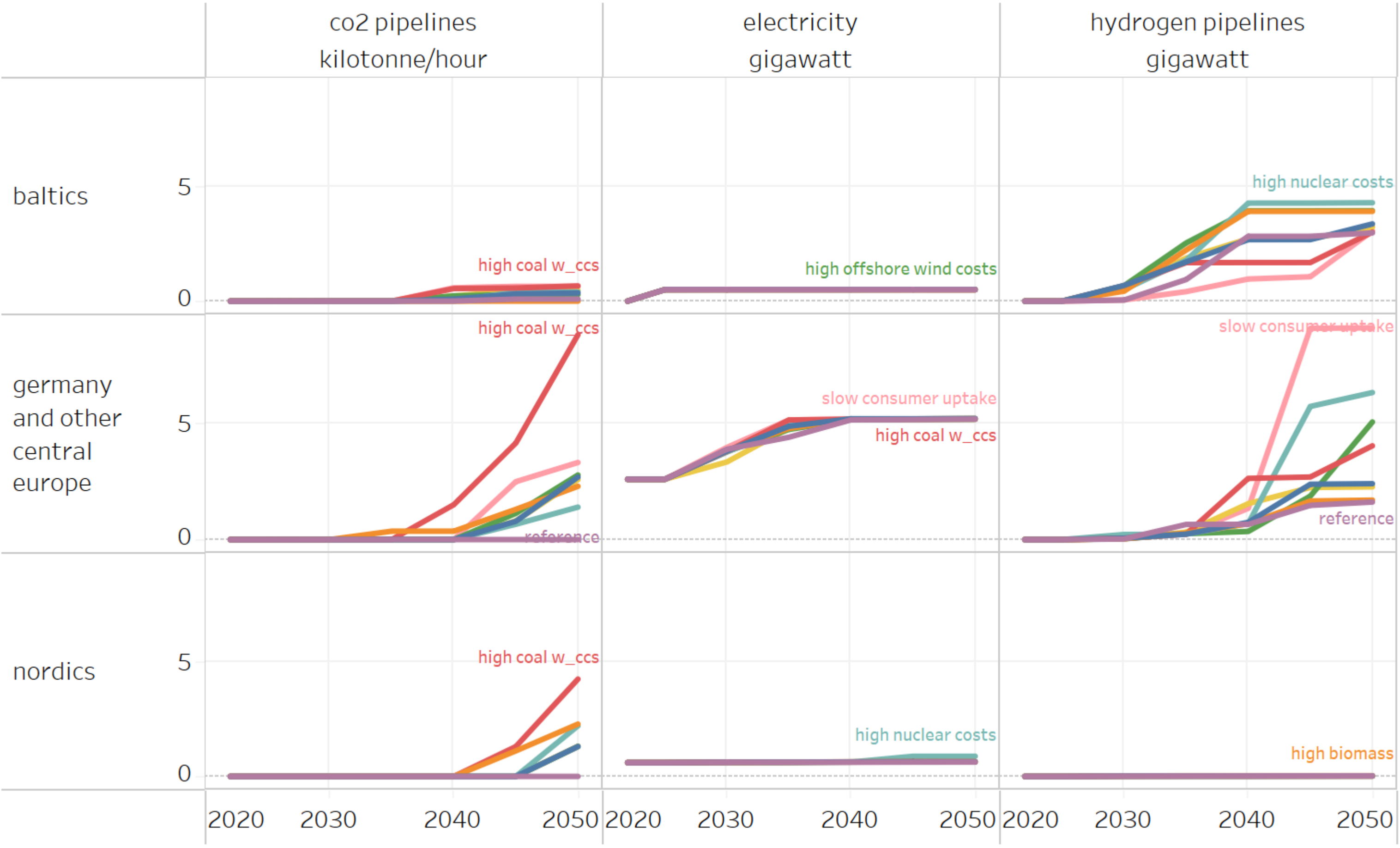


Resource Utilization

- Key decarbonization resources include renewable potential, biomass, and geologic sequestration
- Assessing how each scenario uses the overall resource potential an be illuminating as to their robustness as well as indicate the attractiveness of different resource types to the model
- Almost all of the estimated fixed-bottom offshore wind is deployed in all scenarios
- Floating offshore wind is deployed as an alternative in the **High Nuclear Costs** or **No Additional Onshore Wind** scenarios
- Except for the highest cost supplies, almost all biomass is used in all scenarios, with **High Biomass** leveraging almost the entire increase in supply

Connectivity

- Greater interconnection with Germany and other Central European countries is economic in all cases
- The model also builds transboundary H2 pipelines from the Baltics through to Germany
- In the **High Coal w/CCS** scenario, the necessity to store over 100 MTs of CO2 requires expansions of pipelines to both Germany and the Nordic countries



