

CO₂ Supply Chain Specification

1. Conceptual Structure

CO₂ Production: CO₂ is a by-product of many other industrial processes. Each of these processes is governed by market demand for its product of interest. Changing demand means changing production levels for these various industrial processes, and therefore CO₂ as well, independent of CO₂ demand.

Demand for primary products: Many of the products produced to acquire CO₂ are fuels and chemicals used in industrial farming. When these industries experience changes in demand, they adjust production levels accordingly. As a result, CO₂ production is affected as well.

CO₂ Demand: CO₂ is a chemical used in a wide array of industries. It most notably has a vital role in the food and beverage industry and water purification and shortages could have negative impacts on people everywhere. Demand for CO₂ increases with demand for any of the products that it is a component of.

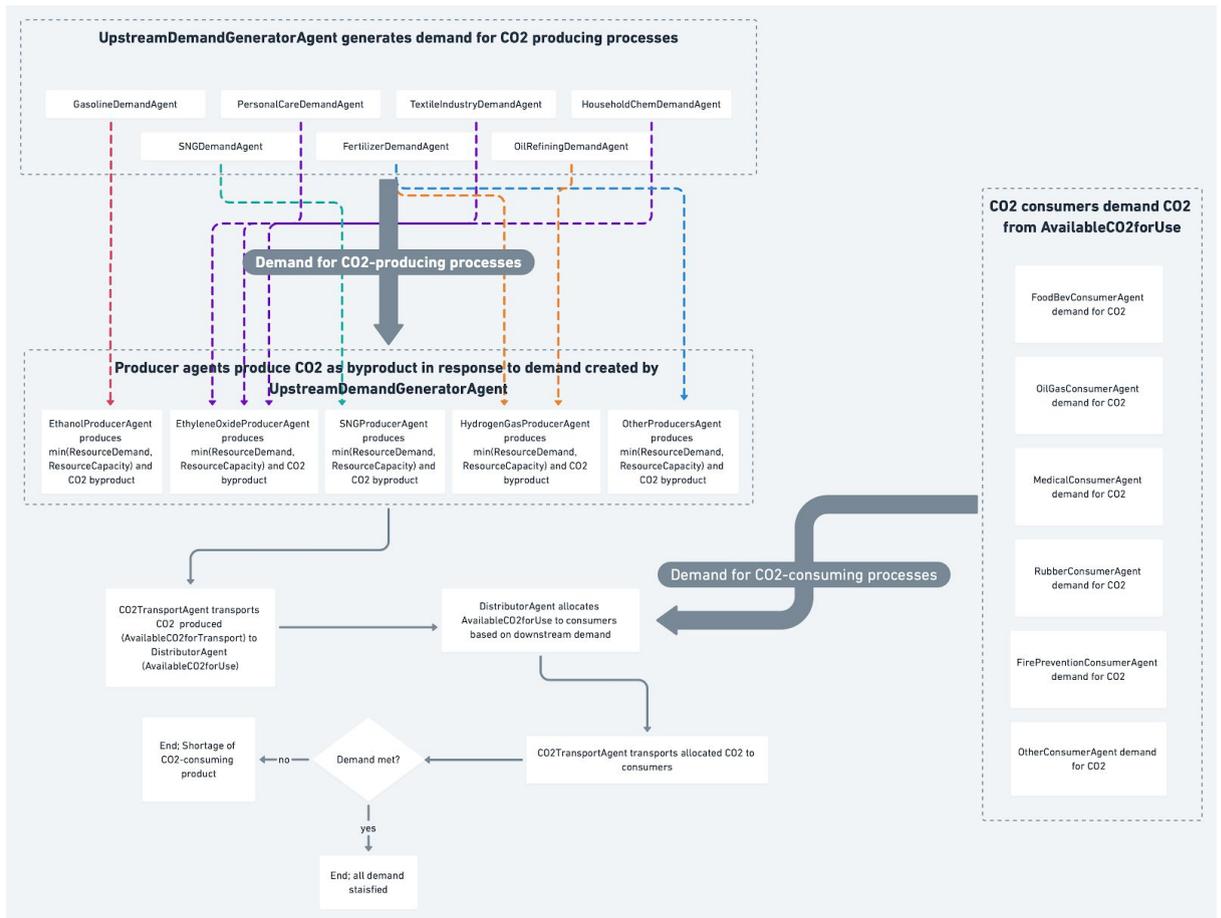
2. Agent Definition

- **UpstreamDemandGeneratorAgent** - generates upstream demand for primary products that produce CO₂ as a byproduct; can be treated as a “black box” for all of market demand or broken down into the following demand-producing agents (likely not a complete list):
 - **GasolineDemandAgent** - impacted by commuting, traveling (planes, cars, public transit), etc. for individuals and business; creates demand for ethanol (15% of gasoline by volume)
 - **PersonalCareDemandAgent** - demand for products used for personal care/hygiene; creates demand for ethylene oxide, most of these products should have inelastic demand
 - **TextileIndustryDemandAgent** - textile manufacturers require ethylene oxide for producing polyester
 - **HouseholdChemDemandAgent** - ethylene oxide is a component of the manufacturing process for many chemicals
 - **SNGDemandAgent** - Synthetic natural gas can be used in any situation that natural gas can be used in. In 2018, SNG accounted for .2% of natural gas use in the US (30.6 trillion cubic feet Tcf). Overall natural gas [demand is increasing](#).
 - **FertilizerDemandAgent** - fertilizer production requires the use of hydrogen to produce ammonia (about 35 million tons hydrogen in 2019) and ammonia itself is a source of CO₂

- **OilRefiningDemandAgent** - hydrogen is demanded by oil refineries for “hydrocracking” (another 35 million tons)
- **EthanolProducerAgent** - produces ~35% of CO2 in market; biggest driver is gasoline demand; around 1,100,000 barrels produced per day on average in steady market, dropped to 563,000 barrels per day in April 2020
- **EthyleneOxideProducerAgent** - produces ~25% of CO2 in market; goes to many chemicals, personal care products, textile production; production was at 2,925,000 tons in 2019 in the US
- **SNGProducerAgent** - produces ~25% of CO2 in market; substitute natural gas producers; accounted for .02% natural gas production in the US in 2018, which is 611,800,000,000 cubic feet per year
