A Step Towards Hydrogen Economy Avoid CO_2 & Make Business

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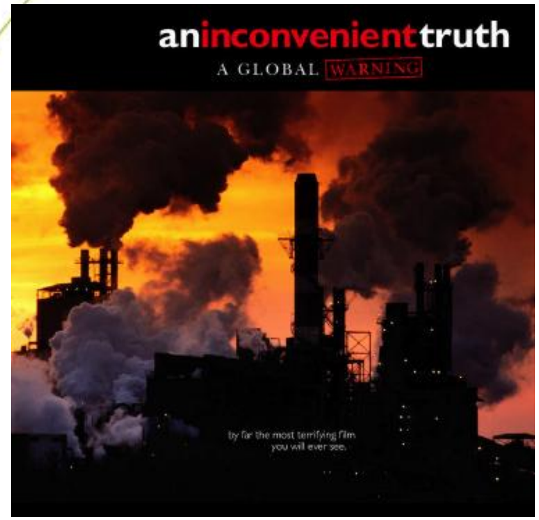
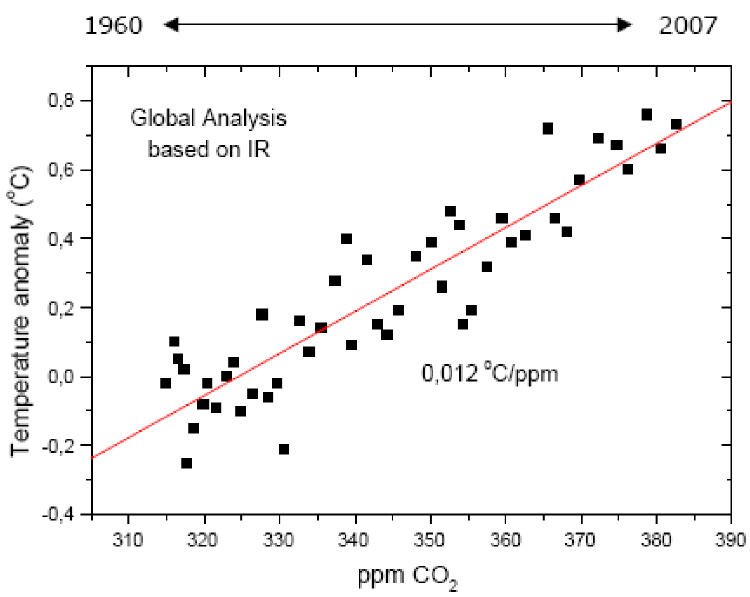
The CO_2 Dilemma

