AIChE® 13th SOUTHWEST PROCESS TECHNOLOGY CONFERENCE

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Overview of Decarbonization Pathways

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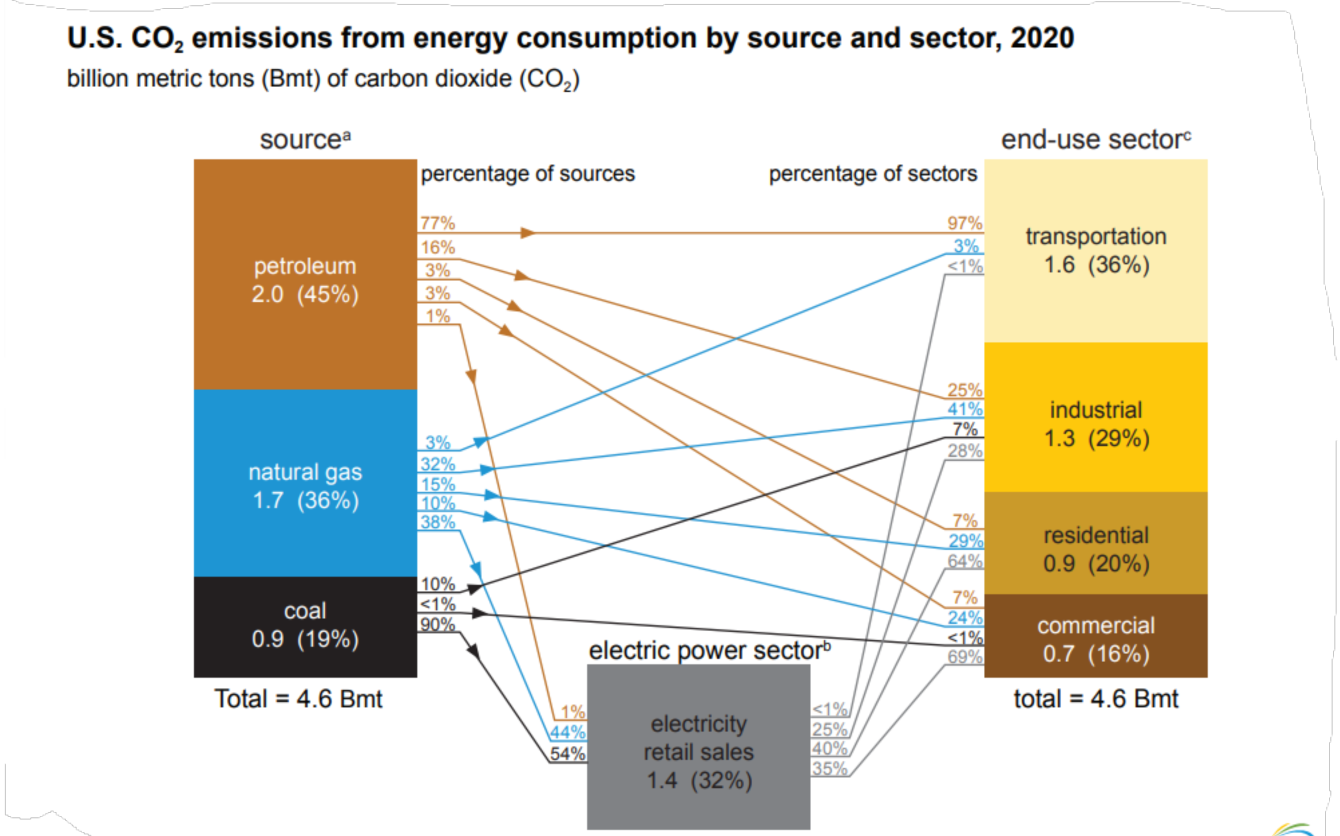
Why Do We Need Decarbonization?

- CO_2 is a GHG that traps heat contributes to Global warming –keep global warming to less than 1.5C
- EU goals –By 2030 reduce CO_2 emissions by 55% below 1990 levels; carbon net zero by 2050
- US aspirational goal 80% reduction CO_2 from power generation by 2030, 50% reduction all CO_2 by 2050
- Major oil companies –reduce CO_2e emissions by 35% by 2030 and be carbon net zero by 2050
- Rule thumb: burning 2 mmbtu/hr lhv of NG will produce 1 KTA CO_2 100mmbtu/hr NG heater = 50 KTA CO_2 $CH_4 + 2\ O_2 = CO_2 + 2\ H_2O$ (0.058 tonne CO_2 / 1mmbtu lhv NG) -
- Scope 1 Direct Emissions used in process ie Fuel gas, fuel oil, steam, power
- Scope 2 Indirect Emissions – imported energy into process ie purchased steam, grid power, H_2
- Scope 3 End product Emissions – CO_2e produced by using product - car, truck emissions – For integrated oil company 85% of their CO_2e emissions can be Scope 3 from customers using products
- GWP of CO_2 is 1.0 GWP for CH_4 is 86 (20 yr) and 25 (100yr) Must stop methane leakage !!!
- In U.S. 65% of CO_2 from fossil fuel comes from the Transportation (36%) and Industrial (29%)Sectors.!!
  - Transportation –Produce Less carbon intensive fuels,Use Renewable fuels,Renewable electricity, H_2
  - Industrial - Improve energy efficiency, Technology, Use Renewable electricity, Green H_2, CCUS

