CARBON SEQUESTRATION (and all that Jazz)

Yale 50th Reunion

May 31,2019

Conventional Math

(in $GtCO_2$)	
Human Emissions	37
Natural Absorption	(19)
Net Increase	**18**

Difficult Imbalance to Overcome

Income Growth

Population Growth

Behavioral Change

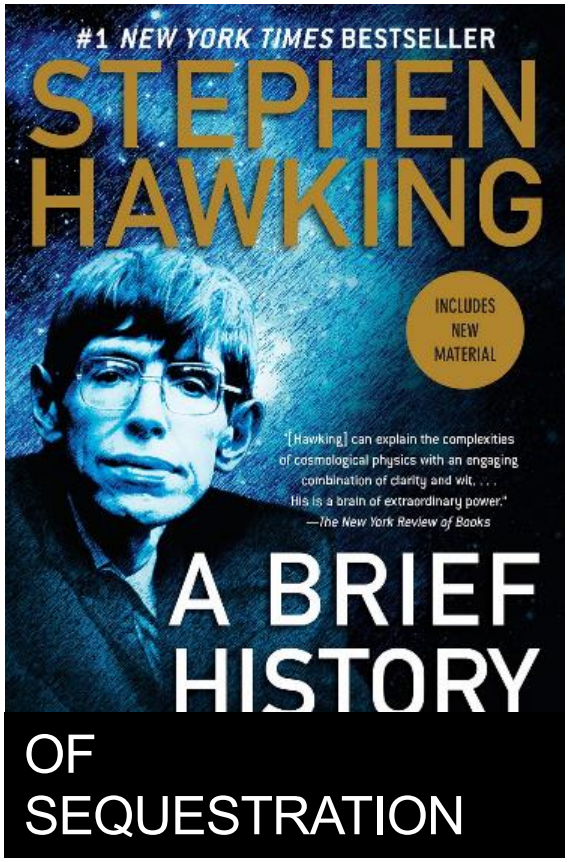
Conservation Technology

Year	Global GDP *($ in trillions)*	Emissions *(Gt)*	Emissions / GDP *(lbs per $)*	Population *(billions)*	Emissions / Capita *(lbs per person)*
1988	$19.2	21.8	2.42	5.1	9,400
2017	$80.7	38.8	1.06	7.5	11,380
Compound Growth	5.1%	2.0%	(2.8%)	1.3%	0.7%

Sources: GDP: St. Louis FRED, PwC. Population: The World Bank, United Nations Population Division, Census reports from national statistical offices, Eurostat, U.S. Census Bureau, Secretariat of the Pacific Community.
Emissions: Global Carbon Project, National Oceanic and Atmospheric Administration.
Note: GDP reflects market exchange rates in current US $.

A Brief History of Sequestration

- Two decades ago: reforestation and soil sequestration etc. added to the climate agenda as mitigation options only
- 2015: the National Academies of Sciences called for research on sequestration and other technologies
- 2018: NAS publishes “Negative Emissions Technologies and Reliable Sequestration: A Research Agenda”



“Nothing but NET”