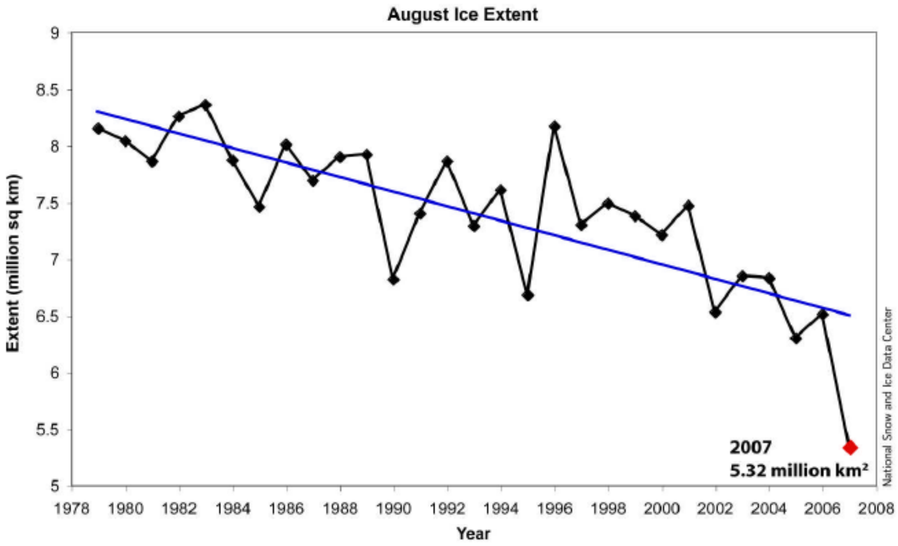


We want: Healthy Environment

We need: More & More Energy

We create: Threats to Mankind

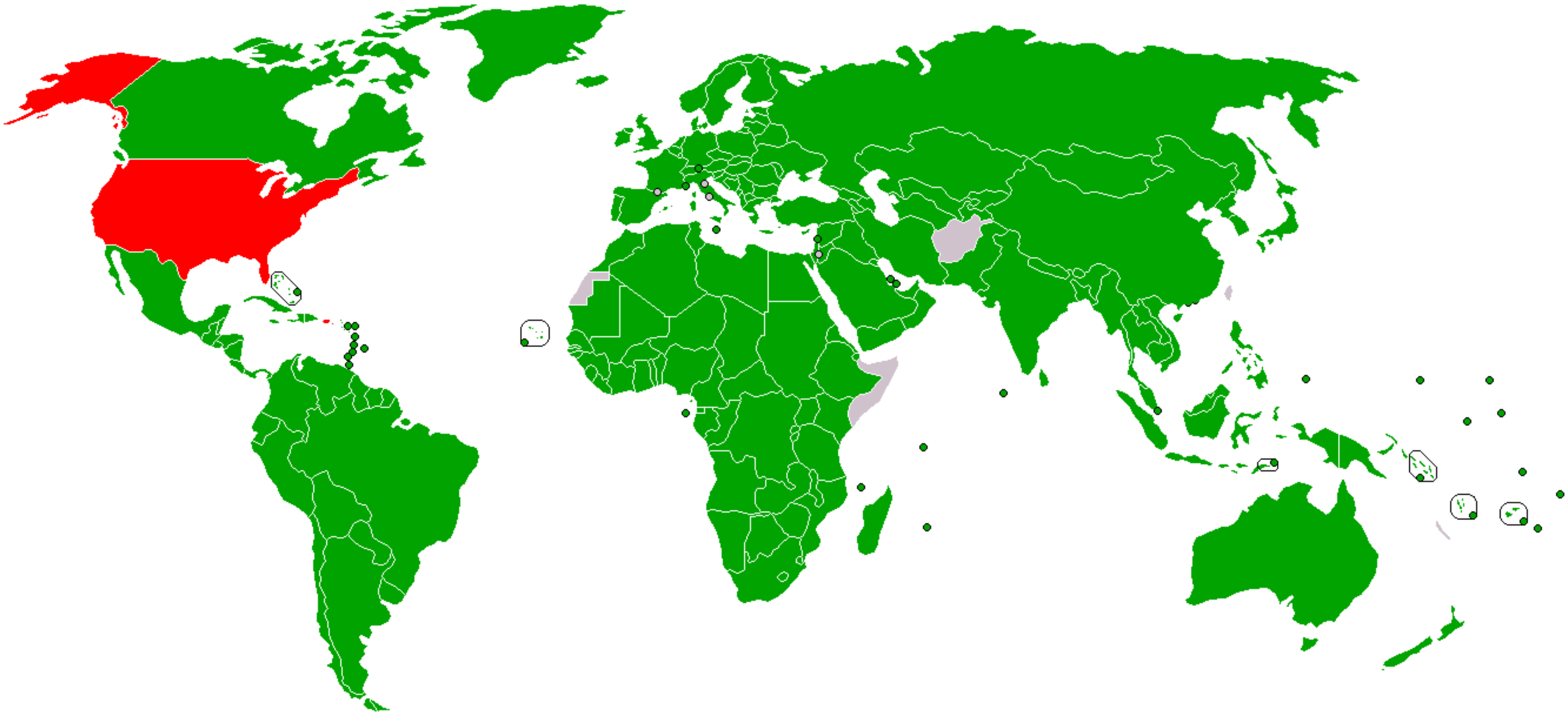




Solution? The Kyoto Protocol

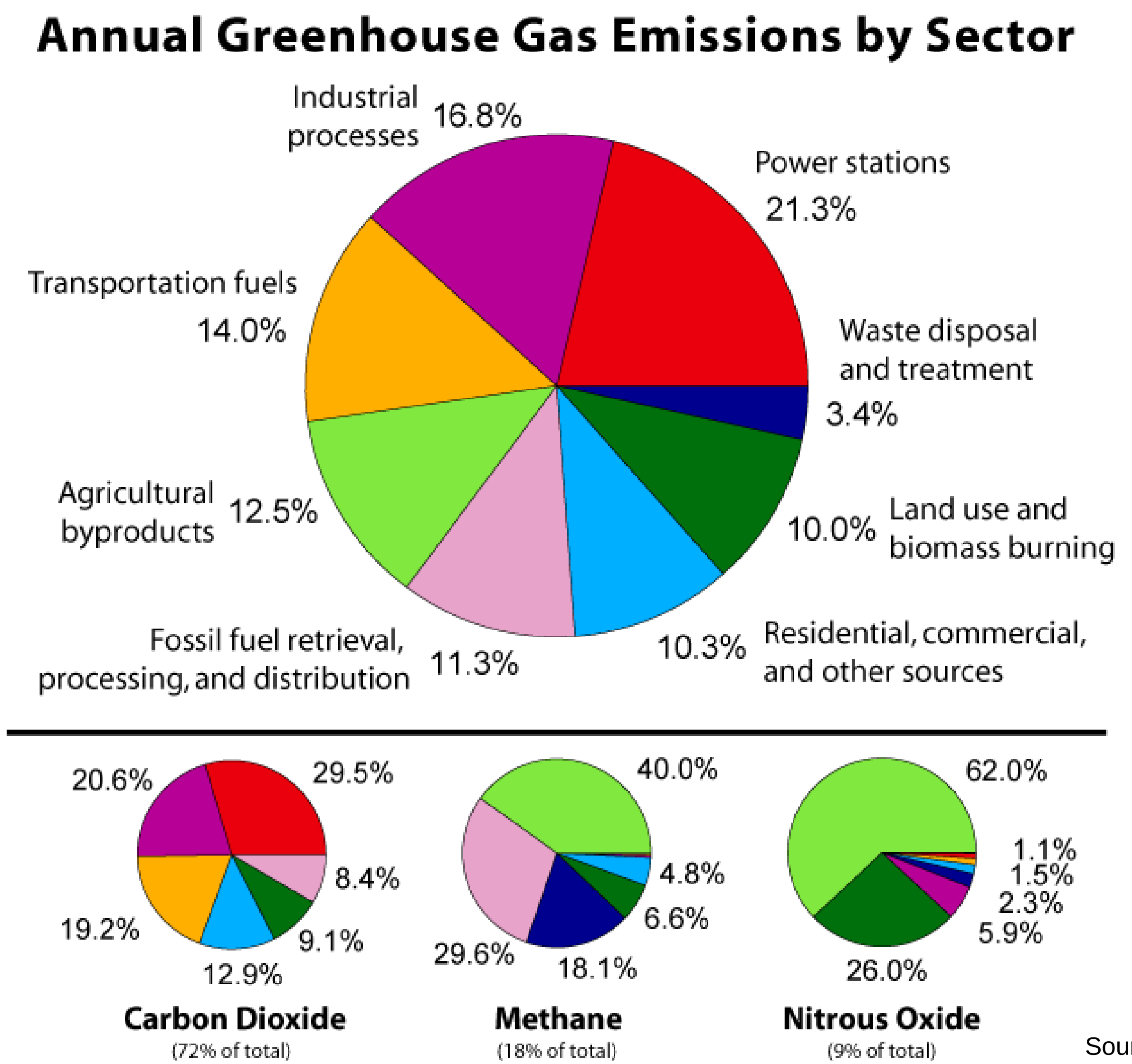
- The objective is the "stabilization and reconstruction of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."
- The objective of the Kyoto climate change conference was to establish a legally binding international agreement, whereby all the participating nations commit themselves to tackling the issue of global warming and greenhouse gas emissions. The target agreed upon was an average reduction of 5.2% from 1990 levels by the year 2012. Contrary to popular belief, the Protocol will NOT expire in 2012. In 2012, Annex I countries must have fulfilled their obligations of reduction of greenhouse gases emissions established for the first commitment period (2008–2012) (see Annex B of the Protocol).
- …

Kyoto Member States



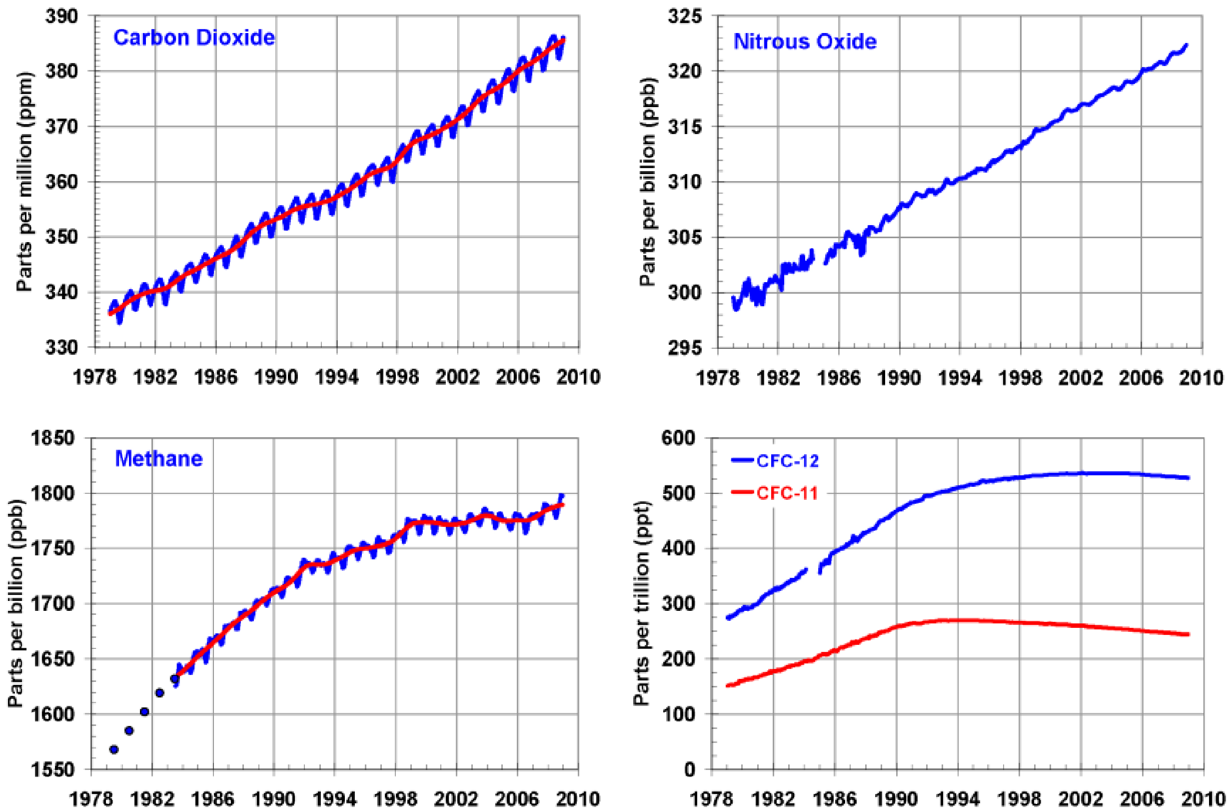
President Barack Obama has, as yet, taken no action with the senate that would change the position of the United States towards this protocol. When Obama was in Turkey in April 2009, he said that "it doesn't make sense for the United States to sign the Kyoto Protocol because it is about to end". At this time, two years and eleven months remained from the four-year commitment period.

