# Managing the Issues Caused by Air Ingress into Geothermal Non-Condensable Gas when Capturing $CO_2$

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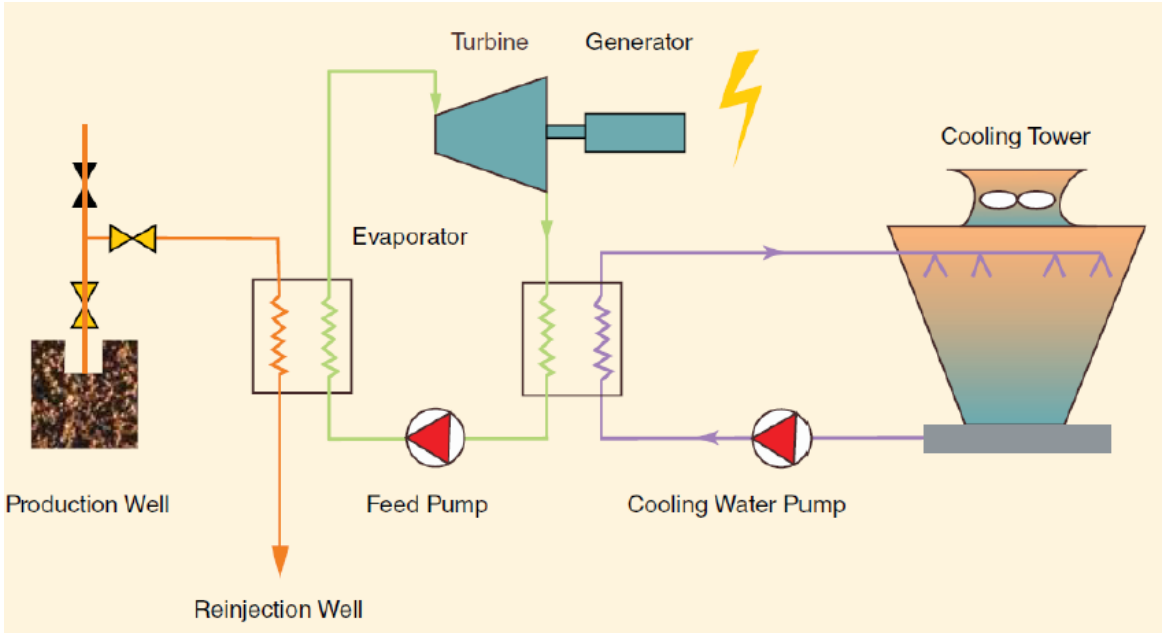
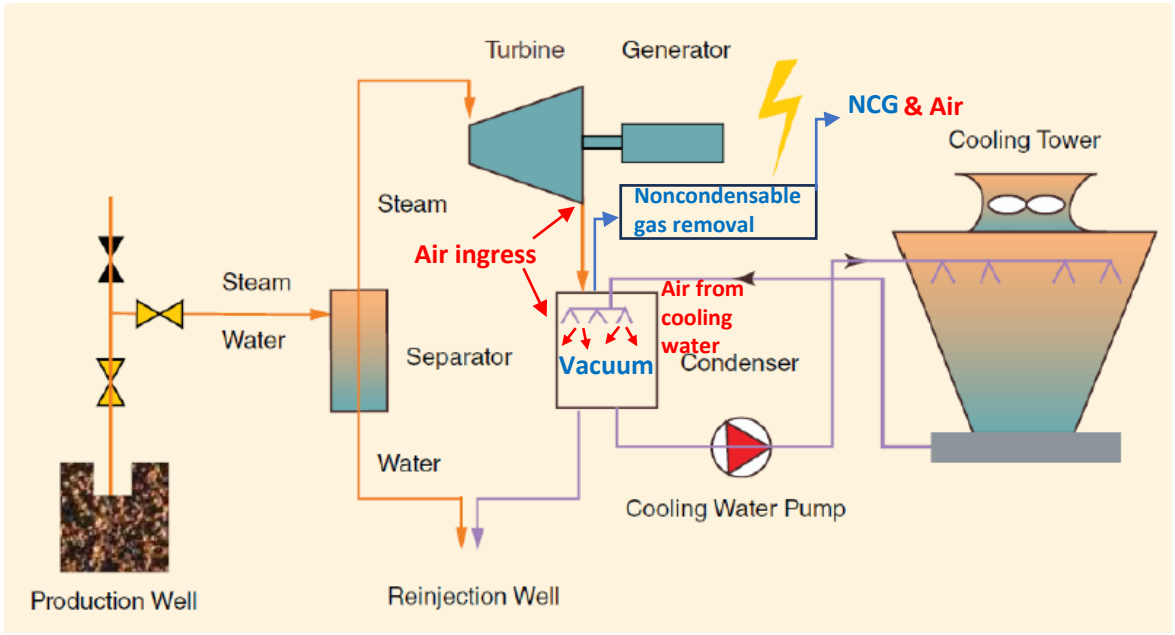
# Background