Net Costs

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- In the short-term, electrification of both vehicles, heating, and industry drives additional costs (+3B in the Core scenario in 2030 vs. .1B in **Slow Consumer Uptake)**
- In the longer-term, however, this delay significantly increases costs, with costs becoming significantly larger by 2050 with an incomplete demand-side transformation (5.3B vs. 12.1B)
- The **High Coal w/CCS** scenario increases costs in most years, with the most significant increase coming by 2050 where the relatively high costs of this electricity generation source, couple residual uncaptured emissions from coal imposing a significant burden on other sectors to additionally decarbonize, results in the highest cost scenario

2050 Net Cost by Sector

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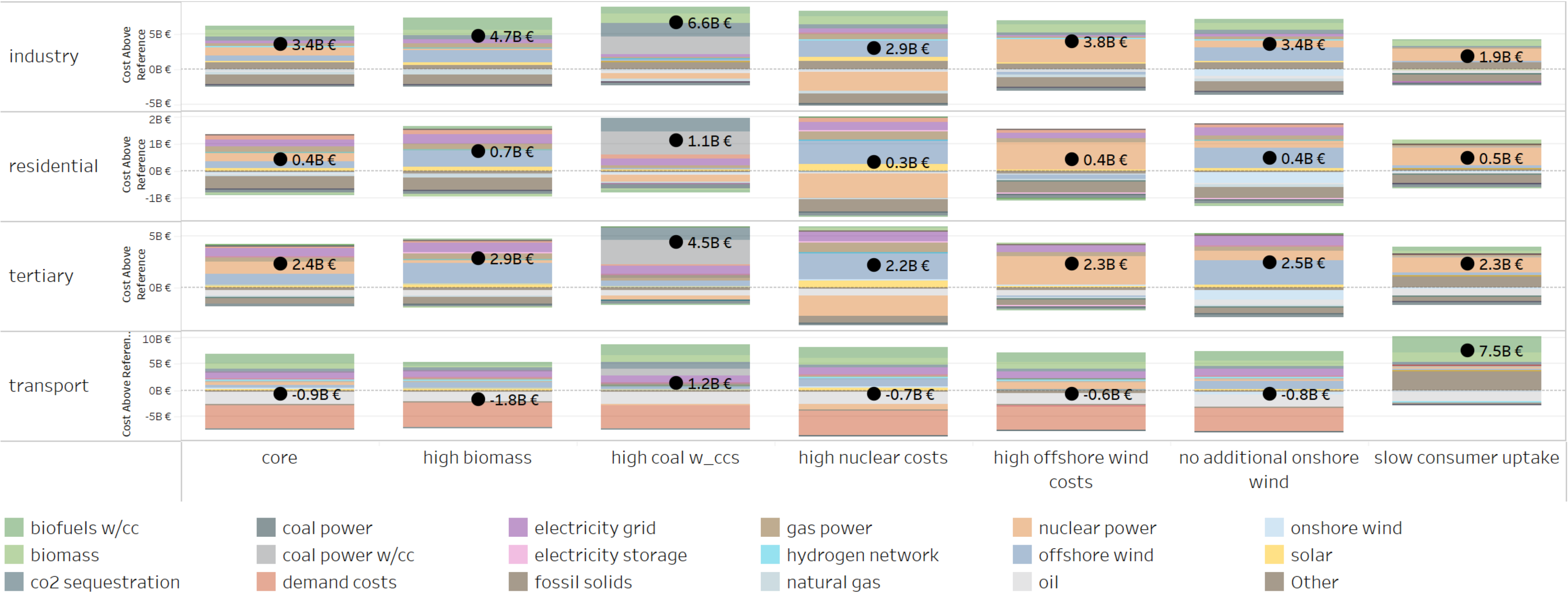