Man-Made GHG



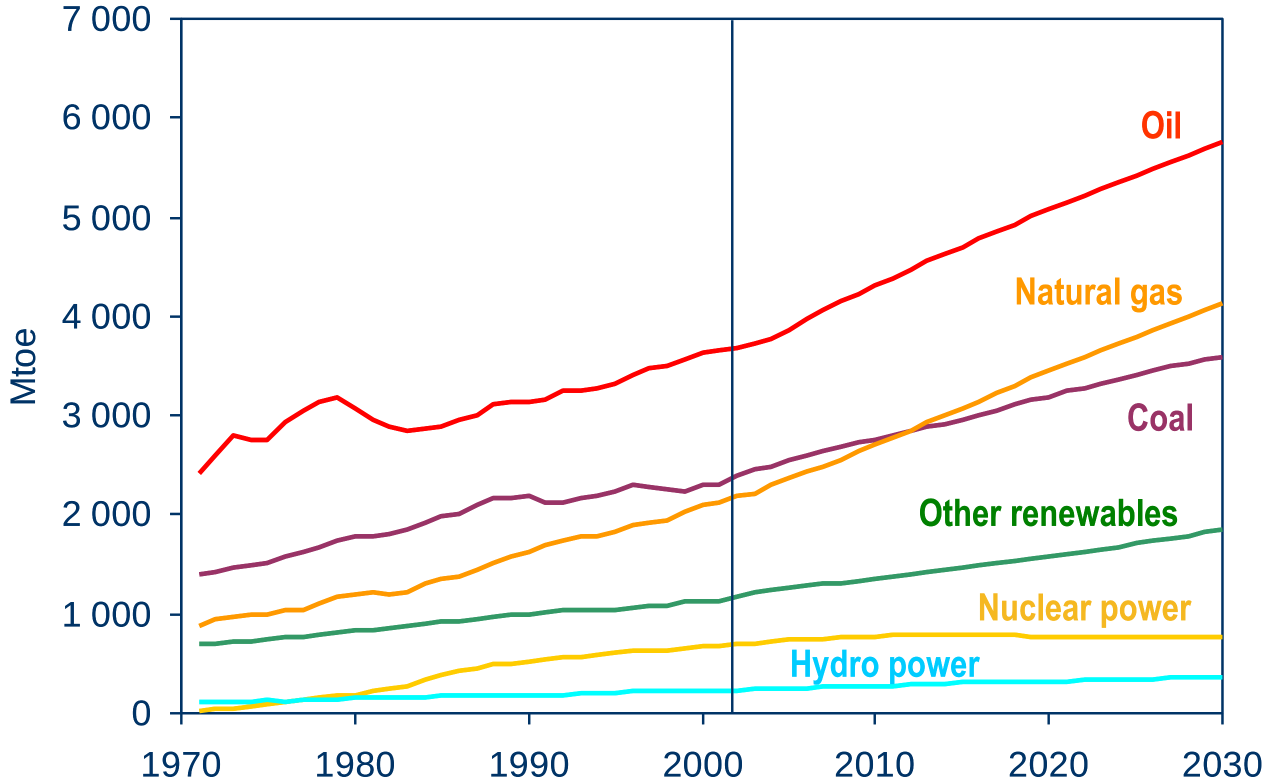
Source: Emission Database for Global Atmospheric Research

Kyoto Results: GHG Charts …



Source: http://www.cmdl.noaa.gov/aggi

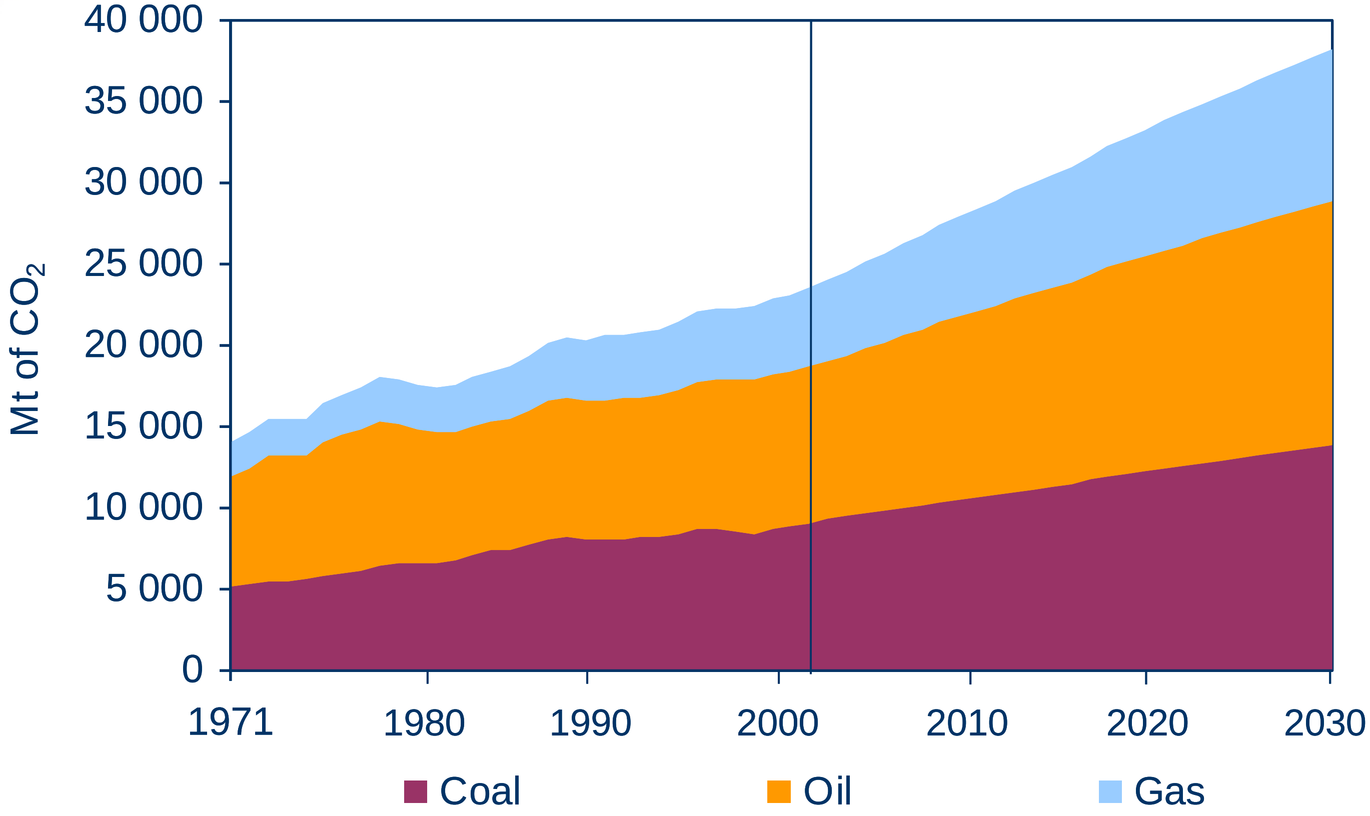
World Primary Energy Demand



Fossil fuels will continue to dominate the global energy mix, while oil remains the leading fuel

Source: IEA

World Energy Related CO_2 Emissions



Global emissions grow 62% between 2002 & 2030, but fuel shares hardly change

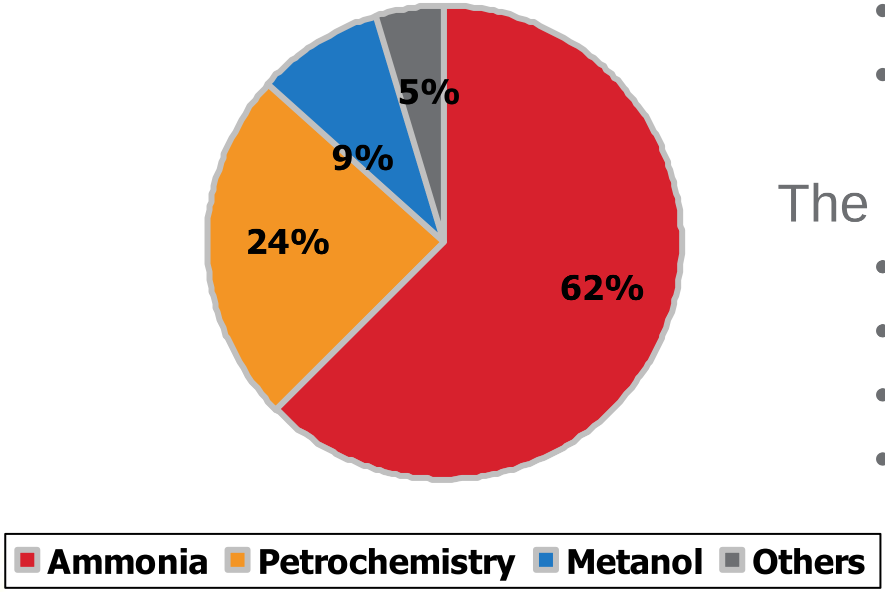
Source: IEA

Declaration

Hydrogen is the Worlds clean Energy Choice

Hydrogen is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the planet.

