AMERICA IS ALL IN

Technical Appendix: An All-In climate strategy can cut U.S. emissions by 50% by 2030

Overview of GCAM-USA-AP

The estimates of economy-wide emissions reductions in this analysis are based on a version of the Global Change Analysis model (GCAM) with a detailed representation of the U.S. energy system at the state level (GCAM-USA). We refer to the version of GCAM-USA used in this study as GCAM-USA-AP.

The global version of GCAM is an Integrated Assessment Model that represents the energy and economic systems for 32 geopolitical regions, including the United States. GCAM represents land use and agriculture in 384 land regions nested within 235 water basins. GCAM tracks emissions of a range of GHGs and air pollutants from energy, agriculture, land use, and other systems.

GCAM-USA is a version of GCAM that disaggregates the U.S. energy and economy components into 50 states and the District of Columbia while maintaining the same level of detail in the rest of the world and for water and land sectors. The energy system formulation in GCAM-USA consists of detailed representations of depletable primary sources such as coal, gas, oil and uranium, in addition to renewable resources such as bioenergy, hydropower, wind, and geothermal.

GCAM-USA also includes representations of the processes that transform these resources to final energy carriers, such as refining and electric power. These energy carriers, in turn, are used to deliver services to end users in the buildings, transportation, and industrial sectors. The electric power sector includes representations of a range of power generation technologies, including those fueled by fossil fuels, renewables, bioenergy, and nuclear power.

GCAM-USA is a market equilibrium model. The equilibrium in each period is solved by finding a set of market prices such that supplies and demands are equal to one another in all markets as the actors in the model adjust the quantities of the commodities they buy and sell. GCAM operates in 5-year time-increments, with each new period starting from the conditions that emerged in the last.

GCAM-USA-AP is based on the open-source release of GCAM-USA 5.3. GCAM-USA-AP has been modified for the purposes of this study, for example to reflect the latest renewable energy costs and vehicle technology costs. It is also calibrated to the latest non-CO_2 marginal abatement cost curves from the U.S. Environmental Protection Agency.[i]

Bottom-up aggregation of sub-national climate actions

This analysis relies on a previously developed methodology for aggregating the impact of non-federal climate actions across state, city, and business actors. Impacts are quantified sector by sector and actor by actor and aggregated to the state level, accounting for overlaps, before then being integrated with GCAM-USA-AP for simulation of full economy-wide impacts. A brief summary of the methodology is given below, followed by a table of key policies evaluated and underlying data sources (Supplementary Table 1). For a more detailed description of the aggregation methodology, please see the Accelerating America's Pledge Technical Appendix (2019)[ii] and Hultman, et al. research article (2020) and accompanying supplementary information.[iii]

The approach synthesizes current policies and commitments at multiple scales as well as the potential for accelerated and expanded policies. Sub-national entities implement emissions-related policies for many reasons, including cost savings, consumer benefits, health, economic growth, and climate. For simplicity, in this analysis we refer to any policy that reduces GHG emissions as a climate policy and overall categories of actions as policy sectors. The approach to quantifying the impact of city, state, and business actions was informed by existing protocols and methodologies such as the Non-State and Subnational Action Guide developed through the Initiative for Climate Action Transparency[iv], the Compact of Mayors Emission Scenario Model,[v] and the Greenhouse Gas Protocol Policy and Action Standard,[vi] among others.

Overall, the bottom-up aggregation process can be summarized as follows:

1. Survey, at a minimum, all 50 states and the 285 most populous cities in the U.S.
2. Identify a subset of high-impact actions for inclusion in the analysis
3. Collect the necessary data to quantify each action
4. Estimate a reference "no policy" scenario for each actor and emissions sector through 2030
5. Calculate combined impacts for each actor level (e.g., cities and states) for a "current measures" scenario reflecting only on-the-books actions
6. Calculate combined impacts for each actor level (e.g., cities and states) for "enhanced" scenarios that assume additional policy ambition beyond present-day levels
7. Aggregate impacts within each sector to the state level, taking into account overlaps.
8. Pass the information to GCAM-USA-AP.