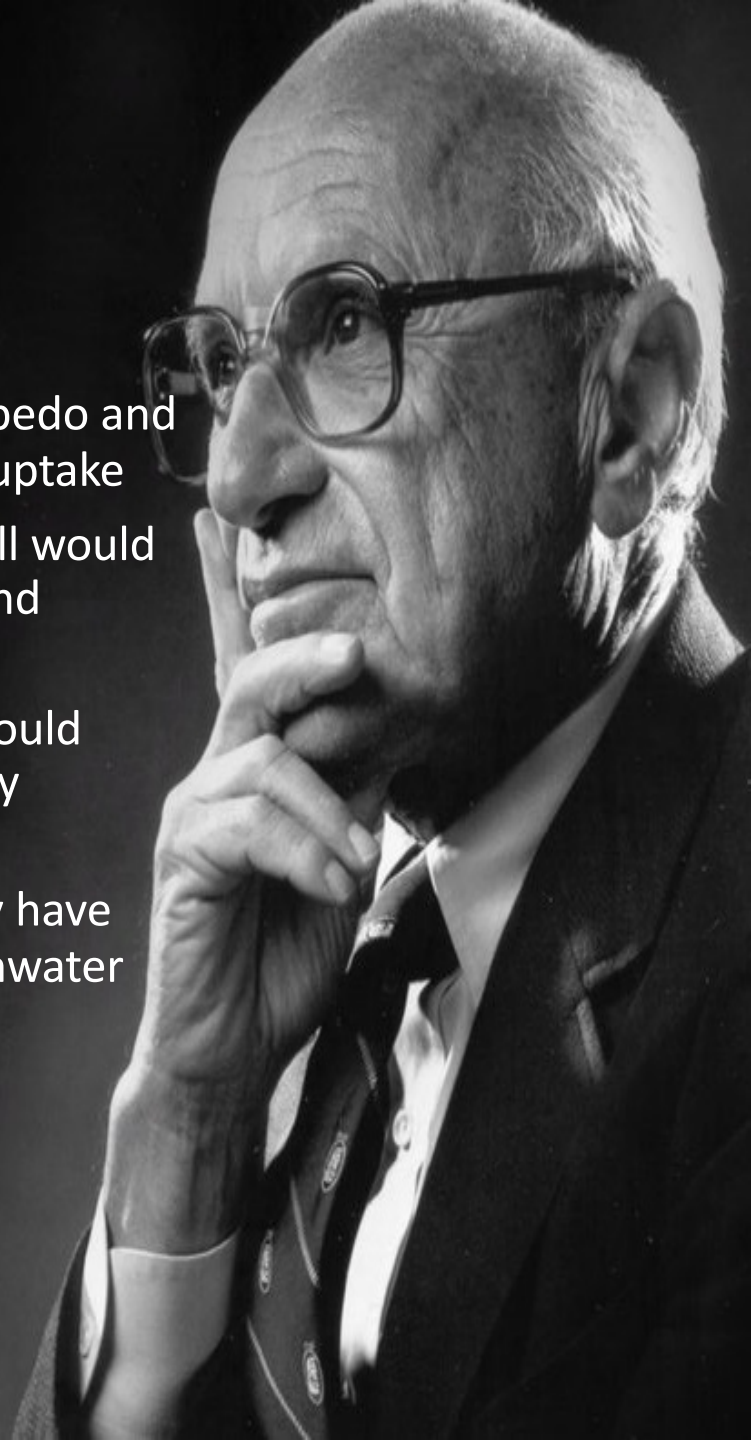
- Increases in biomass
  - Reforestation and Afforestation
  - Blue Carbon
- Biomass Energy and Carbon Capture
- Direct Air Capture
- Carbon Mineralization/Geologic Capture

The State of the Art

Type	Potential (in Gt/Yr)	Comments
Coastal Blue Carbon	1	Needs global buy-in/land use
Terrestrial	4.5	Limited by land / practices
Biomass with CC	3.5 – 5.2	cost / not proven/food
Direct Air Capture	0	Cost greater than demand
Carbon Mineralization	?	Science unknown

No Free Lunches

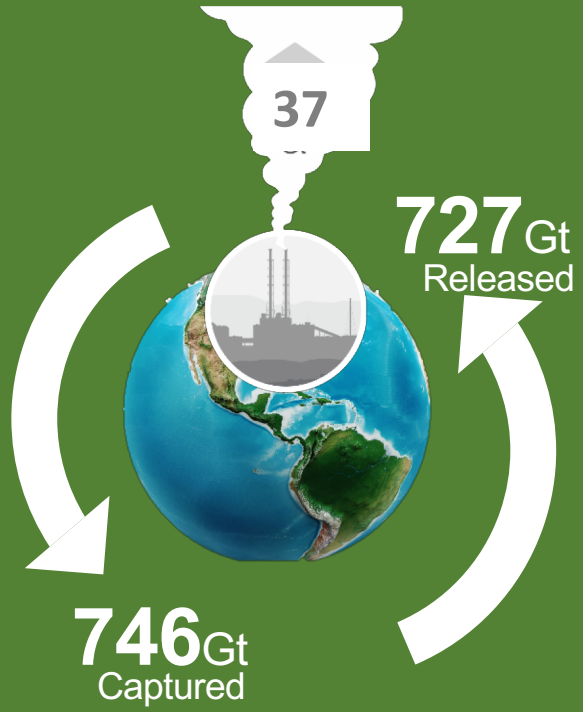
- Forests established at high latitudes decrease albedo and thus would cause net warming the forest's CO_2 uptake
- Forests established in regions with limited rainfall would have adverse effects on streamflow, irrigation, and groundwater resources
- Mining minerals that spontaneously bind CO_2 would create enormous volumes of waste rock that may contaminate water and/or air
- BECCS can increase nitrous oxide emissions, may have substantial water requirements and lead to freshwater ecosystem degradation and biodiversity loss
- Direct Air Capture may increase energy usage