H_2 Use (just) in Industry



95% of H_2 is mainly produced at the customer, where 24% go into

- Gasoline and Diesel Fuel
- Polymers

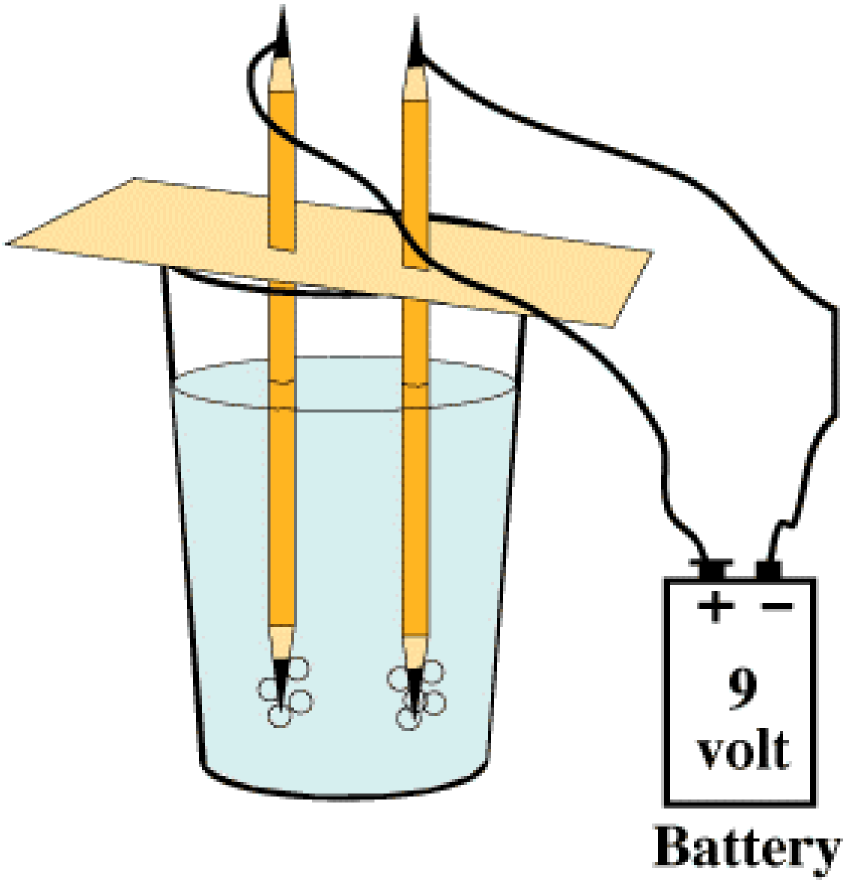
The remaining 5% go into

- Fuel Cell
- Fine Chemical Production
- R&D
- ....

Hydrogen Production

- Natural Gas Reforming
  - large CO_2 emissions, consumes much energy
- Renewable Electrolysis
  + wind, solar power, - process safety of electrolysis
- Gasification
  + uses organic waste matter, - CO_2 emissions
- Renewable Liquid Reforming
  is questionable as it uses biomass needed for food production
- Nuclear High Temperature Electrolysis
  + uses excess heat of NPPs, - centralized, expensive materials for plant
- High Temperature Thermochemical Water Splitting
  + uses solar concentrators, - centralized, expensive materials for plant
- Photobiogical and Photoelectrochemical
  - low H_2 yield

Electrolysis

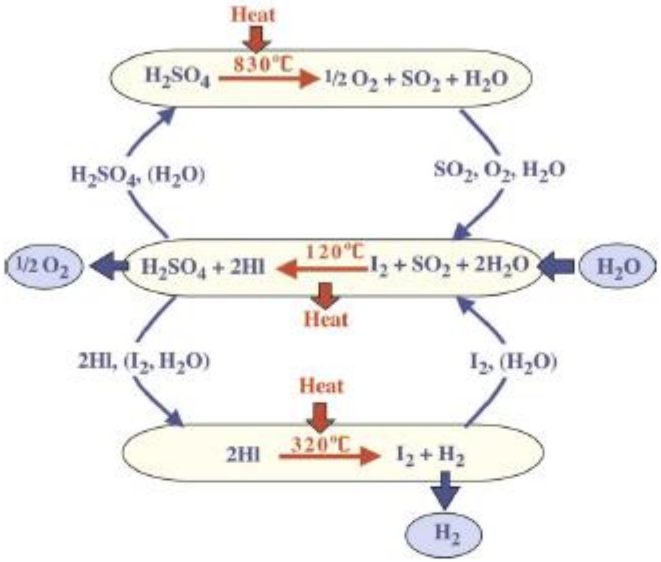


So simple but not that feasible!

Sulfur – Iodine Cycle

The characteristics of the S-I process can be described as follows:

+ All fluid (liquids, gases) process, therefore well suited for continuous operation;
- High utilization of heat predicted (about 50%), but very high temperatures required (at least 850 deg C);

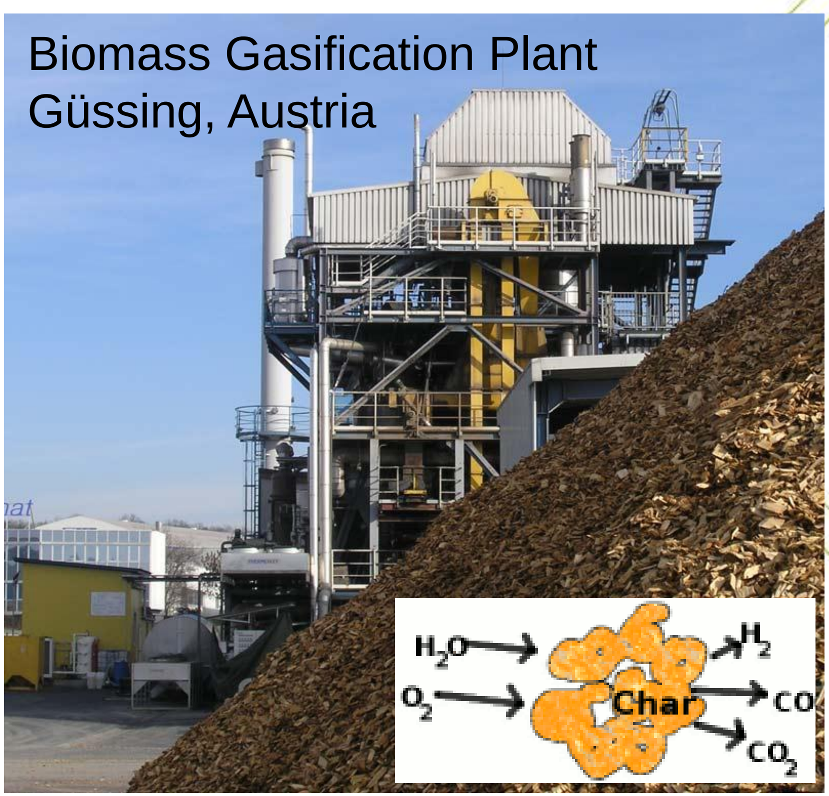


- Completely closed system without byproducts or effluents (besides hydrogen and oxygen);
- Corrosive reagents used as intermediaries (iodine, sulfur dioxide, hydroiodic acid, sulfuric acid); therefore, advanced materials needed for construction of process apparatus;
+ Suitable for application with solar, nuclear, and hybrid (e.g., solar-fossil) sources of heat;
- More developed than competitive thermo-chemical processes (but still requiring significant development to be feasible on large scale).