U.S. Sources CO2 from Energy Consumption in 2020



U.S Electrical generation accounts for 32% CO2

U.S. power % generation , % CO2

type fuel	% power generated	% CO2
petroleum/misc	1	2
NG	40	44
coal	19	54
nuclear	20	xxx
renewable	20	xxx
	100	100

World CO2e by type of GHG Gas

type gas	%	
methane	16	***
CO2 from forestery and land use	11	
CO2 from fossil fuels & industry	65	***
Nox	6	
Florinated gases	2	
	100	

Source –U.S. Energy Information Administration

How can we reduce Process Industry Carbon Footprint? (1 of 2)

- Pathways to Reducing Carbon Footprint Include a combination of following methods:
- Reduce Scope 1 and 2 Emissions -Direct & Indirect CO2 emissions from fossil fuels
- Energy Efficiency Improvement – Existing and New facilities – Maintain energy recovery equipment
- Use new technology, new catalysts improve yields which will reduce energy intensity
- Electrification of process equipment using renewable electric power (wind, solar, hydro, nuclear)
- Use Renewable wind (on shore & offshore) and solar power , build battery energy storage systems (BESS)
- Produce, Use, and Sell Green and Blue H2- use H2 as an energy carrier
- Reduce methane leakage from abandoned oil wells, gas wells, P/L's, LNG plants, landfills, livestock manure
- Stop routine flaring – minimize flaring on start-up and shut-down
- CCUS – Cost effective Carbon capture with storage or utilization of the CO2
- Good news –Have technology & assets for offshore wind, blue/green H2, CO2 sequestration, and hydrocrackers to make renewable fuels

How can we reduce Process Industry Carbon Footprint? (2 of 2)

- Reduce Scope 3 Emissions Oil and Gas Industry– Emissions from using products
- Rystad Energy Energy predicts World oil demand will peak in 2028 at 102 M bbls/d and then reduce to 55 M bbls/d by 2050
- Oil and Gas companies will transition to become Energy companies selling less petroleum based fuels and will sell fuels with low carbon intensity like:
  - Low carbon LNG -CCS and electrification of refrigeration compressors
  - renewable electricity - wind and solar
  - Green H2 and Blue H2
  - convert refinery units to produce renewable fuels
  - Bio-fuels / renewable fuels like renewable diesel, Sustainable aviation fuel (SAF)
  - Synthetic e-fuels like e gasoline - (use of renewable H2 + captured CO2 =e-fuels)
- Scope 3 Petrochemicals- Polyethyene, Polypropylene -Reprocess waste plastic, stop singular use
  - Recycle waste plastic -Circular carbon economy by either mechanical means or chemical (pyrolysis) recycling waste plastic
  - Utilize New more efficient technologies and use renewable feedstocks to produce the ethylene, propylene feedstocks

Improving Energy Efficiency

<u>Improving energy efficiency is cheapest way to reduce CO2e</u>

If don't burn the fuel , you don't make the CO2 and save the cost of the fuel – WIN/ WIN

- Some energy projects will have negative cost of CO2 capture
- Maintain energy recovery equipment and Use New Technology and new catalysts
- Capital energy projects can have less than 2 -3 yr payback & maintenance projects 2 – 3 months
- Fired heater efficiency - stack temperature, excess air, adjust burners, clean convection section -
- 2% O2 reduction = 0.6 % eff improvement ; 20deg C reduction stack temp = 1 % eff improvement
- On line real time monitoring of Energy KPI's, monetize $ GAP, APC, optimizers, Digital Twins
- Monitor vacuum on condensing turbine vacuum- 1.2 in Hg (0.6psia) = 5.0% eff improvement!! - On large 200Klb/hr cond turbine 5% improvement worth $525K/yr. Have done this.
- Steam trap, steam leak program (pays for itself <6 mo), air header leaks -shutdown rental diesel AC's
- Use PINCH analysis optimize HX network – Can reduce process heating and cooling requirements
- Use Organic Rankin cycle to increase low temperature heat source to useable higher temperature
- Stop continuous flaring, minimize flaring on startup and shutdowns
- Conduct an Energy & GHG Reduction Study at your plant – use your internal company specialists or outside consultants to get an independent review