Supplementary Table 1. Summary table of climate policies and actions included in aggregation analysis and key data sources by sector:

Policy Sector	Key climate policies/actions evaluated	Key underlying data sources
Emissions Caps	State-level power sector emissions caps (RGGI); state-level economy-wide emissions caps	C2ES[vii]; CARB[viii]
Renewable electricity generation	State-level renewable portfolio standards and clean electricity standards; city-level renewable electricity targets; utility-level renewable electricity/emissions reduction targets	LBL[ix]; EIA historic data[x]; Sierra Club[xi]; DOE/NREL[xii]
Oil and gas methane abatement	State-level regulations covering new and existing facilities; business-level reductions reported through EPA Natural Gas STAR	EDF[xiii]; EPA[xiv]
Nuclear fleet retention	State-level zero-emission generation incentives and nuclear fleet maintenance policies	EIA[xv]
Vehicle electrification	State-level ZEV mandates; city-level fleet procurement targets	EIA[xvi,xvii]; NREL[xviii]
Vehicle fuel economy/tailpipe emissions standards	State-level vehicle emissions standards	California Air Resources Board[xix]; EDF[xx]; ICCT[xxi]
VMT reduction	State-level VMT reduction targets; city-level VMT reduction targets	ACEEE[xxii]; FHWA[xxiii]; DOE/NREL[xxiv]
HFC phasedown	State-level SNAP and RMP policies; business-level reductions reported through EPA GreenChill program	EPA[xxv]; CARB[xxvi]; WRI[xxvii]
Energy efficiency	State-level EERS policies; State-level building code adoption; city-level energy savings targets; city-level building code adoption; industry energy management standards	ACEEE[xxviii],[xxix];EIA[xxx]; PNNL[xxxi]; NEEP[xxxii]; LBL[xxxiii]
Natural and working lands	State-level climate solutions such as natural forest management, optimal nutrient application, and the use of cover crops.	Nature 4Climate[xxxiv]

Implementing Policies in GCAM-USA-AP

This emission reduction policy scenario projects how much GHG emissions could be reduced under a comprehensive, "all in" national climate strategy. In this scenario, the Biden-Harris Administration and Congress work in partnership with leaders across all levels of government to implement a suite of new ambitious measures to decarbonize the economy.

The policies explored in this study are described in Table 1 in the Working Paper. These policies were implemented by changing specific model parameters. In some cases, where appropriate, these policies are explicitly modeled in GCAM. In other instances, where an explicit approach is not appropriate or feasible, model parameters were adjusted to meet policy goals (Supplementary Table 2).

Supplementary Table 2. GCAM Implementation of Policy Assumptions

Sector	Modeled Policy	GCAM Implementation
GHG emissions	GHG Targets	All state and regional GHG emission targets, legislated or otherwise, are implemented using $MTCO_2e$ caps, aggregated to the grid region.*
Power	Clean Electricity Standard	A federal clean electricity standard is modeled through a combination of electricity policies and standards, which are described in greater detail below.
	Renewable Energy Targets	State and federal renewable energy targets are implemented by setting a minimum % of total electricity load to be met by renewable generation and aggregated to the grid region.
	Renewable Energy Incentives	Federal production tax credit (PTC) and the investment tax credit (ITC) are modeled through their current phase-down schedules.
	Standards on new gas	Federal and state constraints on new gas generation are modeled by prohibiting new gas plants without CCS starting in 2025.
	Incentives for Carbon Capture and Sequestration	Federal 45Q tax credit for CCS projects is modeled by specifying 556 TWh of gas CCS electricity generation in 2030.
	Nuclear Retention Incentives	State and federal incentives to retain existing nuclear generation are modeled by specifying nuclear generation pathways by state through 2030, resulting in 800 TWh of generation in 2030.
Transport	Combustion Engine Performance	State and federal ICE GHG performance goals are modeled by improving state-level vehicle fuel efficiency so that nationally, fuel efficiency reaches 118gCO2/mi for new passenger cars and 160g/mi for new light trucks and SUVs by 2030.
	LDV ZEV incentives	Aggregated state and federal 2030 ZEV targets are implemented by specifying additional ZEV stock necessary to meet targets at the state level. Federal policies to accelerate removal of old and inefficient vehicles is modeled by reducing the expected lifetime of vehicles manufactured prior to 2015, leading to the retirement of 100% of such vehicles by 2030.
	M/HDV ZEV incentives	2030 federal and state ZEV sales targets and incentives for ZEV HDVs are modeled by exogenously specifying state-level electric truck deployment to reach 7.4% for medium-duty vehicles and 9.3% for heavy-duty vehicles.
Buildings	Electrification	Combined federal and state building electrification standards and incentives are modeled by raising state-level consumer preferences for electric appliances.
	Energy efficiency	Combined state and federal energy efficiency targets and programs are modeled by reducing state-level building service demands.
Industry	Energy efficiency	The combined effects of state and federal energy efficiency performance standards and other policies are implemented as state-level aggregate energy efficiency improvements in the industry sector.
	Incentives for Carbon Capture and Sequestration	Federal 45Q tax credit for CCS projects is modeled by specifying 50 $MTCO_2$ sequestration in cement and biofuel sectors.
Non-CO2 emissions		Non-CO_2 reductions are modeled by implementing marginal abatement cost curves for CH_4, N_2O, and HFCs emissions based on the EPA MAC report. Baseline oil and gas methane emissions were updated from prior analysis to reflect reduced oil and gas consumption. State and federal level policies to mitigate CH_4 emissions were implemented by assuming a 60% emissions reduction from the baseline in 2030. Federal and state HFC phaseout policies were implemented by specifying state-level % reductions from the baseline scenario.
LULUCF		LULUCF emissions are specified to reach -941 MMTCO2e/yr of LULUCF emissions by 2030. This is based on an analysis of the state-by-state additional mitigation potential of 11 natural climate solutions. California, with its own goals for natural and working lands, is assumed to reach -40 MMTCO2e. Remaining states are assumed to achieve 60% of the