Gasification

Gasification is a process in which coal or biomass is converted into gaseous components by applying heat under pressure and in the presence of steam. A subsequent series of chemical reactions produces a synthesis gas, which is reacted with steam to produce more hydrogen that then can be separated and purified.

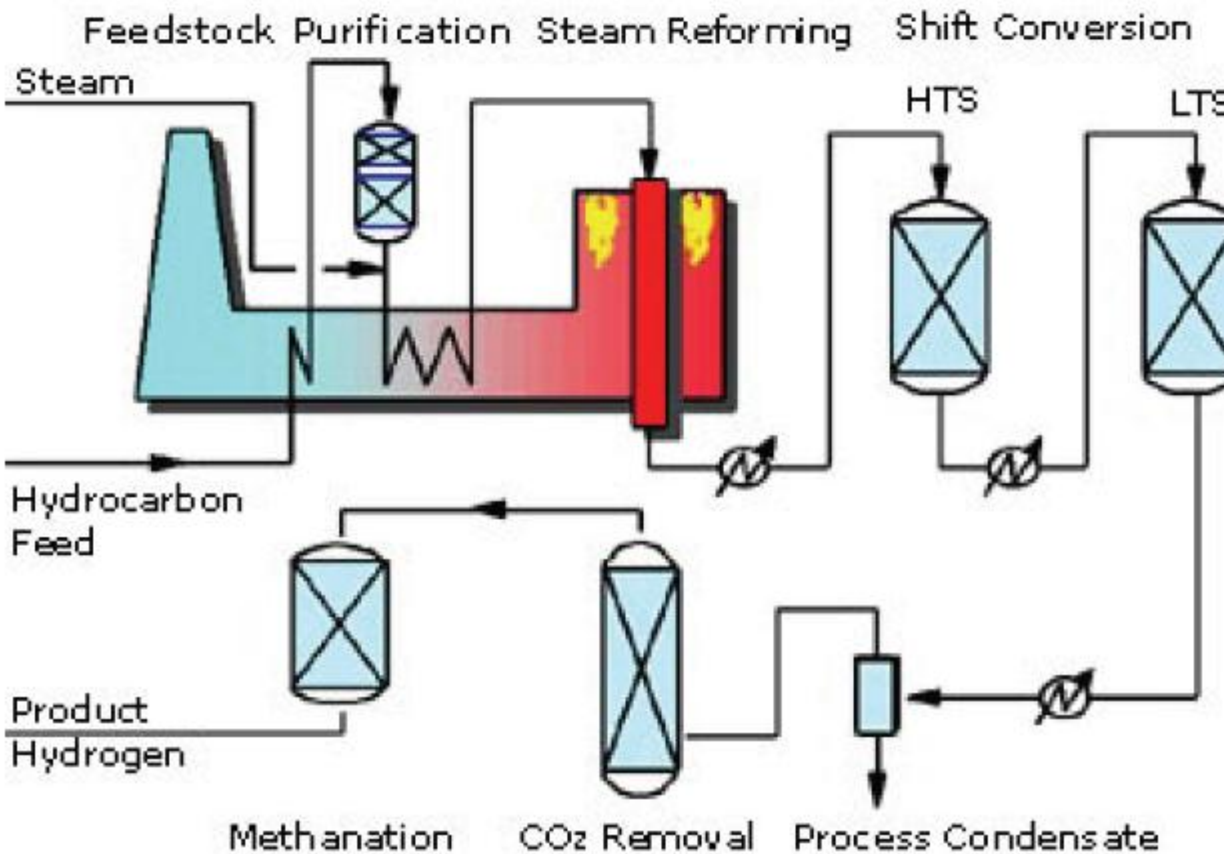
Like coal, biomass can be gasified using high temperatures and steam to produce hydrogen. Because biomass resources consume CO2 in the atmosphere as part of their natural growth process, producing hydrogen through biomass gasification releases near-zero net greenhouse gases.