- **HydrogenGasProducerAgent** - produces ~10% of CO2 in market; producers of hydrogen gas, driven by demand for fertilizer and oil refineries; around 3,000,000,000 cubic ft per day
- **OtherProducerAgent** - produces ~5% of CO2 in market; consists of a few other processes that aren’t taken into account already; for purposes of this report normal production is 100 units
- **AvailableCO2Agent** - total CO2 produced by all agents in market, represents companies that purchase gas from producers to resell to CO2 users
- **CO2TransportAgent**- consists of pipelines, trucks, rail transport, and ship transportation mediums for CO2 from producers to consumers; for purposes of this model, transport capacity will not be a limiting factor, but could be in other cases
- **FoodBevConsumerAgent** - accounts for ~40% of CO2 market share; could consist of the following or be an aggregate agent
 - **BeverageAgent** - producers of soft drinks, beer, cider, etc. use CO2 for carbonation, sterilization, bottling, etc.
 - **IndustrialFarmsAgent** - used in grain fumigation and to promote photosynthesis in greenhouses
 - **PerishableFoodsAgent** - used for atmosphere replacement to prevent growth of bacteria in packaged perishable food
 - **SlaughterhousesAgent** - used for stunning pigs/poultry during slaughtering process
- **OilGasConsumerAgent** - accounts for ~20% CO2 market share; used for EOR (enhanced oil recovery)
- **MedicalConsumerAgent** - accounts for ~16% CO2 market share; used during surgeries
- **RubberConsumerAgent** - accounts for ~ 8% CO2 market share; used in production process
- **FirePreventionConsumerAgent** - accounts for ~8% of CO2 market share; component in fire-suppression systems and fire extinguishers
- **OtherConsumerAgent** - accounts for ~8% of CO2 market share; includes some chemical production, municipal water purification, Urea production (fertilizer component), etc.

- **DownstreamDemandGeneratorAgent** - generates downstream demand for products/processes that require CO2; can be treated as a “black box” for all of market demand

3. Process Diagram



<https://whimsical.com/CMrKLa2suts45oT7BhyGks>

4. Detailed Description of Agents

UpstreamDemandGeneratorAgent

```

{
    DemandEthanol: Draw from EthanolDemandDist
    DemandEthyleneOxide: Draw from EthyleneOxideDemandDist
    DemandSNG: Draw from SNGDemandDist
    DemandHydrogen: Draw from HydrogenDemandDist
    DemandOther: Draw from OtherDemandDist
}

```

Actions:

```
generate_demand{
    Requires: demand distributions are defined in environment
    Effect: upstream demand is generated
}
```

EthanolProducerAgent

Attributes:

```
{
    ResourceDemand: DemandEthanol
    ResourceCapacity: 1,100,000 barrels/day
    PrimaryProduced: 0
    CO2Produced: 0 (tons/year)
}
```

Actions:

```
produce_ethanol{
    Requires: ResourceCapacity > 0
    Effect: increase PrimaryProduced by min{ResourceDemand,
    ResourceCapacity}, increase CO2Produced by .040*PrimaryProduced,
    decrease ResourceCapacity by PrimaryProduced
}
```