Geoengineering and Terraforming

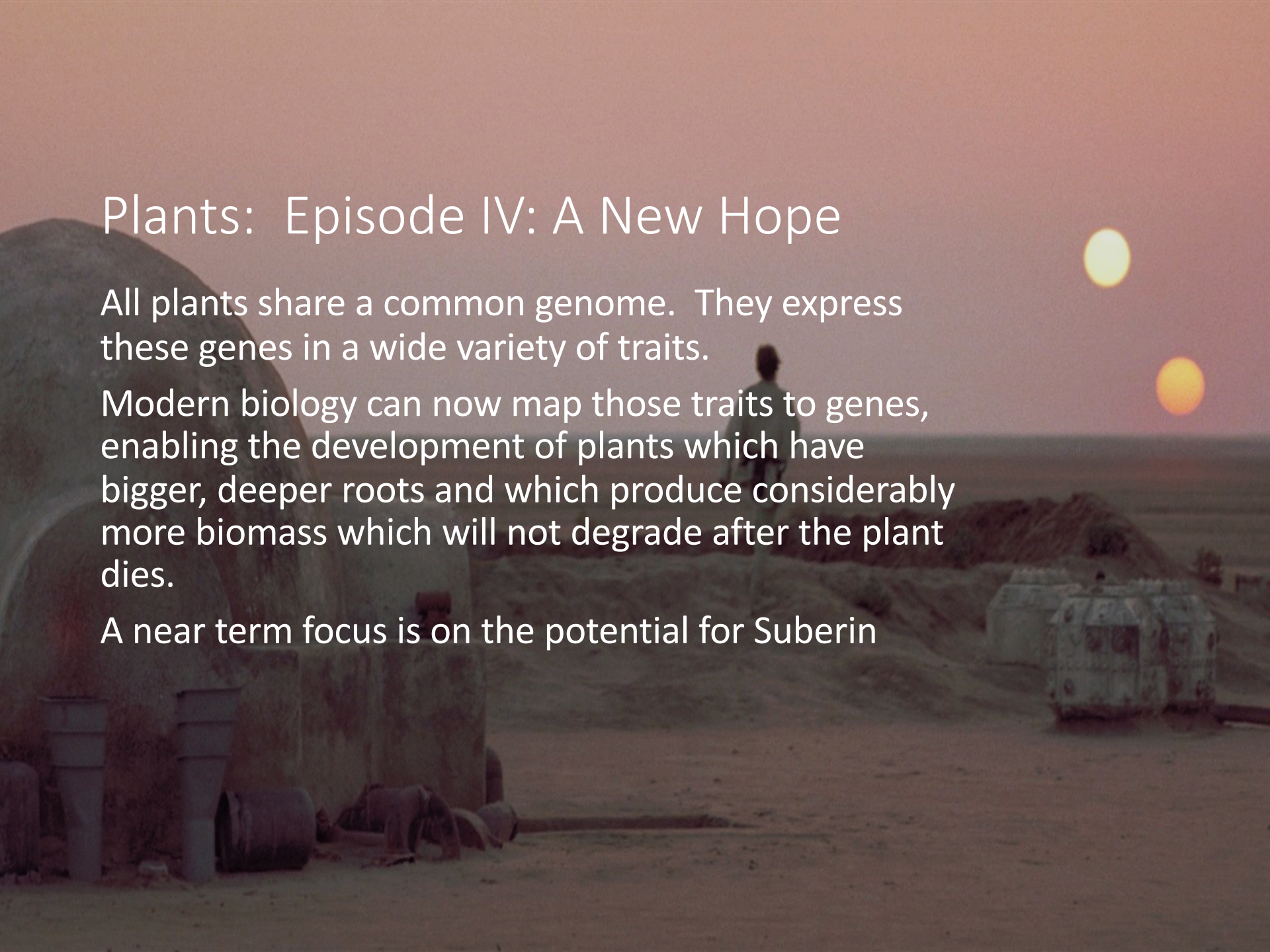
- Iron Fertilization
- Ocean Alkalinization
- Solar Radiation Management
  - High altitude reflecting particles
  - Geo-stationary umbrellas
  - Brighter clouds
- Nuclear Winter
- Dan Brown's Inferno