	mitigation potential of natural climate solutions that would be profitable at a $10/ton carbon price.

* Only California's GHG cap is binding, and all other state's GHG cap is overachieved by all other sectoral policy implementations.

Harmonization with EPA Inventories

GCAM independently builds up historical emissions from underlying activity level and emission factors. This creates differences with the U.S. EPA Inventory of Greenhouse Gas Emissions. To harmonize GCAM results to the EPA inventory, GCAM subsectors were first re-mapped according to EPA categories, and then GCAM's historical emissions were proportionally rescaled by gas, sector, and year, in order to account for remaining differences. The rescaling factors from GCAM's final calibration period (2015) were then carried forward to rescale emissions in future years by the same factor.

CO_2 emissions were harmonized for each of the following sectors: electricity, buildings, industry, transportation, and agriculture. Emissions from international transport and U.S. territories are handled separately. In addition to energy emissions, harmonization in the industry sector applies to CO_2 from oil and gas systems, cement, fertilizer production, and industrial feedstocks. Agriculture CO_2 includes liming and urea fertilization.

Non-CO_2 harmonization covers the following: CH_4 emissions from oil and gas systems, coal mining, landfills, and livestock; N_2O emissions from croplands, livestock, and nitric and adipic acid production; and emissions of HFC, PFC and SF6. Because GCAM's non-CO_2 emissions inventory is based on the Emissions Database for Global Atmospheric Research (EDGAR), it differs from the EPA inventories used for the purposes of calculating the emission reduction in the U.S. Biennial Report. Net CO_2 removal from natural and working lands in the U.S. was estimated separately, and added to the total GHG estimates.

Core Assumptions, Results, and Sensitivity Analyses

The results of this study depend on many assumptions about how the U.S. and the world might evolve in the future. This study uses a set of core assumptions for drivers including economic growth, population growth, fossil fuel prices, and EV sales (Supplementary Table 3). Economic impacts associated with COVID-19 in 2020 and subsequent recovery in the following years have also been incorporated into these assumptions. Our core assumptions draw from data sources such as EIA's *Annual Energy Outlook*[xxxv], the Federal Reserve System[xxxvi], IMF's *World Economic Outlook*[xxxvii], and Rhodium Group[xxxviii]. These assumptions lead to the results summarized in Figure 1 and Supplementary Table 4.

To help understand the possible range of outcomes and contextualize the results, we generated a range of sensitivity assumptions for important drivers (Supplementary Table 3). Four sensitivity factors were taken as the focus of this exercise: population growth, economic growth, oil and gas prices, and LULUCF emissions. While these sensitivities are not a full representation of all factors that might influence the overall emissions trajectory, they nonetheless provide insight into the range of possibilities and the level of certainty associated with the projections in this assessment (Supplementary Figure 1).