EthyleneOxideProducerAgent

Attributes:

```
{
    ResourceDemand: DemandEthyleneOxide
    ResourceCapacity: 2,925,000 tons/year
    PrimaryProduced: 0
    CO2Produced: 0 (tons/year)
}
```

Actions:

```
produce_ethyleneoxide{
    Requires: ResourceCapacity > 0
    Effect: increase PrimaryProduced by min{ResourceDemand,
    ResourceCapacity}, increase CO2Produced by .015*PrimaryProduced,
    decrease ResourceCapacity by PrimaryProduced
}
```

SNGProducerAgent

Attributes:

```
{
    ResourceDemand: DemandSNG
}
```

```
ResourceCapacity: 611,800,000,000 cubic ft/year
PrimaryProduced: 0
CO2Produced: 0 (tons/year)
}
```

Actions:

```
produce_SNG{
  Requires: ResourceCapacity > 0
  Effect: increase PrimaryProduced by min{ResourceDemand,
ResourceCapacity}, increase CO2Produced by .00000007*PrimaryProduced,
decrease ResourceCapacity by PrimaryProduced
}
```

HydrogenGasProducerAgent

Attributes:

```
{
  ResourceDemand: DemandHydrogenGas
  ResourceCapacity: 3,000,000,000 cubic ft/day
  PrimaryProduced: 0
  CO2Produced: 0 (tons/year)
}
```

Actions:

```
produce_hydrogen{
  Requires: ResourceCapacity > 0
  Effect: increase PrimaryProduced by min{ResourceDemand,
ResourceCapacity}, increase CO2Produced by .000015*PrimaryProduced,
decrease ResourceCapacity by PrimaryProduced
}
```

OtherProducerAgent

Attributes:

```
{
  ResourceDemand: DemandOther
  ResourceCapacity: 100 units
  PrimaryProduced: 0
  CO2Produced: 0 (tons/year)
}
```

Actions:

```
produce_other{
  Requires: ResourceCapacity > 0
}
```

Effect: increase PrimaryProduced by $\min\{\text{ResourceDemand}, \text{ResourceCapacity}\}$, increase CO2Produced by $438.525 * \text{PrimaryProduced}$, decrease ResourceCapacity by PrimaryProduced

}

CO2TransportAgent

Attributes:

{

AvailableCO2forTransport: see environment

AvailableCO2forUse: 0

}

Actions:

transport_co2_to_distributor{

Requires: AvailableCO2forTransport > 0

Effect: decrease AvailableCO2Transport by AvailableCO2forTransport initial value (so final result is 0); increase AvailableCO2forUse to initial value of AvailableCO2forTransport (basically transfer all AvailableCO2forTransport to AvailableCO2forUse)

}

transport_co2_to_consumer{

Requires: AvailableCO2forUse > 0

Effect: decrease AvailableCO2forUse by CO2Demand for consumer agents, increase CO2Received of relevant consumer agent by CO2Demand of that agent (or amount that is allocated to this agent if demand cannot be met - see environment)

}

DistributorAgent

Attributes:

{

AvailableCO2forUse: received from CO2TransportAgent

AmtToFoodBev: 100% (or determined by environment parameter)

AmtToOilGas: 100% (or determined by environment parameter)

AmtToMedical: 100% (or determined by environment parameter)

AmtToMetRubber: 100% (or determined by environment parameter)

AmtToFirePrevention: 100% (or determined by environment parameter)

}

Actions:

receive_co2_from_transporter{

Requires:

```

    Effect: increase AvailableCO2forUse by AvailableCO2forUse of
    CO2TransportAgent
}

allocate_to_consumers{
    Requires: environment definition of how demand will be satisfied if there is not
    enough supply
    Effect: generate percentage of demand for each sector to be met based on
    AvailableCO2forUse and environment rules; if all demand can be met: 100%
}

```

DownstreamDemandGeneratorAgent

Attributes:

```

{
    Name: DownstreamDemandGeneratorAgent,
    DemandFoodBev: Draw from FoodBevDemandDist
    DemandOilGas: Draw from OilGasDemandDist
    DemandMedical: Draw from MedicalDemandDist
    DemandRubber: Draw from RubberDemandDist
    DemandFirePrevention: Draw from FirePreventionDemandDist
    DemandOther: Draw from OtherDemandDist
}

```

Actions:

```

generate_demand{
    Requires: demand distributions are defined in environment
    Effect: demand for downstream CO2 is generated
}

```

FoodBevConsumerAgent

Attributes:

```

{
    CO2Demand: DemandFoodBev
    AmtDemandMet: AmtToFoodBev
    CO2Received: AmtDemandMet*CO2Demand
    UnmetDemand: CO2Demand-CO2Received
}