Many more opportunities – may cover topic at Spring conference

New / Innovative Technologies to Improve Energy Efficiency Reduce CO2 Footprint

- Divided wall column – 1 distillation column instead of 2 columns – less capex and less opex
- Heat pumps on columns where separating close boiling temperature components – Ethylene/ Ethane splitter; P/P splitter
- Adding heat recovery to open cycle gas turbines – compact light weight vertical HRSG – LNG plants, offshore
- Electrify offshore platforms with renewable green power – North Sea , Malaysia
- Low emission cracking furnace – shift more fired duty to process and generate less steam in convection section
- Look at new more efficient process technology and not just replicate process with lower yields and higher energy intensity
  - For revamps or new units use new improved catalysts to increase yield and reduce recycle thus reducing energy intensity
  - New MEG technology –Shell OMEGA process reduces steam usage by 20%
  - New PO process – BASF/DOW HPPO process – Hydrogen peroxide + Propylene to PO – reduces steam usage by 35%
  - New ethylene processes – Methane to ethylene OCM , ethane oxidative dehydrogenation to ethylene
- Allam cycle for power generation – oxy fired gas turbine using super critical CO2 cycle – CO2 ready for P/L

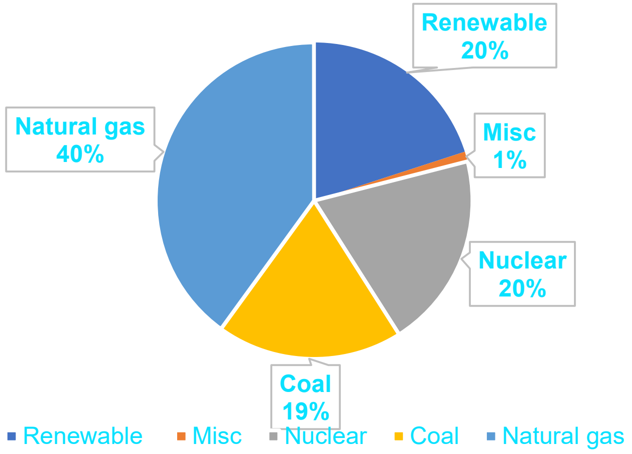
Electrification - Use Renewable Electric Power 1 of 2

- **26% world electric generation in 2019 was renewable power (IEA). No CO_2 footprint**
- **Use Renewable electricity in an electrolyzer to produce Green H_2 (64% eff) or to produce e-fuels**
- **Electricity generation accounts for 32 % US CO_2 emissions. 1GW electric powers 200 – 250 homes**
- **Renewable Electric Power Sources - Solar PV, concentrated solar, wind, hydro, nuclear, geothermal**
- **Solar and wind are variable power sources – day /night /cloudy for solar; day vs night & summer/winter for wind – Over year capacity utilization is – solar 20- 25%; wind 35 -40%; hydro 30-40%**
- **Energy storage is required to stabilize use of variable power generated by renewable energy– BESS Battery Energy Storage System – issue is amount power can store and the dispatch rate of the power back into grid**
- **In addition to batteries, Can store power using compressed air, pumped-storage hydropower, thermal – molten salts , generation of green H_2 – lot of R&D on going**
- **Will need to expand U.S. electrical grid –High Voltage DC (HVDC) cables for offshore and onshore**
- **Cost to install solar has dramatically reduced -utility scale solar and wind are now competitive with Combined cycle power plants**
- **In 2020 79% of U.S. NEW installed utility scale power generation was from wind (42%) and solar (37%) balance NG**
- **Solar PV, wind turbines will not be able to supply all green power –will also be role for nuclear (SMR)**

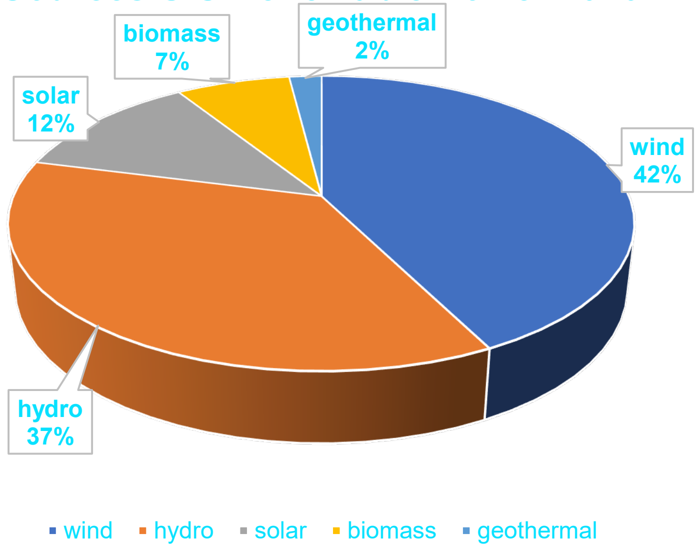
U.S. Electric Power Generation in 2020

Sources: U.S.Energy Information Administration

Fuel Sources U.S Electric Power in 2020
Power = 4.12 Trillion kwh



Sources U.S Renewable Power 2020



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Wind and solar will not produce enough green electricity –
There is a role for more nuclear power in decarbonization