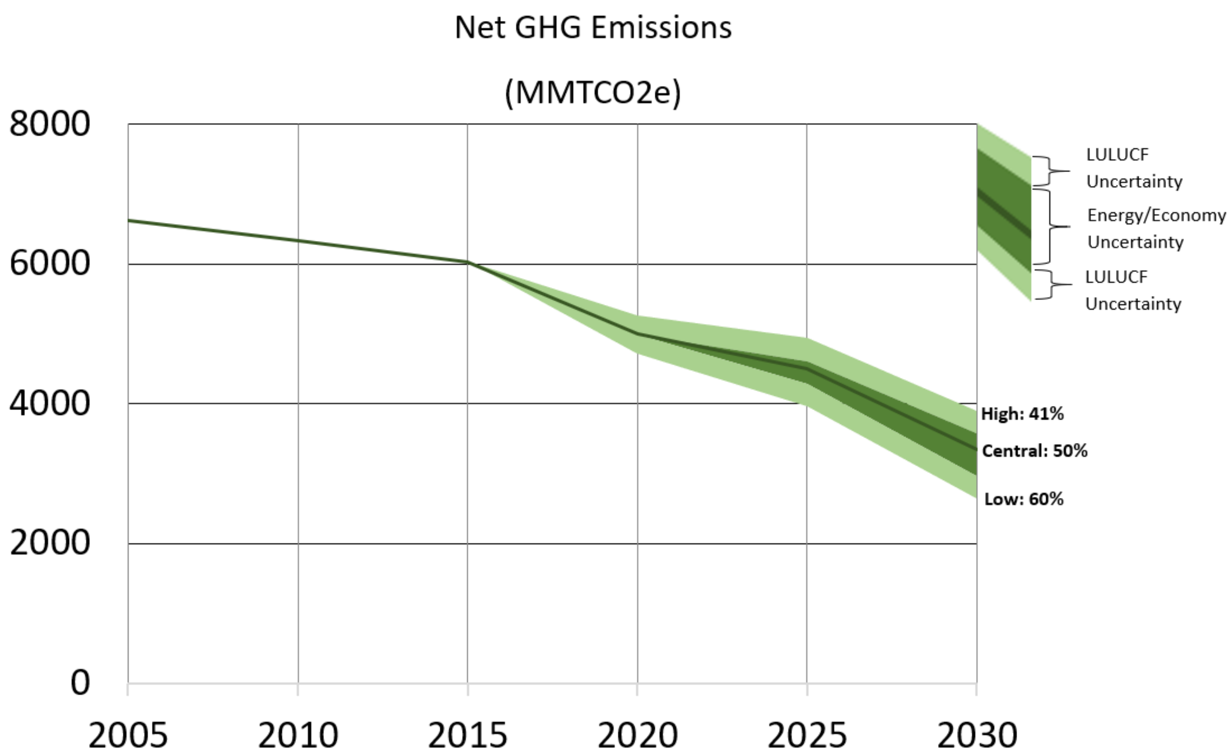
Supplementary Table 3. Core Assumptions and Sensitivities for GCAM-CGS Analysis

Drivers	Scenario assumptions
Economic Growth	Overall GDP decreases by 3.5% year-on-year in 2020, then increases by 2.2% per year through 2030. (Low: 5.0% decrease in 2020, 1.0% per year increase through 2030 High: 2.0% decrease in 2020, 3.3% per year increase through 2030)
Population Growth	Population grows by 0.65% per year through 2030. (Low: 0.53% per year through 2030 High: 0.76% per year through 2030)
Fuel Prices	Gas price is assumed to drop by 19.5% year-on-year in 2020, then increase by 4.9% per year through 2030. (Low: 2.6% per year increase through 2030 High: 9.3% per year increase through 2030) Oil price is assumed to drop by 30.8% year-on-year in 2020, then increase by 6.2% per year through 2030. (Low: 0.09% per year decrease through 2030 High: 13% per year increase through 2030)
Transportation Energy Demand	Transport sector energy demand is assumed to decrease by 14.7% from 2015 levels in 2020, with recovery through 2030.
Industry Energy Demand	Industry sector energy demand is assumed to decrease by 4.1% from 2015 levels in 2020, with recovery through 2030.
Buildings Energy Demand	Buildings sector energy demand is assumed to decrease by 1.7% from 2015 levels in 2020, with recovery through 2030.
Technology Costs	Technology costs are updated with NREL Annual Technology Baseline 2020 assumptions. Solar and wind base technology costs decrease by 49% and 42% from 2015 levels by 2030, respectively.