The New Math



(in $GtCO_2$)	
Natural Absorption	(746)
Natural Release	727
Human Emissions	37
Net Increase	**18**

18 Gt of CO_2 more per year than the earth can handle



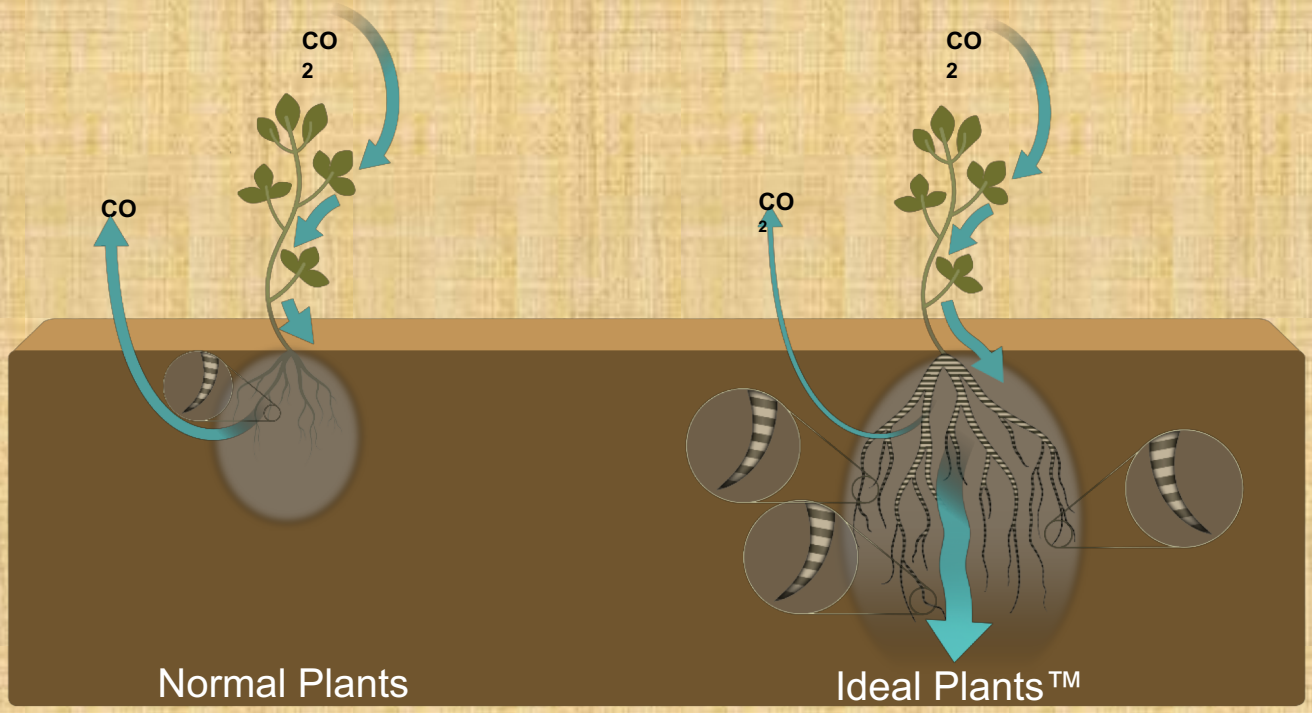
Plants: Episode IV: A New Hope

All plants share a common genome. They express these genes in a wide variety of traits.

Modern biology can now map those traits to genes, enabling the development of plants which have bigger, deeper roots and which produce considerably more biomass which will not degrade after the plant dies.

A near term focus is on the potential for Suberin

Keeping Carbon Underground



Plants: Episode IV: A New Hope (Cont'd)

Salk estimates the sequestration potential of the 6 most common row crops to be between 4-8 GT/yr at a cost of under $10/ton within 10 years

A similar potential exists in 3 common cover crops, and from genetic informed aquatic restoration