2020 to 2025 World Renewable power
Onshore wind increase by 38%
Solar will more than double
Offshore wind will more that triple

Electrification - Use Renewable Electric Power 2 of 2

- **For solar PV need approximately 4 acres to generate 1 MW electricity (18% efficiency)**
- **500MW wind farm with 116 turbines, uses 200 square miles near McCamey Tx.**
- **By 2030 new turbines will be 6 MW land based and 18 MW offshore. Turbine blade Diameter can be 100 meters (2x50m blade)**
- **Large offshore wind farms in North Sea and planned for U.S NE. coast - off-shore uses less onshore land!!**
- **Offshore oil/gas platform technology can be applied to offshore wind.**
- **Land use for wind and solar will compete with the land needed for agriculture (food production).**
- **Oil companies are getting into renewable power generation and direct sale of electricity to customers!**
- **Electrification of transportation - cars/trucks In U.S, 2030 goal is 50% new vehicles will be electric (EV or FCEV). By 2035 GM will stop making ICE cars**
- **Industrial opportunities for Electrification**
  - **Switch condensing turbine to electric drives –consider impact on steam and FG balance**
  - **Switch medium temperature fired heaters to electric heaters and for large heaters use H2 fuel**
  - **Replace gas turbine drives in LNG plant with large electric drive motors – Freeport LNG**
  - **Offshore platforms –replace GTs with motors -use offshore wind turbines, land based renewable power**
- **Can Use renewable power in electrolyzer (64% eff) to make green H2 but lose 36% of green energy**
- **Power-X (P2X) - Convert renewable power (via electrolysis to H2) to make gaseous or liquid fuels or chemicals**
  - **If use captured CO2 as feedstock the fuels are carbon neutral**
- **Let’s look at impact of using renewable power to reduce CO2 at power plant**

Impact of Using Green Renewable Electricity

CO2 reduction by using renewable power vs generation from fossil fuel	Kg CO2/ MWh generated	KTA CO2 for 100 MW power plant
Modern CCPP 64% efficiency NG fuel	283	248
NG fired open cycle peaking plant 34 % efficient	532	466
Coal fired power plant 34% efficiency	1040	911

Impact of green electricity on auto CO2 emissions

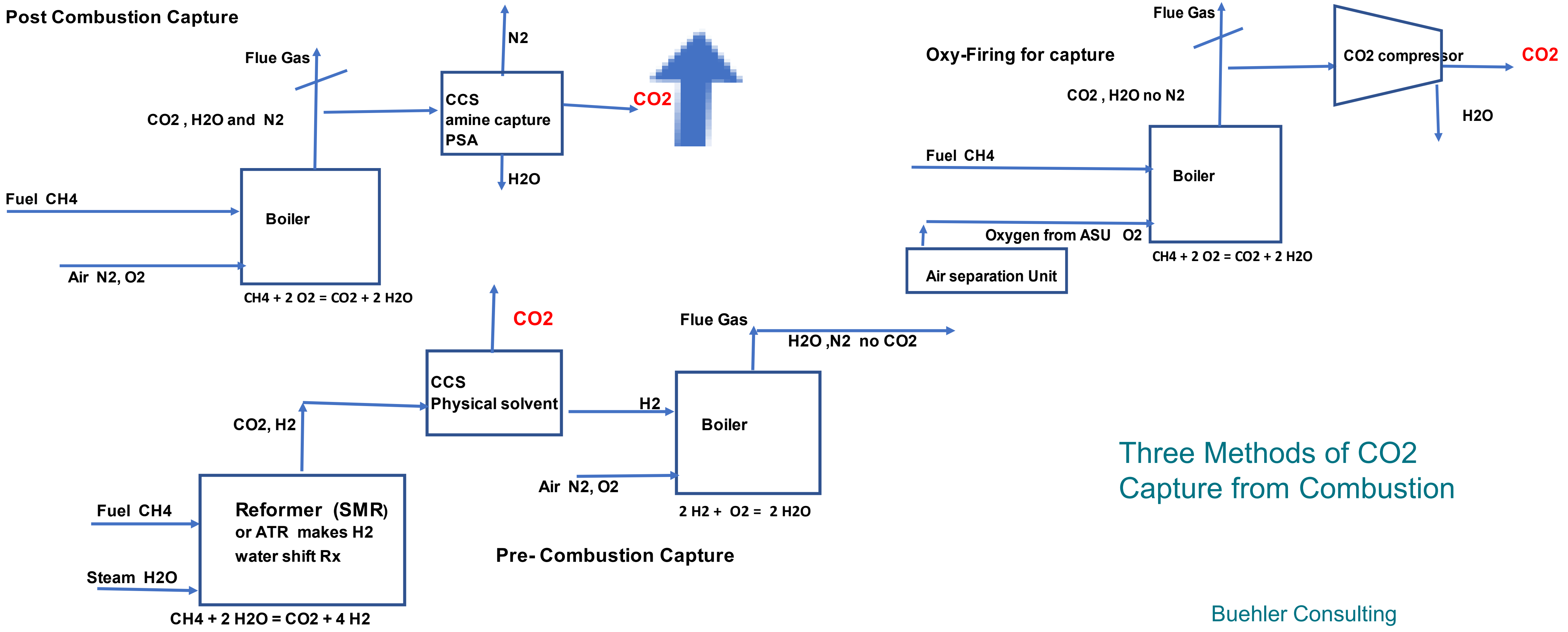
Burning 1 gal gasoline will generate 8.87 Kg CO2
If drive 20,000 mile/yr with 35 mpg car you make 5 tonne/yr CO2. - 200 electric cars reduces CO2 by 1 KTA

