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Commentary

Mission net-zero America: The nation-building path to a prosperous, net-zero emissions economy

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The Biden administration has committed to reduce U.S. greenhouse gas emissions to 50%–52% below 2005 levels by 2030 and net-zero by 2050.[1] These aspirations are achievable and affordable, but only if the federal government engages state and local governments, the private sector, and communities in a mission-oriented, nation-building effort to transform the U.S. energy system at unprecedented pace and scale.

Macro-scale energy systems modeling studies can help inform net-zero transition planning, but most lack granularity to elucidate the many real-world challenges that must be overcome.[2–4] The *Net-Zero America (NZA)* study[5] is a notable departure for the granularity of its spatial, temporal, and sectoral mapping of five distinct pathways, each relying only on technologies with a high level of technological readiness (Technology Readiness Level 6

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or greater), and each of which achieve 2030 emissions similar to the Biden administration's target and net-zero emissions by 2050. The study finds similarities among pathways over the next decade, and annual spending on energy services as a share of gross domestic product remains similar to current levels throughout the transition.

The national level findings of the *NZA* study are broadly supported by results of other modeling studies, including economy-wide energy-system studies[6–9] and sector-specific studies.[10–12] Yet no prior studies have mapped thousands of low-carbon energy and infrastructure assets at politically and socially relevant scales, as the *NZA* study has done, to illustrate what the transition could look like "on the ground" (Figure 1). The study's geospatially resolved methods put in sharp relief the extraordinary scale and pace of change that a successful transition to net-zero emissions by 2050 entails. It also reveals four interdependent failure modes with the potential to derail the net-zero transition:

1. *Failure to deploy physical assets and infrastructure at the unprecedented pace required.* Each of the five *NZA* pathways requires from 400 to 750 gigawatts (GW) of new utility-scale wind and solar capacity by 2030, which entails several thousand large-scale projects. In the U.S., renewable energy projects currently take 5–8 years on average from concept to completion. In 2020, 225 GW of utility-scale solar and wind project proposals were added to the queue to interconnect to U.S. grids,[13] but only 25 GW of new capacity came online. While 2020 represents the largest single-year expansion in U.S. history,[14] four times as many projects were canceled as completed that year. Dramatic improvements in both project timelines and completion rates are necessary. If recent trends continue, developers would implausibly need to initiate between 4 and 7 terawatts (TW) of projects in the next four years to ensure enough capacity actually comes online to meet 2030 goals. Meanwhile, with demand for renewable energy expected to grow globally, any tightening of global wind and solar supply chains has the potential to further delay projects in the U.S. Moreover, renewable energy deployment depends on expanding high-voltage transmission capacity by about 60% by 2030, as well as improving its resilience. Transmission projects historically take 6 to 15 years to complete, and many are abandoned after failing to obtain permits and support from each state and community they transect. Current practice in transmission expansion is therefore also insufficient to meet the 2030 goal. In the least-constrained *NZA* pathway, over 3 TW of wind and solar are installed by 2050 (Figure 1A), requiring average annual build rates four times the rate achieved in 2020 (Figure 1D). Another pathway has less than half as much solar and wind (Figure 1C) but requires much greater reliance on carbon dioxide (CO_2) capture, utilization, and storage infrastructure and hundreds of new nuclear power plants, neither of which are experiencing significant commercial deployment today and face scale-up challenges of their own.
2. *Failure to mobilize the capital needed for the transition.* *NZA* finds annual energy expenditures will remain comparable (as a share of GDP) to today throughout the net-zero transition but that the required upfront capital investment is substantially larger. Nearly $3 trillion in capital must be mobilized for energy supply infrastructure in the 2020s alone, more than double a reference "no new policies" scenario. By 2050, cumulative supply-side capital investments reach as much as $14 trillion, or nearly quadruple the reference scenario. Deploying capital represents another potential bottleneck in the net-zero transition. Project proposals must be de-risked through a sequence of investments to conceive, site, and design projects, prepare contracts, and obtain permits prior to a final investment decision (FID). Given that such pre-FID investments hold the highest level of risk and a significant portion of proposals do not reach FID, pre-FID spending today typically relies on the relatively limited pool of private-developer balance sheet equity. *NZA* estimates that $190 billion in pre-FID capital is needed in the 2020s alone, at least double the reference scenario.
3. *Failure due to public opposition to large-scale construction impacts and changing landscapes.* All *NZA* scenarios involve sustained multi-decadal construction activity that can result in massive transformations of local landscapes. The transformation is largest in the 100% renewable scenario (Figure 1B), in which wind and solar farms directly, or by visual extent, span 14% of the continental U.S. land area, but other pathways also present siting challenges. Opposition to wind and solar projects is already becoming a barrier to development.[15] Failure to secure and sustain social license will likely manifest in intensifying public opposition as cumulative impacts emerge from ubiquitous development of wind and solar, transmission, biomass conversion facilities, nuclear power plants, CO_2 pipelines and storage projects, and other infrastructural features of net-zero pathways.