Biomass Gasification Plant
Güssing, Austria

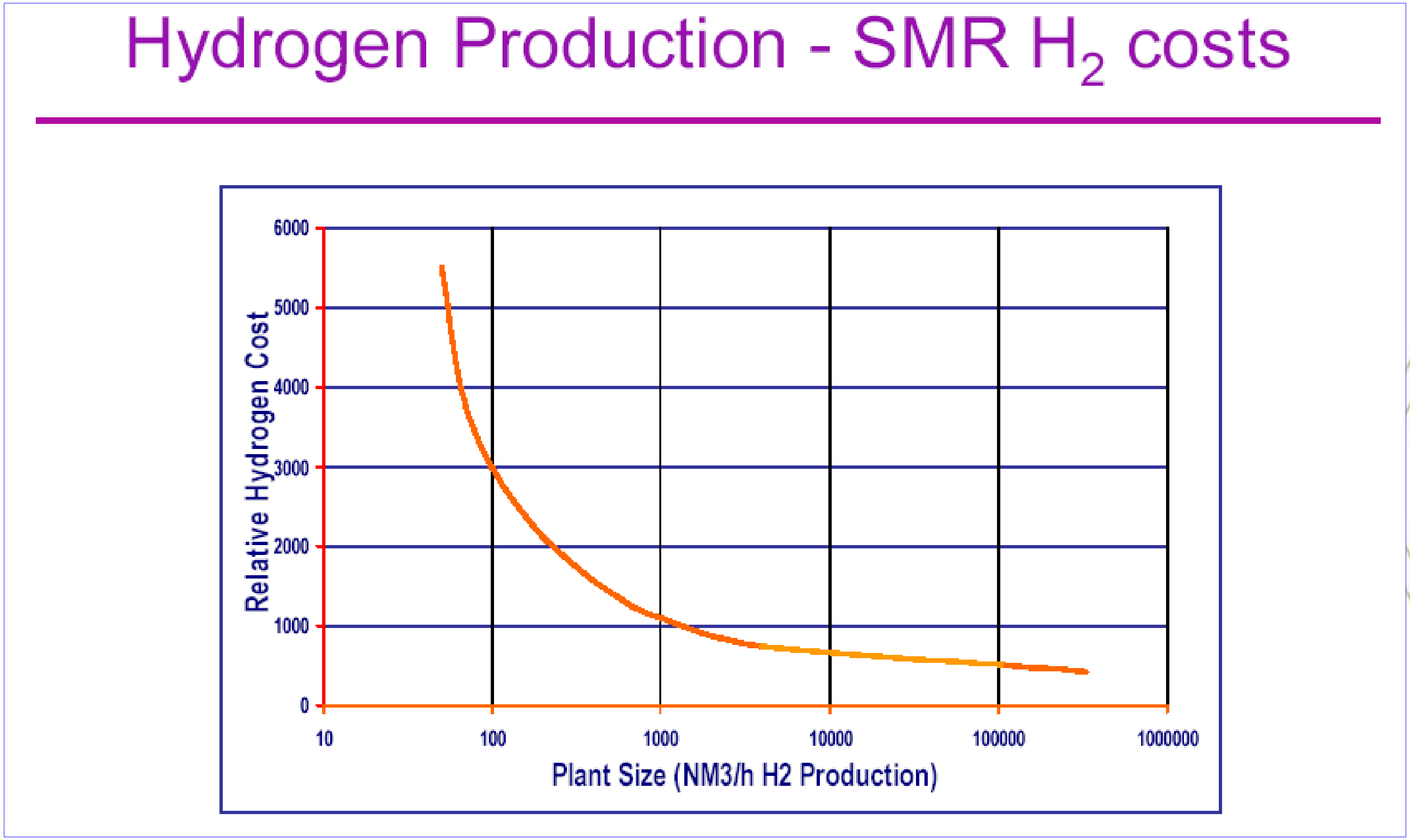
State of the Art H_2 Production

Steam Reforming of Natural Gas - SMR



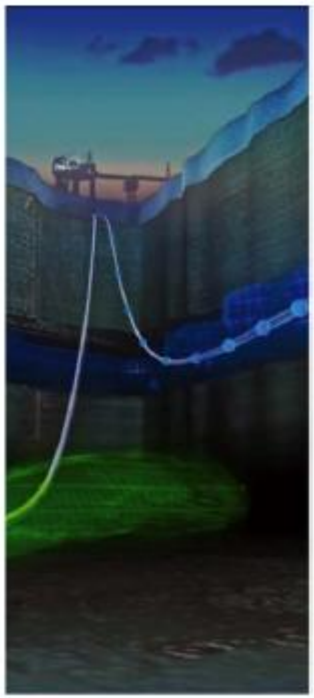
5.5 T CO_2 per 1T H_2, process energy not included!

SMR: Cost – Plant Size Relation

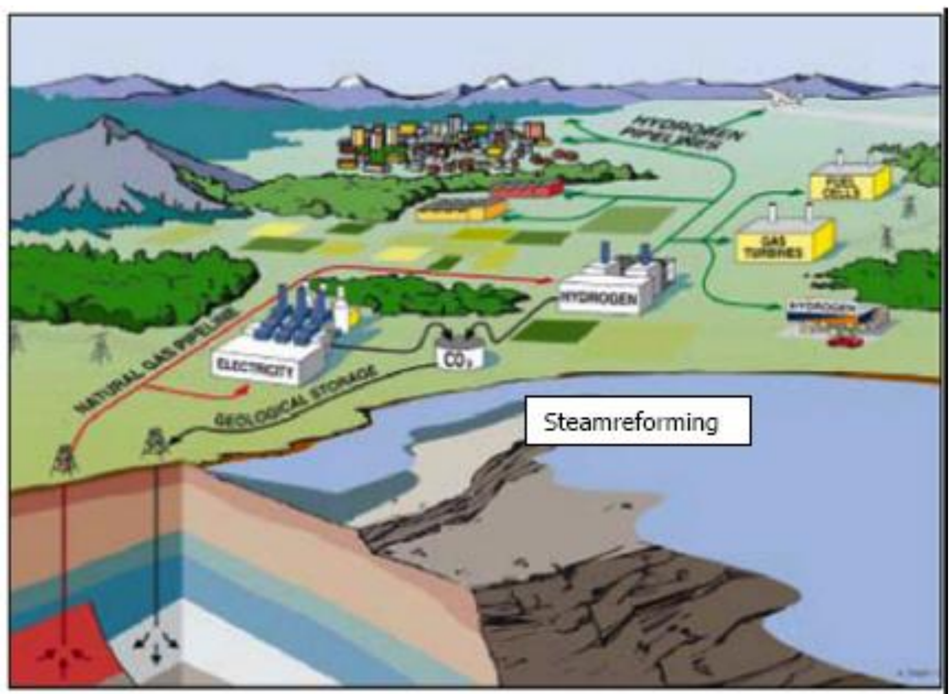


Questionable CO_2 Exit

CO_2 Capture and Sequestration



? Costs
? Risks & Safety
? Efficiency
? ...



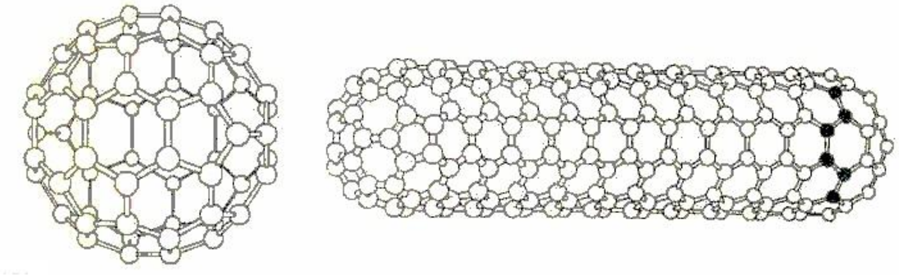
Novel Process Technology

Thermo-Catalytic NG Cracking

$$CH_4 \xrightarrow[\text{catalyst}]{\text{heat}} C + 2H_2$$

Utilizing appropriate catalysts the process affords except Hydrogen high quality Carbon nanoTubes or Carbon nanoFibers

The By-Product CNT



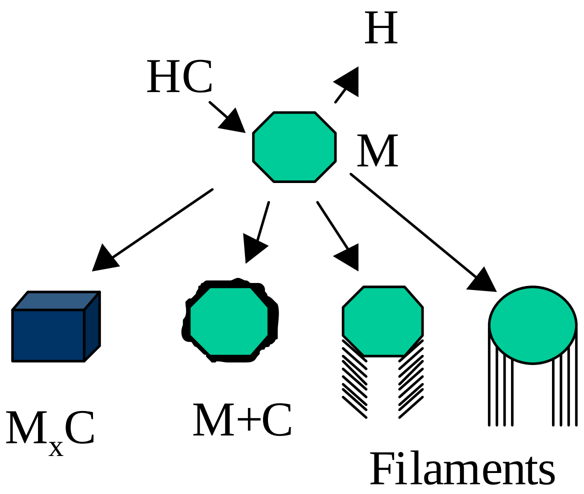
A Mix of 2 highly ordered Carbon Modifications
Buckminster Fullerene & tubular Graphene

Graphene: One Single Layer of Graphite

The CNT/H_2 Catalysis

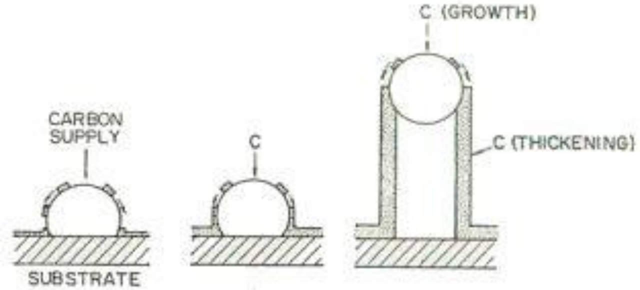
By interaction of a Hydrocarbon existing in the gaseous phase with a Metal-Catalyst at elevated temperature.