If you take the green power and covert to H2 for fueling a fuel cell electric vehicle (FCEV) which convert H2 back to electricity **you will only reduce 50% as much CO2 vs using the green power directly in electric vehicle**

Source: Federal register EPC:40 CFR part 98:e-CFR June 13, 2017 Tables c1 , c2 plus calculations using these values

Carbon Capture Utilization and Storage CCUS (1 of 2)

- In U.S. 45Q provides tax credit incentive to build CCS of $35/tonne for EOR and $50/tonne for storage. - NOT high enough for capture in dilute CO2 streams!!! - Oil pay $20-30/tonne for CO2 to use in EOR
- Cost to capture CO2 in power generation ranges from $60 /tonne to $90/tonne of CO2.
- Adding CCS to combined cycle power plant derates power output by 15%. (heat to regenerate solvent and CO2 compression).
- Processes like ethylene oxide, ethanol, H2 SMR, have high CO2 concentration process streams that are easy to capture. Capture cost range $30 – 40/tonne CO2
- Only 0.1% of world's anthropogenic (man-made) CO2 is being captured –some say needs to be 15%!!
- There are three primary methods of CO2 capture from combustion:(Covered in later H2 presentation)
- <u>Post combustion</u> – Capture CO2 fired heater flue gas – 8-10%CO2 , 80% N2 ,10% H2O at atm pres– (Note open cycle GT exhaust has only 3 -5% CO2)
- <u>Oxy-firing</u> - Combust CH4 fuel with O2 (from ASU) in fired heater. Flue gas has CO2 +H2O with no N2. No capture unit required. Compress flue gas knocks out H2O and have pure CO2.
- <u>Pre-combustion</u> – Convert CH4 fuel in reformer /shift reaction to H2 & CO2 . Capture CO2 at RX outlet (higher % CO2 and higher Pres) Burn H2 in heater -Flue gas has no CO2. ATR=Auto Thermal Reformer



Three Methods of CO_2 Capture from Combustion

Buehler Consulting

Carbon Capture Utilization and Storage CCUS (2 of 2)

- CO_2 capture Research is on-going looking at:
  - Absorption with Chemical solvents (amines)
  - Absorption with Physical solvents (methanol, propylene carbonate) – regenerate with vapor flashing not steam
  - Other NAS (non-aqueous or water lean solvents) –energy efficient with Capture cost
  - Adsorption onto solids– mol sieves , metals with thermal or vacuum swing adsorption
  - DAC Direct Air Capture – challenge is CO_2 in air at 420 ppm (0.042%) vs flue gas at 10% (Process 235 times volume air)
  - Grow algae with CO_2 and convert algae to biofuels
- Large CCUS installations proven technology with capacity of 1.1M TPA to 3M TPA
  - CCUS on: Boundary Dam and Petra Nova-Houston(both coal) fired; QUEST (H_2 SMR); large NG fired heaters
- CO_2 must be compressed to 100 bar to supercritical state for pipeline and store underground storage.
- Regional CO_2 pipelines collect CO_2 and deliver CO_2 feedstock to plant or to CO_2 storage. Hubs & clusters –need CO_2 volume.
- Several CCS PL projects announced in UK, EU Rotterdam/North Sea) & discussion Houston ship channel CCS network
- For CO_2 storage can use - underground saline reservoirs, porous rock, subsea, basalt, or depleted oil reservoirs. Must Measure, Monitor, Verify the stored CO_2.
- CO_2 uses: – EOR Enhanced Oil Recovery, freeze drying food, soft drinks fizz, Produce urea ($CO_2 + NH_3$), CO_2 mineralized concrete, enhanced photosynthesis in greenhouse ($6\ CO_2 + 6\ H_2O = C_6H_{12}O_6$ (glucose) $+ 6\ O_2$)
- Power-to-X (P2X) –Use captured CO_2 + green H_2 to make Synthetic Fuels via Fischer-Tropsch (F-T) Rx. Syngas is $CO + H_2$
- CO_2 e-chemistry - Green H_2+CO_2 to make synfuels ($CO_2+H_2=CO+H_2O$) then $CO+2H_2$ = e-methanol(CH_3OH), e-gasoline, SAF
- CO_2 super dry reforming make synfuels ($3\ CO_2 + CH_4 = 4\ CO + 2\ H_2O$) Then use $CO + H_2$ with F-T Rx to make synfuels.