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4. *Failure to mitigate disruptions to the workforce of incumbent fossil fuel industries and to mobilize the workforce needed for the net-zero transition.* Transforming the energy system also entails transforming the energy workforce,[16] with fossil fuel employment declines and increasing labor demand in low-carbon industries experienced during the transition. Driving down technology costs and increasing deployment rates of low-carbon infrastructure will, in part, depend on increasing labor productivity and automation. There is nevertheless the potential for substantial increases in employment, even when accounting for increased productivity: on the order of 0.3–0.9 million additional jobs (relative to the reference scenario) are supported by 2030 and 0.6–5.2 million jobs by 2050 in energy supply-side sectors alone (Figure 2A). Much of this expansion will be due to wind, solar, and power grid infrastructure deployment, along with new bioenergy industries that will drive capital investment, farm revenues, and jobs across rural America. In parallel, *NZA* found that fossil job losses in the 2020s will be concentrated in coal-mining communities in the Appalachian and Powder River basins (Figure 2B) in both net-zero and reference scenarios, following a declining trend observed since 1990. More widespread but gradual declines in the oil and natural gas workforce begin and accelerate in the 2030s and 2040s across the Gulf coast, Oklahoma, and the Dakotas (Figure 2B). Failure to address the repercussions of declining incumbent industries, employment opportunities, and public revenue streams, in addition to training and mobilizing the workforce to meet increasing labor demands in growing clean energy sectors, risks a formidable political backlash.

In short, the *NZA* study shows that any pathway to net-zero emissions by 2050 will be difficult to traverse. Each requires unprecedented feats of engineering and construction to succeed, which in turn relies on the mobilization of unprecedented risk capital. Each depends on enduring support of communities in the face of significant infrastructural changes and disruptions of incumbent industries and traditional livelihoods.

A new nation building opportunity

Avoiding these cascading failure modes will require fundamental changes in the way we select, site, permit, finance, and deliver energy projects.

A bold "nation building" effort is needed that combines the laser-focus of past mission-oriented public-private partnerships, such as the Moon Shot or Operation Warp Speed,[17] with the kind of multi-decadal national-scale programs that built the foundations of the U.S.'s 20th century economy, collectively represented by the New Deal, World War II industrial mobilization, and post-war investments in national infrastructure.

The Biden administration has signaled the shape of what is needed with its "whole-of-government" approach and commitment to leverage all tools at its disposal, from executive orders and regulation to RD&D programs and government procurement designed to catalyze critical technologies. President Biden's American Jobs Plan proposed about $1 trillion in federal investments across key energy sectors and technologies,[18,19] positioning the energy transition at the heart of the administration's economic agenda. Currently pending Congressional legislation could deliver a substantial portion of this commitment,[20] and if well directed, could stimulate the significant additional private investment needed through 2030 to be on a path to net-zero.

A recent report by the National Academies of Science, Engineering, and Medicine (NASEM)[21] outlines a complementary set of policies, programs, and institutions that would help manage the net-zero transition. The report recommends the development of sector-specific regulatory standards (e.g., clean electricity, zero emissions vehicles, efficient heating, and appliances) to steer commercial and consumer investments, as well as regulatory reforms to facilitate timely siting and permitting of transmission lines and funding to begin nationwide planning of long-distance electricity transmission and CO_2 transport and storage systems. The NASEM report further recommends the creation of new institutions such as the National Transition Task Force, Office of Equitable Energy Transitions, and National Transition Corporation that would offer planning, monitoring, reporting, funding, and community support functions, in addition to a "Green Bank" sufficiently capitalized to underwrite roughly half a trillion dollars of financing for clean energy infrastructure. A comprehensive workforce development initiative to train the net-zero workforce and help transition displaced workers is also proposed.

