# CARBON DIOXIDE REMOVAL: ALTERNATIVE PATHWAYS AND POLICY NEEDS

## Executive Summary (1 page)

## Carbon dioxide removal in a net-zero future (2-3 pages): the case, the need, the role

1. Given the strong likelihood of continued emissions from hard-to-decarbonize sectors, carbon dioxide removal (CDR) methods will be needed to produce the "negative emissions" required to achieve economy-wide carbon neutrality.

2. Scaling up CDR in a timely fashion requires a fuller understanding of the economic, social, and environmental ramifications of alternative approaches and the policies needed to advance them.

3. Carbon removal is not a substitute for cutting emissions. Accelerating efforts to decarbonize the economy by reducing emissions remains an urgent priority.

## Key criteria for evaluating CDR solutions (1 page)

(Mapping out the evaluation matrix and the scale/scope of different criteria)

1. Technical potential
2. Cost
3. Readiness
4. Scalability
5. Permanence
6. Benefits and co-benefits
7. Challenges

## CDR Solutions (4-6 pages)

1. Nature-based Solutions and enhanced natural processes (2-3 pages)

   a. Afforestation, reforestation, coastal habitat restoration

      i. Potential: 180-360 $MtCO_2$ per year (over the next 20 years with additional carbon removal till tress reach maturity) (Fargione et al. 2018)

ii. Cost: relatively low-cost options
iii. Readiness: nature-based solutions offer the advantage of being deployed at scale sooner than the technological ones (where things are now)
iv. Scalability: deployment-ready at scale, but with concerns about how saturation can limit scalability
v. Permanence: the climate benefits are reversible through degradation of forests
vi. Benefits and co-benefits: The positive environmental impacts of replacing cropland or degraded land with forests (e.g., improved soil quality, reduced flooding and erosion)
vii. Challenges: The concerns over biodiversity, impermanence, impacts on food supply, leakage, lifecycle impacts, and additionality

b. *Biochar, enhanced mineralization*
   i. Potential: enhanced mineralization can sequester larger amounts of $CO_2$ than biochar or other nature-based solutions
   ii. Cost: it's more expensive than other nature-based solutions
   iii. Readiness: large-scale field trials are needed to refine estimates of the potential and side effects
   iv. Scalability: will take longer time to scale up
   v. Permanence: the climate benefits are reversible through degradation of soils
   vi. Benefits and co-benefits: protecting biodiversity, providing ecosystem services
   vii. Challenges: competition with BECCS for biomass inputs

2. *Technological solutions (2-3 pages)*
   a. BECCS
      i. Technical potential: large carbon removal potentials of BECCS, ~ 180 $MtCO_2$ per year (NAS 2018)
      ii. Cost: relatively expensive
      iii. Technology readiness: Until a large-scale $CO_2$ pipeline network or biomass transportation infrastructure is available, BECCS will have to be limited to sites where biomass and suitable $CO_2$ storage are both available.
      iv. Scalability: limited by available waste and competing use for feedstock
      v. Permanence: the $CO_2$ yield can be permanently stored
      vi. Benefits and co-benefits: could help reduce lifecycle carbon footprint of biofuels and ramp up CCUS infrastructure

vii. Challenges: Purpose-grown biomass and the fuel vs food dispute, combining a mature technology, bioenergy from biomass, with CCS that is largely at the demonstration stage, ensuring secure geologic storage.

b. Direct Air Capture

i. Technical potential: may be able to sequester extremely large amounts of $CO_2$

ii. Cost: the very high cost is the main barrier for deployment

iii. Technology readiness: one-off pilot or demonstration stage

iv. Scalability: scalable to demand at a given location, it needs longer time to scale

v. Permanence: the captured $CO_2$ can be permanently sequestered

vi. Benefits and co-benefits: ramping up CCUS infrastructure and $CO_2$ as feedstock for $CO_2$-sequestering products, small land footprint of DAC facilities (with a concern over the large land footprint of the associated RE sources)

vii. Challenges: high costs in the absence of a natural economic driver (a cost on carbon) and depend heavily on abundant low-carbon energy sources, ensuring secure geologic storage.

**Redacted - First Amendment**