→ Catalytic Chemical Vapor Deposition, CCVD

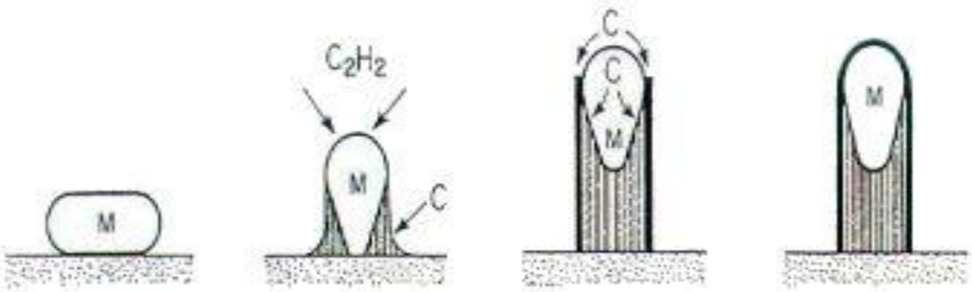


eg. Ti **eg. Cu** **Ni, Fe, Co**

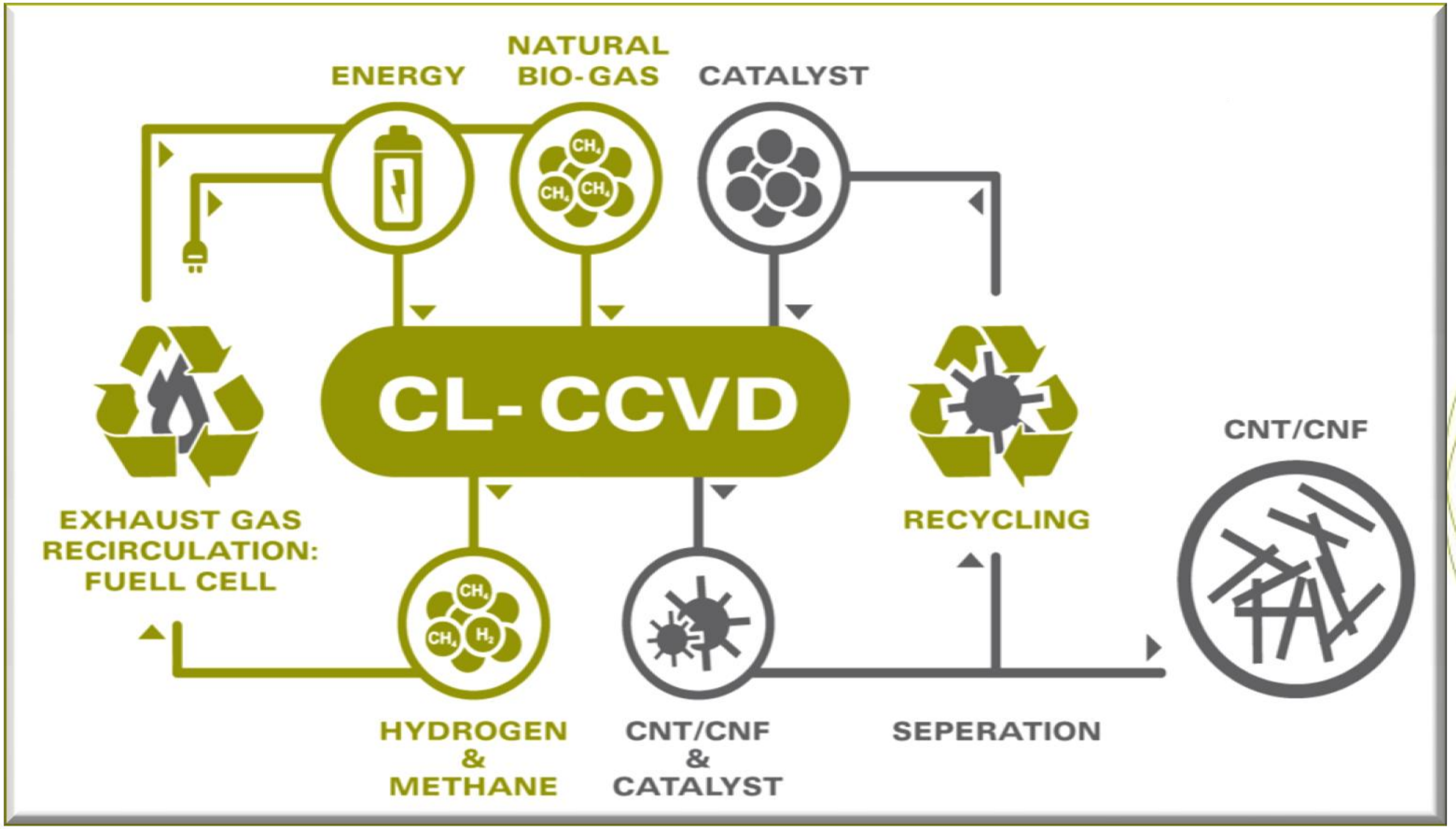
Filament or nano Fiber Growth



CNT Growth

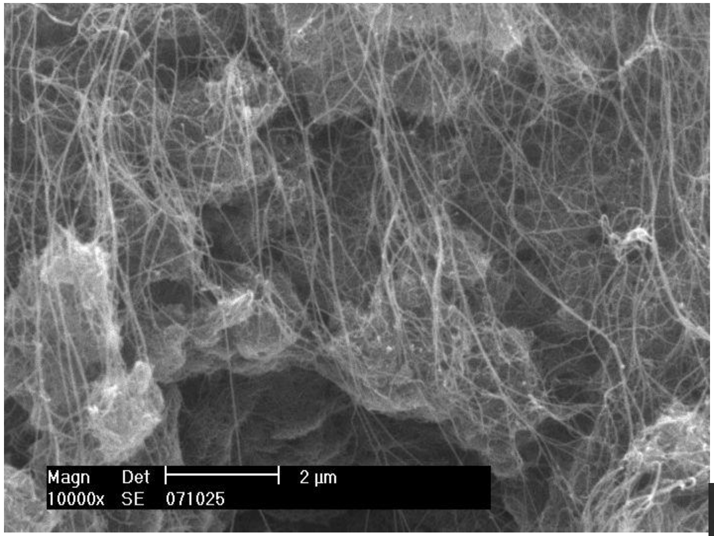


CL-CCVD Process

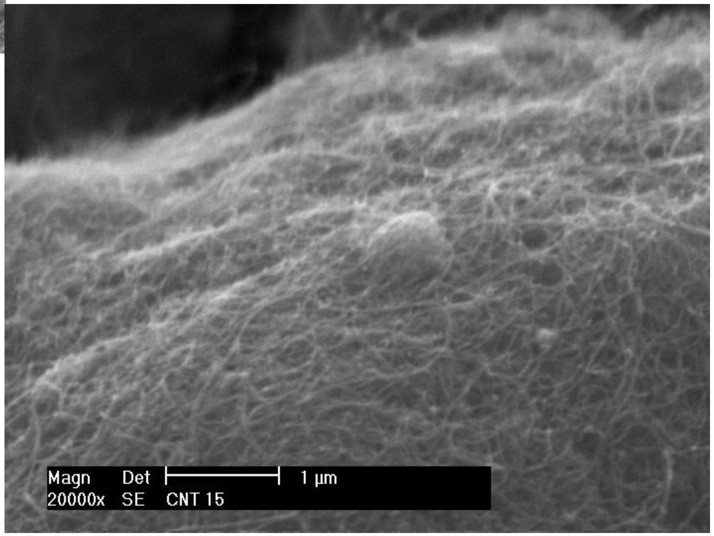


CNT/H_2 Pilot-Facility

CNT Purification



Removal of Catalyst



CNT Agglomerates

Outstanding Material Properties

- Spec. electrical Resisitivity: 10^{-3}-10^{-4} Ohm cm
- Max. Current Density: up to 10^{13} A/cm²
- Thermal Conductivity: > 2000 W/mK
- Young's Modulus: ~ 1 – 1,5 TPa
- Tensile Strength: ~ 1 TPa
- Temperature Stability on Air: 550 – 750 °C
- Specific Weight: 1,6 – 1,8 g/cm³
- High Chemical Inertness
- Specific Surface Area: ~ 350 m²/g