Together, the large-scale public investments in the American Jobs Plan and the policies, institutions, and programs envisioned by the NASEM committee would begin to contend with the four failure modes identified in *NZA*, yet more is needed.

Mission net-zero

The U.S. will not succeed at the pace and scale required if we continue to leave it to private developers to propose individual projects and commence a lengthy process wherein multiple governmental bodies and community stakeholders

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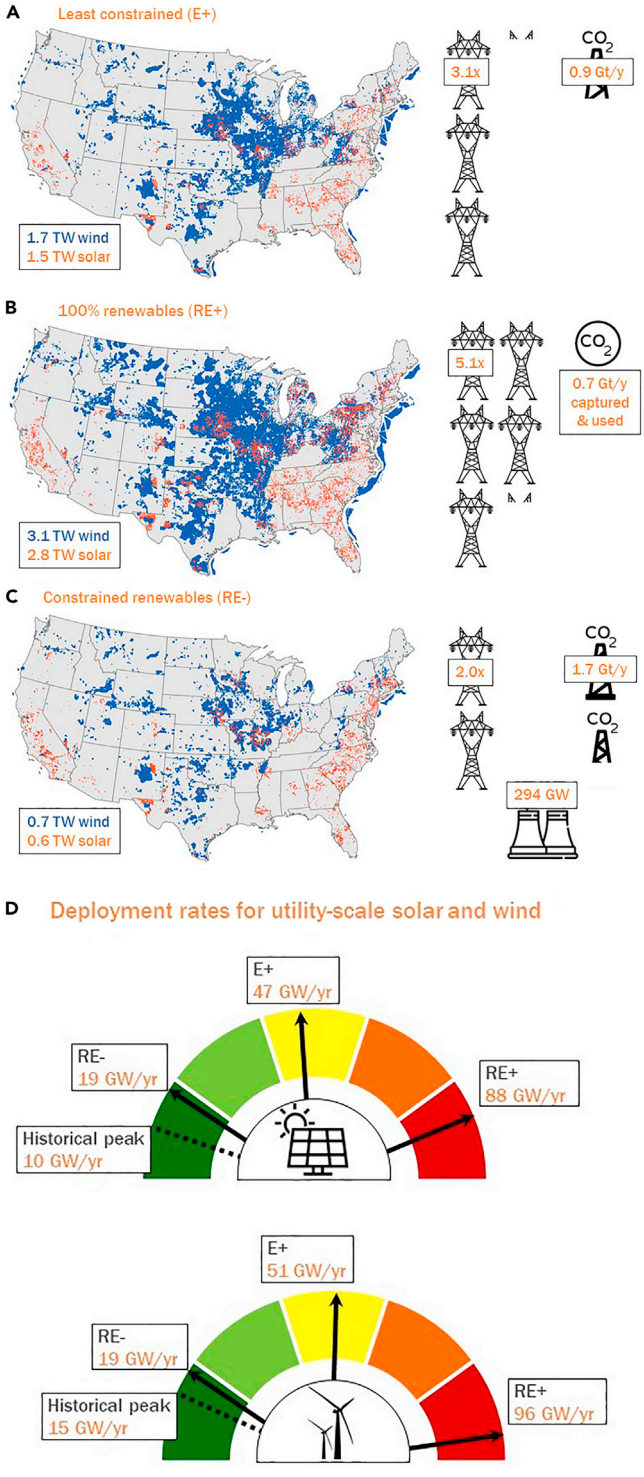

Figure 1. Scale and pace of modeled electricity-supply system expansion to 2050 for three of five pathways in the *Net-Zero America* study

In 2050, all three pathways deliver the same level of energy services, have nearly fully electrified road transport and buildings sectors, use the same level of biomass in the energy supply mix, and achieve net-zero emissions economy-wide. Differentiations in the pathways result primarily from different exogenously imposed technology constraints in modeling energy supply. The *NZA*[5] model builds the energy supply mix that minimizes the total cost of the energy system while