H2 Role in Decarbonization - H2 as an Energy Carrier (1 of 2)

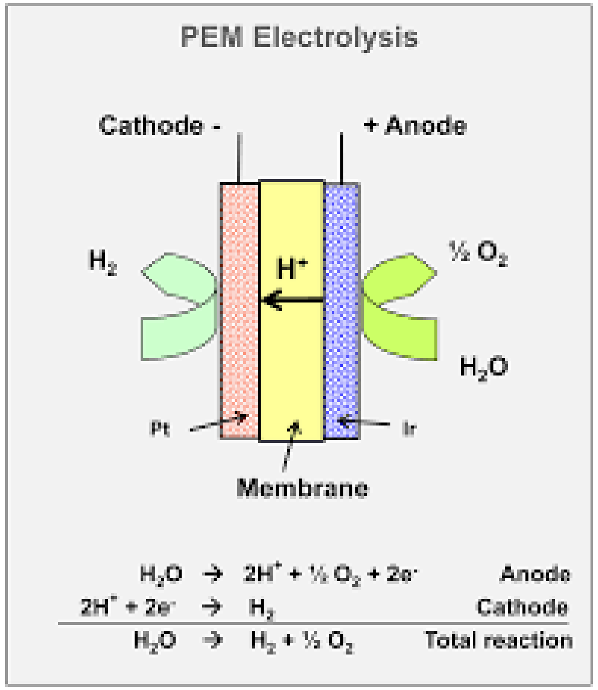
- **For H2 to help with decarbonization it must have zero or low carbon footprint- Green, Blue, or Pink H2**
- **In decarbonized world H2 demand could increase by factor of 8 to 10 fold**
- **Gray H2 is made with CH_4 in steam-methane reformer (SMR) $CH_4 + 2H_20 = 4\ H_2 + 1\ CO_2$**
- **Blue H2 is Gray H2 with capture of the CO_2**
- **Green H2 is made by electrolysis of water using renewable energy - electrolyzer (64% eff) $2\ H_2O = 2\ H_2 + O_2$**
- **In PEM electrolyzer it take 52 kw electricity to make 1 kg H2 thus need <u>52MW electricity to make 1 tonne H2</u>**
- **Some Colors of H2 Blue and Green H2 Production Processes to be discussed in later H2 presentation**
  - **Turquoise H2 - electric plasma pyrolysis of CH_4 to $2\ H_2 + C$ (carbon powder)**
  - **Green H2 - electrolysis of water using renewable electricity – low CO_2 footprint 0.4 – 1.0 kg CO_2/kg H2**
  - **Gray H2 - CH_4 in a SMR (steam methane reformer) with no CO_2 capture- 9-10 kg CO_2/ kg H2**
  - **Blue H2 (a) CH_4 in SMR with CCS - capture CO_2 from RX outlet and from flue gas 1.5 kg CO_2/kg H2**
    (b) CH_4 in Autothermal Reactor (ATR) with CCS – capture CO_2 on outlet of RX (no flue gas)
  - **Pink H2 -electrolysis of water using nuclear energy for power – no CO_2 footprint**
- **Relative cost to produce Gray $2/kg; Blue $3/kg; Green $5/kg - <u>1-1-1 H2 Earth Shot</u> $1/ 1 kg green H2/ 1 decade**
- **IEA projects by 2030 cost to produce H2 : gray $2/kg; Blue $2.5/kg; green $2/kg($20/MWh grid)**

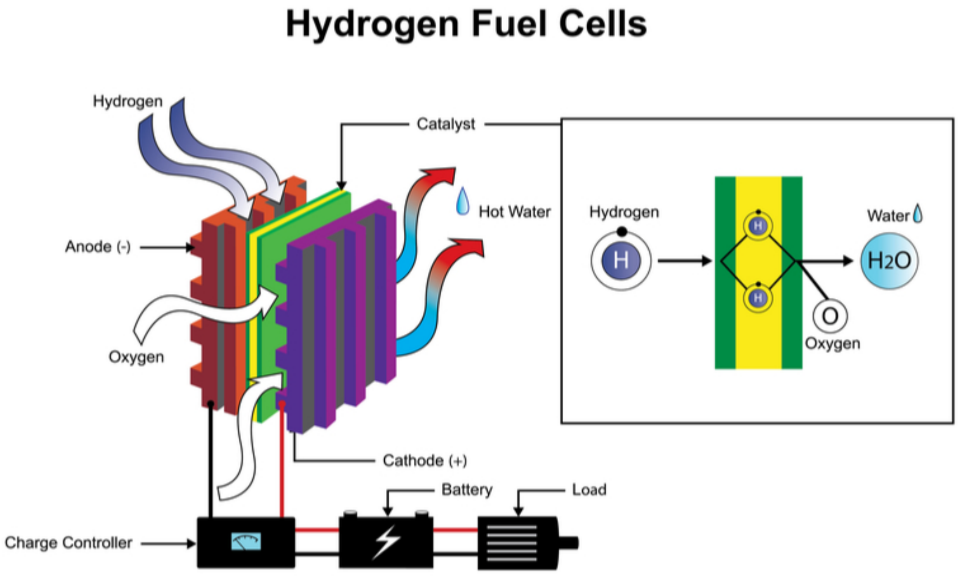
H2 Role in Decarbonization - H2 as an Energy Carrier (2 OF 2)