Multiple Properties in Composite Materials

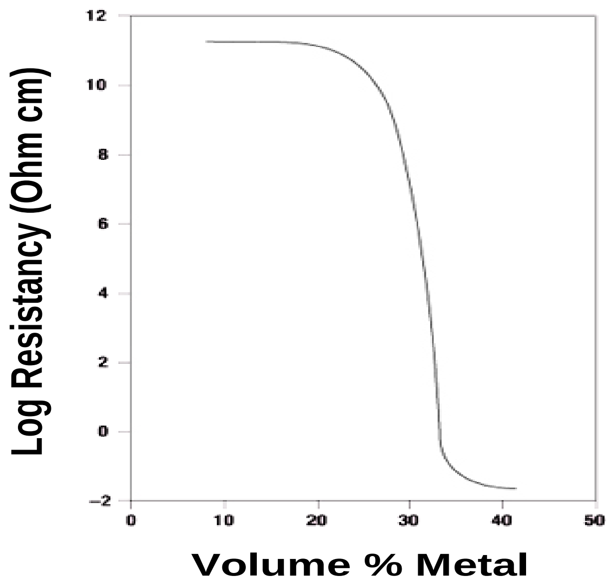
OBVIOUS

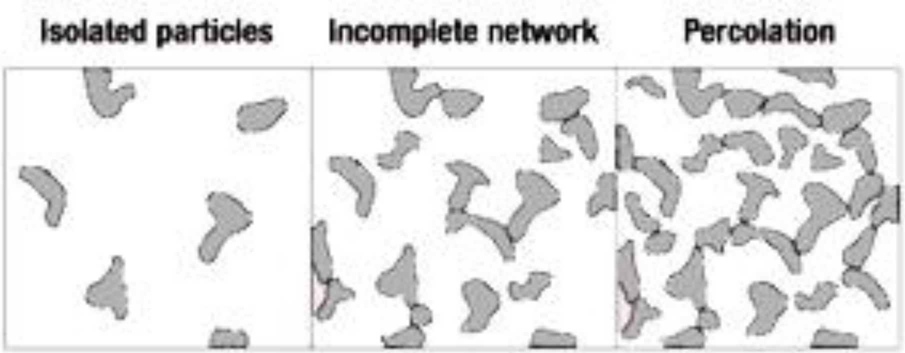
- Light Weight (high strength to weight ratio)
- Excellent Mechanical Properties (filler alone)
- Less Breakdown (of filler) During Processing
- Variable Conductivity (electrical, thermal)
- Property Modification via Large Interface

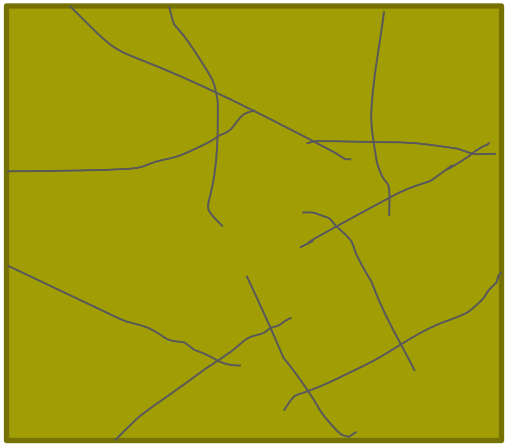
NOT SO OBVIOUS

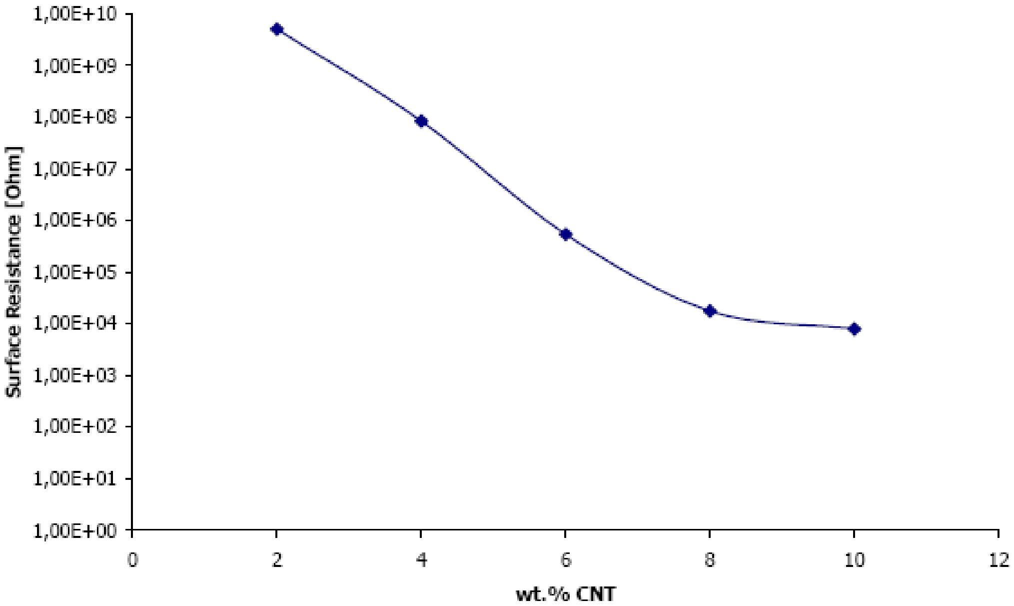
- Interface Bonding / Nanotube-Matrix Interactions
- Load Transfer
- Achieving Homogeneity (Dispersion, Distribution)
- Behavior of Nanotube Aggregates

Application: Conductive Polymers



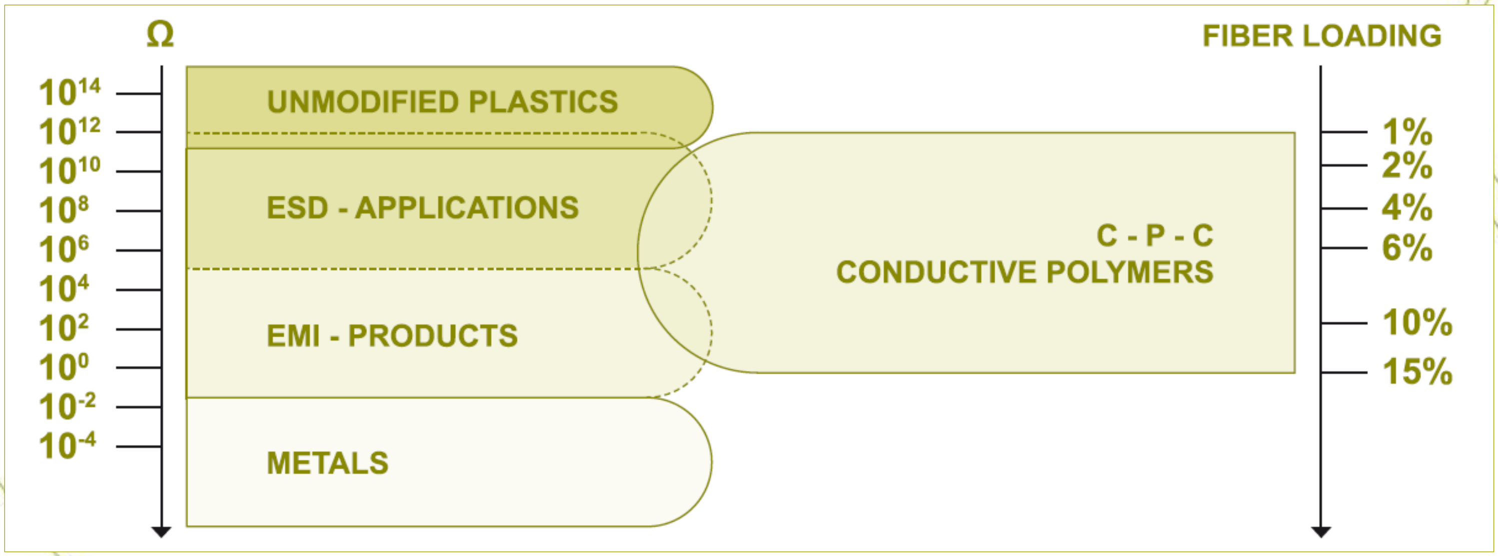






C-Polymers Compounds

- CPC® – Products are immediately applicable, reaching from **antistatic** to **electrically dissipative!**



Process Key Data & Specifics

- Full Continuous Process
- 75 – 80% C-Yield
- Product-Gas: 80 – 90Vol.% H_2
- Optimum Capacity for Pilot to Medium Plant Size (100 T H_2 per year)
- Single Reactor Capacities Scaleable in the Range of 2 to 5 T H_2/yr

- Zero CO_2 Emission
- High Quality Carbon Nanotubes
- Patent Pending Process

Thank You for Attention!

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