```

Actions:

```

Use_co2{
    Requires: CO2Received >= 0
    Effect: decrease AvailableCO2forUse by CO2Received
}

```

OilGasConsumerAgent

Attributes:

```
{  
    CO2Demand: DemandOilGas  
    AmtDemandMet: AmtToOilGas  
    CO2Received: AmtDemandMet*DemandOilGas  
    UnmetDemand: CO2Demand-CO2Received  
}
```

Actions:

```
use_co2{  
    Requires: CO2Received >= 0  
    Effect: decrease AvailableCO2forUse by CO2Received  
}
```

MedicalConsumerAgent

Attributes:

```
{  
    CO2Demand: DemandMedical  
    AmtDemandMet: AmtToMedical  
    CO2Received: AmtDemandMet*DemandMedical  
    UnmetDemand: CO2Demand-CO2Received  
}
```

Actions:

```
use_co2{  
    Requires: CO2Received >= 0  
    Effect: decrease AvailableCO2forUse by CO2Received  
}
```

RubberConsumerAgent

Attributes:

```
{  
    CO2Demand: DemandRubber  
    AmtDemandMet: AmtToRubber  
    CO2Received: AmtDemandMet*DemandRubber  
    UnmetDemand: CO2Demand-CO2Received  
}
```

Actions:

```
use_co2{  
    Requires: CO2Received >= 0  
    Effect: decrease AvailableCO2forUse by CO2Received  
}
```

FirePreventionConsumerAgent

Attributes:

```
{  
    CO2Demand: DemandFirePrevention  
    AmtDemandMet: AmtToFirePrevention  
    CO2Received: AmtDemandMet*DemandFirePrevention  
    UnmetDemand: CO2Demand-CO2Received  
}
```

Actions:

```
use_co2{  
    Requires: CO2Received >= 0  
    Effect: decrease AvailableCO2forUse by CO2Received  
}
```

OtherConsumerAgent

Attributes:

```
{  
    CO2Demand: DemandOther  
    AmtDemandMet: AmtToOther  
    CO2Received: AmtDemandMet*DemandOther  
    UnmetDemand: CO2Demand-CO2Received  
}
```

Actions:

```
use_co2{  
    Requires: CO2Received >= 0  
    Effect: decrease AvailableCO2forUse by CO2Received  
}
```

5. Environment Parameters

Upstream Demand Distributions (These estimates are based on the resources cited below, but more accurate estimates may be desired):

- EthanolDemandDist: $\sim N(1,100,000, 35,000)$ (barrels/day)
- EthyleneOxideDemandDist: $\sim N(2,925,000, 50,000)$ (Tons/year)
- SNGDemandDist: $\sim N(611,800,000,000, 30,590,000,000)$ (cubic feet/year)
- HydrogenDemandDist: $\sim N(3,000,000,000, 150,000,000)$ (cubic feet/day)
- OtherDemandDist: $\sim N(100, 5)$ (units/year)

Downstream Demand Distributions (These are very simplistic estimates of demand with a lot of uncertainty due to the numbers they were based on. More accurate demand distribution estimates are probably desired, but this is a start based on the available information.):

- FoodBevDemandDist: ~N(17325, 11550) (Tons/year)
- OilGasDemandDist: ~N(8662.5, 5775) (Tons/year)
- MedicalDemandDist: ~N(6930, 4620) (Tons/year)
- RubberDemandDist: ~N(3645, 2310) (Tons/year)
- FirePreventionDemandDist: ~N(3645, 2310) (Tons/year)
- OtherDemandDist: ~N(3645, 2310) (Tons/year)

AvailableCO2forTransport: Sum of CO2 produced by all producers

Percentage of demand that gets met by CO2 consumers (if there is more demand for CO2 than supply, how the supply gets distributed):

This could be percentages of total available CO2 that are predetermined, rankings by importance where most important get demand met until there is no more, or some combination.

- AmtToFoodBev: 100%
- AmtToOilGas: 100%
- AmtToMedical: 100%
- AmtToRubber: 100%
- AmtToFirePrevention: 100%
- AmtToOther: 100%

6. Resources

- Some general [CO2 market information](#). This is just a preview of a big report, but I made some estimates for distribution of CO2 use based on the information here. This would probably be a good place to get more accurate demand distributions, but it is quite expensive to access the full report.
- Info on [ethylene oxide](#)
- [The SNG market](#) (really the NG market as a whole, but includes stats about what portion is due to SNG)
- Natural gas [demand by year graph](#)
- Barrels of oil [production by day](#)
- Ethanol [production by week](#)
- Ethylene oxide [production by year](#)
- Natural gas production [info](#)
- Hydrogen gas production [info](#)
- CO2 transportation [factsheet](#)
- [The details of how CO2 pipelines work from energy.gov](#)