- H_2 can be burned directly in fired heaters (have to adjust burners) and up 30% H_2 mix with NG in Gas turbines. Working on going to 100% H_2 for GTs (Siemens, GE)
- H_2 can be blended up to 20% into existing NG pipelines or can have separate H_2 P/L network
- Green H_2 should first be used in chemical and refining processes to reduce product footprint before burning as fuel
- H_2 can be used as renewable electric storage – convert excess renewable power into H_2 for storage. Then can use as H_2 or convert H_2 back to electric power when needed.
- H_2 is an energy carrier. Can move H_2 in PL, trucks, or convert H_2 to NH_3 or methanol or attach to liquid carriers for shipment and storage – moving H_2 can take pressure off electric grid.
- H_2 Fuel cell - Can convert H_2 back to electricity in a fuel cell (SOFC or PEM) - 64% thermal eff
  - (PEM is proton exchange membrane fuel cell; SOFC is solid oxide fuel cell)
- Use H_2 in fuel cell (FCEV) to power electric cars, fork lifts, trucks, buses, trains etc. H_2 Refill in half time of battery recharge. Fuel cell is 64% eff. Round trip Green Power to H_2 and H_2 back to power is 50% eff
- P2X - Using H_2 + CO_2 to make synthetic e-fuels - like methanol ,e- gasoline, e-diesel for transport – reduce Scope 3 $CO_2 + H_2 = CO + H_2O$ then Fischer-Tropsch RX (Maersk -3 ships run on methanol) $CO_2 + 3\,H_2 = CH_3OH + 2H_2O$
- Carbon Circularity –make Synthetic NG - Captured $CO_2 + 4\,H_2 = CH_4\,(SNG) + 2\,H_2O$ (84% thermal efficient) – BUT Need green H_2 from renewable power –
  - this is not thermally efficient use of valuable renewable power. Electrolyzer (64% thermal eff)

PEM Electrolyzer Converts Electricity to H2
(Efficiency of PEM Electrolyzer is 64%)

Fuel Cell Converts H2 and O2 to make H2O and electricity and heat
(Efficiency in 64%)





Biofuels and Renewable e-Fuels – Oil & Gas Industry Pathway to Reduce Scope 3 Emissions

- To reduce Scope 3 CO2 emissions – Oil and gas Industry will Transition to selling renewable power, green H2 and producing renewable fuels, biofuels, and synthetic e-fuels
- California LCFS provides credits to producers of low carbon fuels- by 2035 replace petroleum diesel with renewable diesel
- Demand for gasoline, petroleum diesel will decrease – Some refineries will shutdown or will retrofit hydrocracker and FCC units to process renewable feedstocks to make renewable diesel or biodiesel.
- Biofuels fuels are renewable fuels and have lower CI than fossil fuels because they are made from renewable feedstocks like corn, soybean, rapeseed, sugar cane, vegetable oils, used cooking oil, animal fats.
- CO2 cycle -Plant more renewable corn which then removes more CO2 from atmosphere and makes more renewable feed.
- Renewable diesel meets all specs for petroleum based diesel and is produced by hydrotreating non-petroleum feedstocks like waste vegetable oils, animal fats, or biomass. Renewable diesel can replace 100% petroleum based diesel.
- Biodiesel is produced from vegetable and animal fats by trans-esterification (react with alcohol) which adds oxygen to the oils so can be blended with petroleum based diesel. Biodiesel is limited to blending 10% to 25% with petroleum diesel.
- Renewable diesel has CI that is 60% lower than petroleum diesel (25 -50 gm CO2e/Mj vs of 100 gm CO2e/Mj)
- Sustainable Aviation fuel (SAF) made from waste cooking oil, plants reduces CO2 emissions by 80% vs petroleum jet fuel
- Renewable NG (RNG) is made from bio mass (dairy farms), waste food, and landfills by anerobic digestion. The Bio-gas from digester contains 60% CH4 and 40% CO2 so must remove the CO2 to put RNG into NG pipeline
- Bio fuels like ethanol are made from corn (U.S midwest) and from sugar cane (Brazil). 2nd generation fuels are made from corn stover or sugar cane baggase and do not compete with food chain.
- P2X e-Fuels are synthetic fuels - Use green H2 to react with captured CO2 to make hydrocarbon fuels including e-ethanol, e-gasoline, SAF (sustainable aviation fuel) - Tomorrow session will discuss e-Fuels and bio-fuels in more detail