Key Supply-Side Investments by Decade

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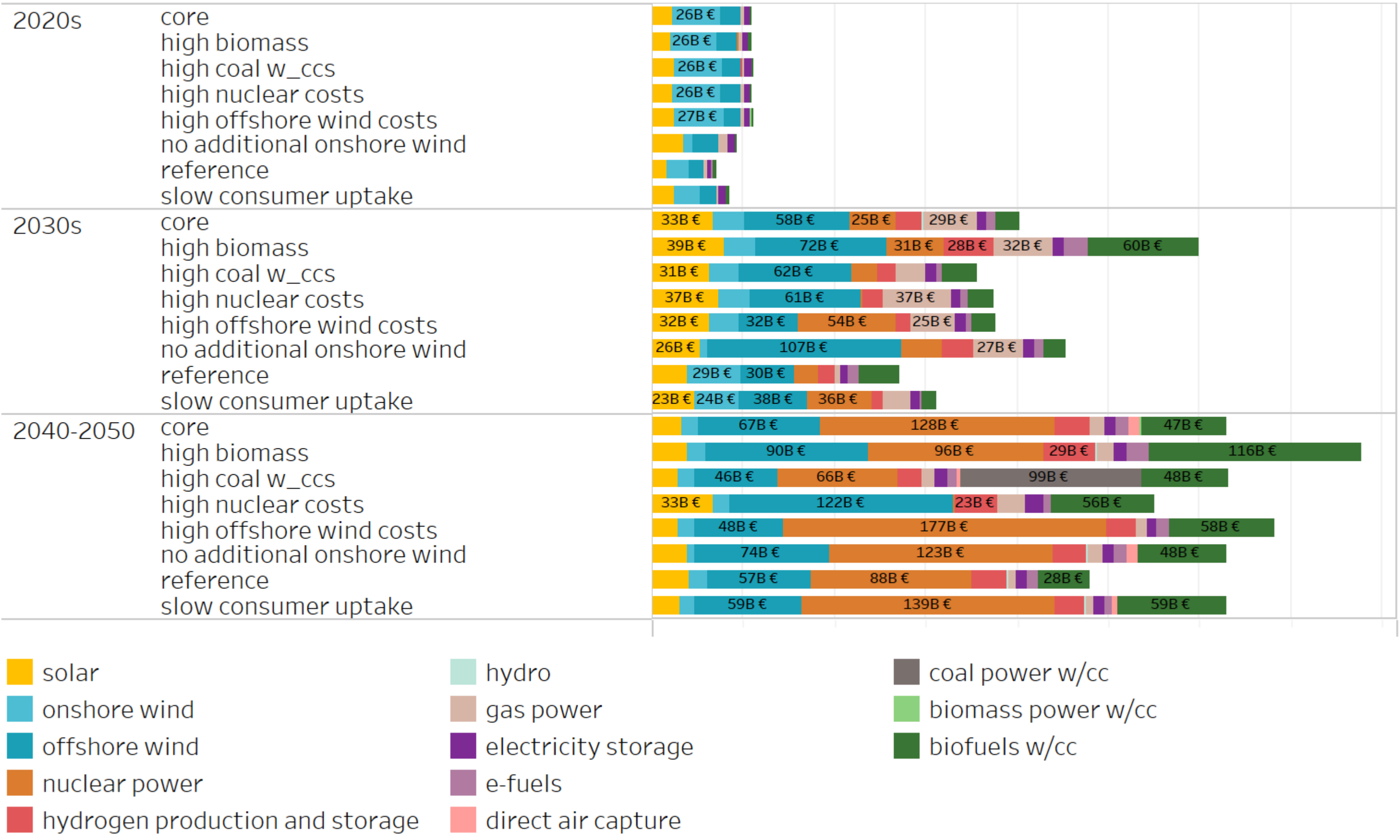
- Investment in key energy producing and converting technologies shows the necessary scale-up in spending (offset by savings from fossil fuels).
- Large differences in primary energy are reflected in the differences in the scale of investments (e.g. nuclear vs. offshore wind)
- Necessary investments peak in the 2040s with the rapid electrification of the economy



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Discussion and Critical Questions

Discussion

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- This analysis improves on previous ADP analysis for Poland by developing a suite of scenarios that reveals some of the critical questions facing decision-makers as they position Poland for rapid decarbonization in the coming decades
- Further work will include a geospatial downscaling by the Princeton team of energy system outcomes modeled here.
- The following slides speak to critical questions identified in the course of this analysis that will need to be answered to ensure a successful energy system transition

Critical Questions

- Pace of coal retirement
  - Meeting aggressive emissions targets in most scenarios means the rapid reduction in uncaptured coal generation, necessitating the simultaneous decarbonization of electricity and heat all while overall demands for both are likely to be increasing.
- The role of nuclear in the long-term under uncertain cost trajectories
  - In some scenarios, nuclear is a lynchpin resource that provides a large source of reliable electricity as well as heat and hydrogen production. In others, nuclear's contribution is much more limited but these systems have very different characteristics in terms of how the electricity system is operated; the economics of hydrogen production; and the necessity for storage and gas power and the scale of renewable build necessary.
- Transmission needs driven by offshore wind expansion
  - Our modeling has built-in transmission costs of for offshore wind resources but a portfolio that becomes offshore-wind dominant may need additional intra-regional transmission North to South that we haven't represented here. Those transmission needs may be mitigated with strategic placement of energy storage and hydrogen electrolysis.

Critical Questions cont.

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- Renewable Resource Availability
  - Poland has an attractive onshore wind resource that may be limited by societal preference. Significantly limiting this deployment will have Poland relying on either Floating Offshore Wind or nuclear facilities, both technologies with cost and performance uncertainty.
- Pace of consumer adoption
  - While electrification of heat and transport may be costly in the near-term, they position Poland for maintaining reasonable energy system costs in the long-term under net-zero pathways. Finding the appropriate middle-ground for Polish consumers will be critical.
- Geologic Sequestration
  - There is some uncertainty about the cost and injection potential of geologic storage in Poland. This limit is critical to many energy sector decisions (especially in the scenario that maintains a large amount of coal generation through 2050) and developing a better understanding of the types of CO_2 networks necessary under different scenarios would be helpful in determining their viability.

Critical Questions cont.

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- Sector Coupling Strategies
  - Sector coupling between electricity, heat, and fuels is important for maintaining reasonable energy system costs in decarbonizing systems. It is even more important in Poland given the large heat loads (building and industry) the potential for becoming a major producer of hydrogen. Decision-making in all of these sectors will have to be supported with good policy, market, and tariff design.

THANK YOU

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