Supplementary Table 4. Emissions to 2030 By Gas and Sector

Sector/GHG	Emissions 2005 ($MMTCO_2e$)	Emissions 2019 ($MMTCO_2e$)	Emissions 2030 ($MMTCO_2e$)	Reduction from 2005 to 2030 ($MMTCO_2e$)	Reduction relative to 2005 (%)	Contribution to economy-wide 50% reduction relative to 2005 (%)
Electricity CO_2	2416	1630	394	-2022	-84%	-31%
Transport CO_2	1866	1852	1257	-610	-33%	-9%
Industry CO_2	1199	1140	1073	-126	-11%	-2%
Buildings CO_2	585	577	406	-179	-31%	-3%
Other CO_2	65	72	35	-31	-47%	0%
CH_4	727	660	572	-156	-21%	-2%
N_2O	432	458	445	13	3%	0%
F-Gases	148	185	99	-49	-33%	-1%
LULUCF	-815	-789	-941	-126	16%	-2%
Net GHG Total	6625	5787	3339	-3286	-50%	-50%

Supplementary Figure 1. Sensitivity Analysis Emission Range



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[i] U.S. Environmental Protection Agency (EPA). Global Non-CO2 Greenhouse Gas Emission Projections & Mitigation 2015-2050. https://www.epa.gov/sites/production/files/2019-09/documents/epa_non-co2_greenhouse_gases_rpt-epa430r19010.pdf

[ii] The America's Pledge Initiative on Climate Change. "Accelerating America's Pledge: Technical Appendix." 2019. https://www.americaisallin.com/wp-content/uploads/2021/02/technical-appendixaccelerating-americas-pledge.pdf

[iii] Hultman et al. "Fusing subnational with national climate action is central to decarbonization: the case of the United States." Nature Communications. 2020. https://www.nature.com/articles/s41467-020-18903-w.pdf

[iv] New Climate Institute and World Resources Institute. "Non-State and Subnational Action Guide. April 2020. https://climateactiontransparency.org/icat-toolbox/policy-assessment-guides/non-state-subnational-action/

[v] Kovac, Alex, and Wee Kean Fong. "Compact of Mayors Emissions Scenario Model." Technical Note. World Resources Institute, December 2015. https://www.wri.org/publication/compact-mayors-emissions-scenario-model

[vi] David Rich, Pankaj Bhatia, Jared Finnegan, Kelly Levin, Apurba Mitra. "Policy and Action Standard, an accounting and reporting standard for estimating the greenhouse gas effects of policies and actions." Greenhouse Gas Protocol. https://ghgprotocol.org/sites/default/files/standards/Policy%20 and%20Action%20Standard.pdf

[vii] Center for Climate and Energy Solutions (C2ES). Regional Greenhouse Gas Initiative (RGGI). https://www.c2es.org/content/regional-greenhouse-gas-initiative-rggi

[viii] California Air and Resources Board (CARB). AB 32 Scoping Plan. https:// ww3.arb.ca.gov/cc/scopingplan/scopingplan.htm

[ix] Lawrence Berkeley National Lab (LBL). Renewables Portfolio Standards Resources. https://emp.lbl.gov/projects/renewables-portfolio

[x] U.S. Energy Information Administration (EIA). Annual Electric Power Industry Report, Form EIA-861 detailed data files. https://www.eia.gov/ electricity/data/eia861

[xi] Sierra Club. Ready For 100. https://www.sierraclub.org/ready-for-100

[xii] U.S. Department of Energy (DOE) and National Renewable Energy Laboratory (NREL). State & Local Energy Data. https://www.eere.energy.gov/sled/#

[xiii] Modeling outputs provided by the Environmental Defense Fund (EDF).

[xiv] U.S. Environmental Protection Agency (EPA). Greenhouse Gas Inventory Annex 3.5: Methodology for Estimating CH4, CO2, and N2O Emissions from Petroleum Systems and Annex 3.6: Methodology for Estimating CH4, CO2, and N2O Emissions from Natural Gas Systems.