Recycling Plastics – Circular carbon – Petrochemical Industry way to reduce Scope 3 Emissions

- To reduce scope 3 emissions- Chemical producers need to invest in recycling of single use plastics
- More than 75% of plastics produced are discarded after single use and end up in landfills and oceans
- In 2018 U.S produced 35 million tons plastics and estimate only 9% was recycled
- American Chemistry Council (ACC) companies established Roadmap to Reuse:
  - By 2030 Ensure 100% of plastic packaging is made to be recyclable or recoverable.
- Plastics going to landfill can be burned for heat value but would need add CCS to capture CO2 – Not way to GO
- **We Need to stop landfill and reuse the plastic by recycling – Two main methods for recycling are:**
- Mechanical recycling – sort plastic, shred, melt ,and re-peletized- works for single type plastic like PE, PP
- Chemical recycling – break down plastic to liquid feedstock – used for more complex plastics
  - Pyrolysis and gasification are most common methods – many companies actively working on this.
  - Pyrolysis can convert polyolefins (PE), and polystyrene back to liquid feedstock that after treatment can be use to make new virgin plastic
  - Tests show can process up to 5% pyrolysis oil (from waste PE) into feed to ethylene furnace
  - Gasification to syngas and then methanol to hydrocarbons feedstocks
- Blend in Renewable feedstocks into chemical processes– Renewable naphtha feed to ethylene cracker made from bio based sources like waste oils, fats, tall oil
- **Key to Circular Plastic Success is the consumer – Let's all do our part and recycle**

Summary of Routes to Decarbonization

- Oil and Gas industry will Re-brand itself as Energy Supplier and will transition:
  - To selling renewable wind and solar power; green /blue H_2; low Carbon LNG; biofuel /renewable diesel, e-fuels, e-gasoline, SAF
- Improving energy efficiency is the cheapest way to reduce CO_2 –You can do this now !!
- Must reduce Scope 1,2 and 3 CO_2 emissions - Pathways to Decarbonization Include:
  - Improve Energy efficiency – Maintenance ,new energy eff technologies, new improved catalysts
  - Electrification of process unit drivers and small heaters using renewable electricity
  - Stop methane leakage
  - Build, Use, and Sell Renewable wind and solar power
  - Build BESS (Battery Energy Storage System) to smooth out variable renewable energy supply
  - Produce and sell Green and Blue H_2 -use H_2 as energy carrier for transportation - H_2, NH_3, methanol
  - Power-to-X - Use Green electricity to make e-Fuels e-gasoline, e-methanol (Green H_2 + CO_2 = e-fuels)
  - Add cost effective CCUS to larger CO_2 emission sources. Support Regional CCUS networks.
  - Reduce Refinery Scope 3 - Sell green H_2 renewable power, biofuels ,renewable fuels and e-Fuels
  - Reduce Petrochemicals Scope 3 - Recycle and Process waste plastic, use renewable feedstocks –
  - Have technology and assets for offshore wind, blue/green H_2, CO_2 storage, hydrocrackers to make renewable fuels
- Wind and Solar PV will not be able to produce enough green power – there is a role for nuclear power

Q /A

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Energy Efficiency and Decarbonization Session

Session Chairs

James Turner - Fluor

Jack Buehler – Shell (retired) Buehler Consulting

Energy Efficiency and Decarbonization Session

TIME	PRESENTATION	SPEAKER
9:05am - 9:35am	An Overview of Pathways to Decarbonization	Jack Buehler, Shell (retired) Buehler Consulting
9:35am - 9:45am	Technology Preview 1: Honeywell	Christina Lowenfeld
9:45am - 10:15am	Decarbonization: Challenges and Needs	Daniela Ferrari, The Dow Chemical Company
10:15am - 10:45am	Coffee Break	
10:45am - 11:15am	Small Modular Nuclear Reactors for Process Applications	Lorena Sullivan, Fluor
11:15am - 11:25am	Technology Preview 2: TLV	Norman White
11:25am - 11:55am	There Is No C in Hydrogen: Low Carbon Footprint Hydrogen Production	Matt Reisdorf, Fluor

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- In PEM electrolyzer it take 52 kw electricity to make 1 kg H2 thus need 52MW electricity to make 1 tonne H2
- Remember renewable power supply will vary so green H2 production will vary – need storage to level out
- Some Colors of H2 H2 Production Processes to be discussed in later H2 presentation
  - Green H2 - electrolysis of water using renewable electricity – low CO_2 footprint 0.4 – 1.0 kg CO_2/kg H2
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- Relative cost to produce Gray \$2/kg; Blue \$3/kg; Green \$5/kg - 1-1-1 H2 Earth Shot \$1/ 1 kg green H2/ 1 decade
- IEA projects by 2030 cost to produce H2 : gray \$2/kg; Blue \$2.5/kg; green \$2/kg(\$20/MWh grid)