Figure 1. *Continued*

achieving net-zero emissions in 2050, subject to other exogenously imposed constraints. For the E+ pathway (A), no additional constraints are placed on which energy supply options can be included. For the RE+ pathway (B), energy supply in 2050 is required to be 100% renewable, nuclear power is prohibited by 2050, and underground CO_2 storage is not allowed through the transition. For the RE− pathway (C), the maximum allowed build of utility-scale wind and solar capacity through the transition is 33 GW/year, or about 30% more than the largest amount added in a single year to date. The maps show modeled locations (at 4 km resolution) of wind and solar projects in 2050. This indicates one of many possible geographic configurations of infrastructure and is based on least-cost siting algorithm. Icons on the right indicate the 2050 level of transmission capacity (as a multiple of 2020 capacity), amount of CO_2 captured and/or stored, and new nuclear power capacity installed. (D) compares the average annual build rates from 2020–2050 for utility-scale solar (top) and wind (bottom) capacity in the net-zero pathways with their historical peaks. The latter occurred in 2020 for both wind and solar.[14]

identify various reasons projects should not proceed. To reach net-zero by 2050, the federal government needs to engage various stakeholders in a mission-driven, national effort to proactively identify locations to site and build infrastructure at the necessary scale. To succeed, this effort will need to be simultaneously inclusive *and* expedient.

To take up this critical mission, we propose a federal planning agency charged with ensuring the rapid build-out of net-zero infrastructure that meets the needs of communities today and into the future. The agency would have the mandate to achieve time-bound deployment targets by identifying regions suitable for infrastructure build-out, proactively engaging communities to address concerns and maximize local benefits, pre-permitting areas for development that have been subject to robust risk assessment, and administering bidding for development of large-scale clean infrastructure "hubs." The agency could also interface with the robust network of new federal energy-transition offices and resources recommended by the NASEM study.

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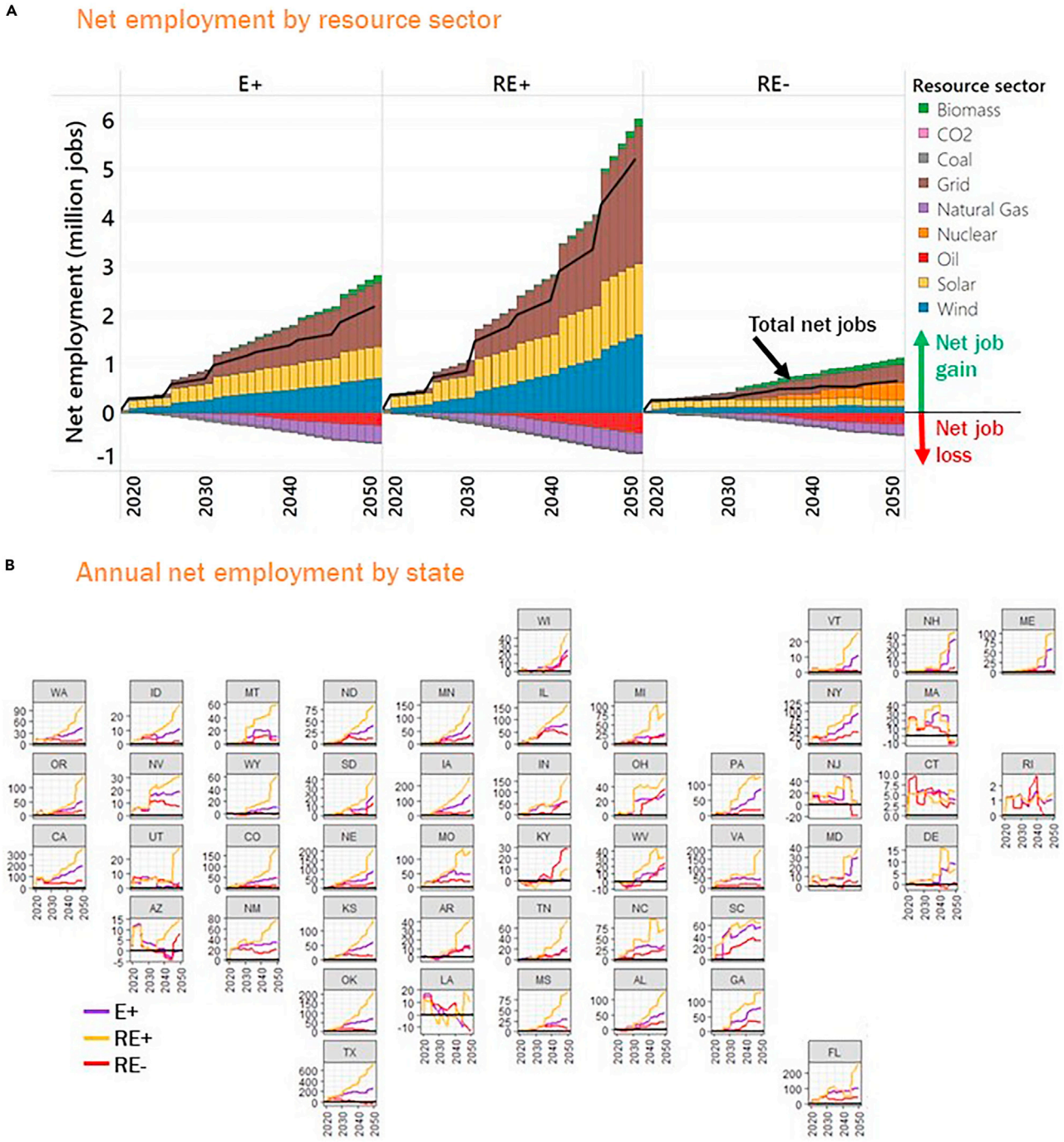