[xv] U.S. Energy Information Administration. “U.S. Nuclear Generation and Generating Capacity.” Accessed Aug 2019. https://www.eia.gov/nuclear/ generation

[xvi] Energy Information Administration. 2019. Annual Energy Outlook 2019. https://www.eia.gov/outlooks/aeo

[xvii] U.S. Energy Information Administration (EIA). Analysis of the Effect of Zero-Emission Vehicle Policies: State-Level Incentives and the California Zero-Emission Vehicle Regulations. https://www.eia.gov

[xviii] National Renewable Energy Laboratory. Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States. https://www.nrel.gov/docs/fy18osti/71500.pdf

[xix] California Air Resources Board. 2019. Terms for Light-Duty Greenhouse Gas Emissions Standards. https://ww2.arb.ca.gov/sites/default/files/2019-07/ Auto%20Terms%20Signed.pdf

[xx] Environmental Defense Fund. Technical Assessment of CO2 Emission Reductions for Passenger Vehicles in the Post-2025 Timeframe. 2017. https://www.edf.org/sites/default/files/content/final_public_white_paper_ post_2026_co2_reductions2.27_clean.pdf

[xxi] International Council for Clean Transportation. Efficiency Technology and Cost Assessment for U.S. 2025-2030 Light Duty Vehicles. 2017. https:// theicct.org/sites/default/files/publications/US-LDV-tech-potential_ICCT_ white-paper_22032017.pdf

[xxii] American Council for an Energy-Efficient Economy, https://database. aceee.org

[xxiii] U.S. Federal Highway Administration (FWHA). Highway Statistics 2017. https://www.fhwa.dot.gov/policyinformation/statistics/2017/mv1.cfm

[xxiv] U.S. Department of Energy (DOE) and National Renewable Energy Laboratory (NREL). State & Local Energy Data. https://www. eere.energy.gov/sled/#

[xxv] U.S. Environmental Protection Agency (EPA). “GreenChill Annual Achievements.” presented at the Energy & Store Development Conference, September 2017. https://www.epa.gov/sites/production/ files/2017-09/documents/gc_recognition.presentation_2017_ceremony.pdf

[xxvi] California Environmental Protection Agency, Air Resources Board. “Table B2. Reductions (MMT CO2 E) each calendar year, shown by equipment production year for all emissions sectors covered by proposed regulation,” Appendix B: Emission Estimates, https://www.arb.ca.gov/regact/2018/ casnap/isorappb.pdf

[xxvii] World Resources Institute. CAIT Climate Data Explorer. cait.wri.org

[xxviii] American Council for an Energy-Efficient Economy (ACEEE). 2019 State Energy Efficiency Scorecard. https://aceee.org/research-report/u1908

[xxix] American Council for an Energy-Efficient Economy (ACEEE). https:// database.aceee.org

[xxx] U.S. Energy Information Administration (EIA). Annual Electric Power Industry Report, Form EIA-861 detailed data files. https://www.eia.gov/ electricity/data/eia861

[xxxi] Pacific Northwest National Laboratory (PNNL). Impacts of Model Building Energy Codes. https://www.energycodes.gov/sites/default/files/ documents/Impacts_Of_Model_Energy_Codes.pdf

[xxxii] Northeast Energy Efficiency Partnership Regional Energy Efficiency Database. https://reed.neep.org/Registration.aspx?Source=https://reed. neep.org/StateDocs.aspx

[xxxiii] Aimee McKane, Peter Therkelsen, Anna Scodel, et al. Predicting the quantifiable impacts of ISO 50001 on climate change mitigation. Energy Policy 107. 2017. https://www.osti.gov/biblio/1408454-predicting-quantifiable-impacts-iso-climate-change-mitigation

[xxxiv] Nature 4Climate. “US State Mapper.” Accessed Sep 2019. https:// nature4climate.org/u-s-carbon-mapper

[xxxv] U.S. Energy Information Administration (EIA). Annual Energy Outlook 2021. https://www.eia.gov/outlooks/aeo/tables_ref.php

[xxxvi] Federal Open Market Committee Projections, December 16, 2020. The Federal Reserve System. https://www.federalreserve.gov/monetarypolicy/fomcprojtabl20201216.htm

[xxxvii] International Monetary Fund (IMF). World Economic OutLook, October 2020: A Long and Difficult Ascent.https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020

[xxxviii] Larsen, K., Hannah Pitt, John Larsen, Whitney Herndon, Trevor Houser, Hannah Kolus, Shashank Mohan, & Emily Wimberger. (2020). *Taking Stock 2020: The COVID-19 Edition*. Rhodium Group. 16 pp. Available at https://rhg.com/wp-content/uploads/2020/07/Taking-Stock-2020-The-COVID-19-Edition.pdf