Figure 2. Modeled estimates of net changes in energy-supply-related employment, i.e., net of jobs in a "no new policies" reference scenario, from 2020 to 2050 for three of the five pathways in the *Net-Zero America* study

(A) Total net jobs disaggregated by resource sector and (B) total net jobs by state.[5] See caption of Figure 1 for descriptions of the E+, RE+, and RE− pathways.

Integral to the agency's mission and mandate would be elements to address (at least in part) all four failure modes. Planning regions and targets for construction of portfolios of projects ("hubs") would be consistent with a net-zero transition. For example, explicit planning would countervail regionally concentrated fossil fuel job losses and ensure broad economic benefits from the transition. Communities that host projects via consent-based

siting processes would be rewarded with block grants to counties and states to supplement local property and sales taxes generated by projects. Bidding for hubs would require formation of stakeholder coalitions composed of landowners, local community organizations, environmental groups, asset operators, investors and banks, engineering firms, original equipment manufacturers, contractors, and others to systematically assess and mitigate risks. Contracts would mandate transparency and knowledge sharing, include guard rails to limit losses and prohibit windfall profits, and stipulate equitable sharing of rewards for exceptional performance and losses for poor performance among all participants, giving the whole coalition a stake in success. Funds to establish coalitions would be advanced through competitive grants to de-risk and ensure equitable participation in the bid process.

Transitioning the U.S. economy to net-zero emissions by 2050 will challenge the capacity to deliver new infrastructure at historically unprecedented scales and rates. The key failure modes made apparent by the *NZA* study will derail a successful transition in the absence of robust federal leadership that engages a broad coalition of stakeholders in nothing less than a new nation-building partnership of government, the private sector, and society at large.

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AUTHOR CONTRIBUTIONS

Conceptualization, J.D.J., S.W.P., E.D.L., and C.G.; methodology, J.D.J., E.N.M., E.D.L., and C.G.; investigation, J.D.J., E.N.M., E.D.L., and C.G.; software, E.N.M.; visualization, J.D.J. and E.N.M.; supervision, J.D.J., E.D.L., and C.G.; formal analysis, E.N.M.; funding acquisition, S.W.P. and E.D.L.; writing – original draft, C.G.; writing – review & editing, J.D.J., E.N.M., S.W.P., and E.D.L.

DECLARATION OF INTERESTS

S.W.P was appointed to the President's Council of Advisors on Science and Technology (PCAST) on September 22, 2021 (after the originally submitted manuscript for this commentary was prepared). J.D.J. is part owner of DeSolve, LLC, which provides techno-economic analysis and decision support for clean energy technology ventures, and he provides policy advisory services to Clean Air Task Force, a nonprofit environmental advocacy group.

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