- Non-condensable gas (NCG) is removed from the condenser system system in flash and dry-steam type geothermal plants
- NCG contains $CO_2$, $H_2$, $H_2S$, $CH_4$, ammonia, and other species
- Air ingress into the NCG occurs in some systems
- Air and fuels ($H_2$, $H_2S$, $CH_4$) may be high enough to support combustion
- Capturing $CO_2$ concentrates the air and fuel and heightens this concern

# Simplified Binary and Flash Geothermal Plants




**Binary Power Plant**




**Single Flash Power Plant**

- Steam expanded across turbine
- Steam condensed under vacuum

Source of Figures: Fact Sheet for Geothermal Development to Promote Public Private Partnerships in East Africa, 2023

# $CO_2$ Capture from NCG

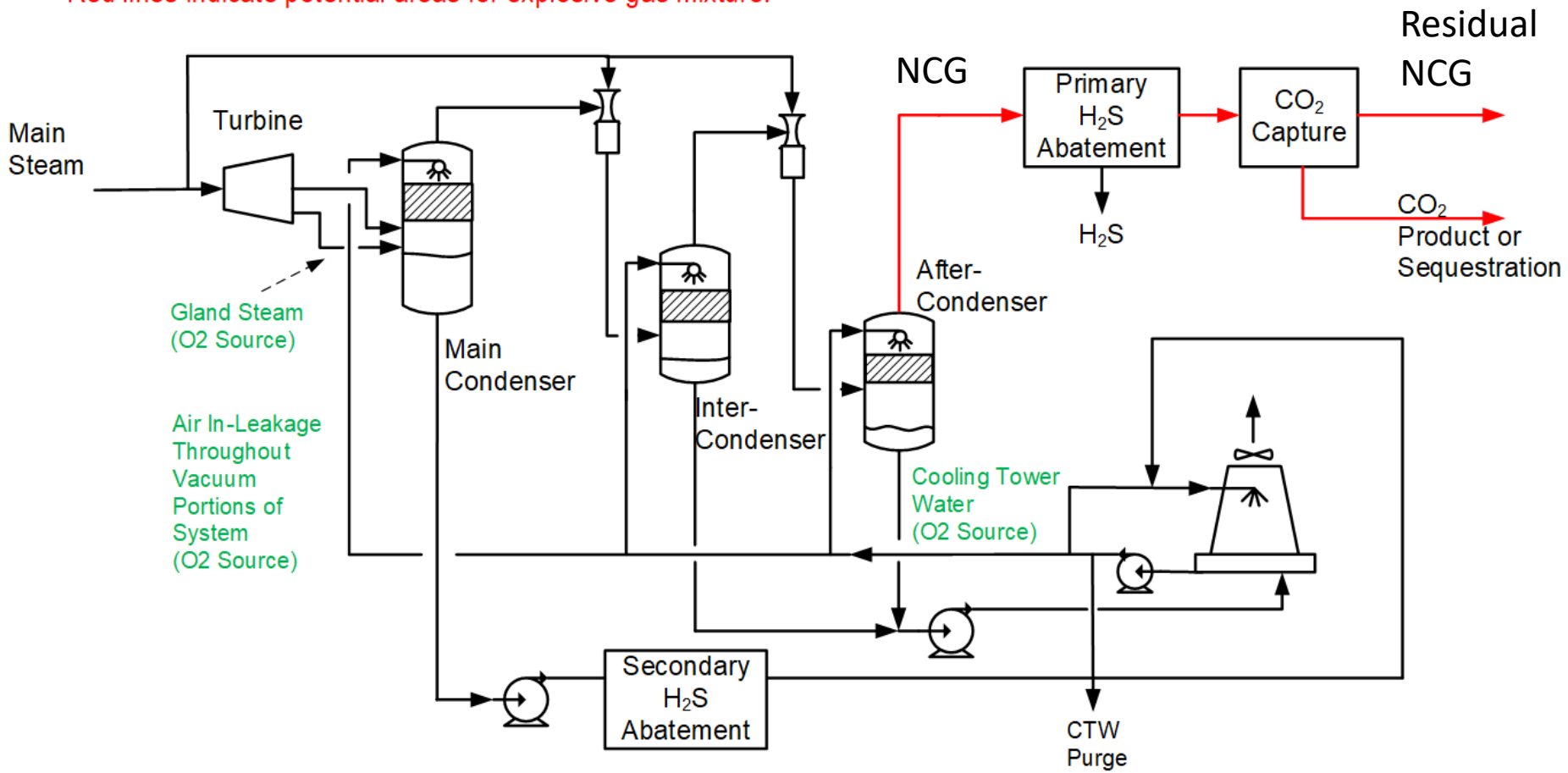
- $CO_2$ capture is commonly done by absorbing the $CO_2$ into a liquid:
  - Alkanolamines – MEA, MDEA, others
  - Pressurized water absorption
- After $CO_2$ removal, the NCG stream consists of:
  - Residual $CO_2$, $N_2$, $O_2$, $H_2$, methane, etc.
  - Remaining components (except $CO_2$) are at higher concentrations
  - Can result in flammable gas mixture

# Definitions of Flammability of Gases and Safety Margins

- ***Combustion requires oxygen and fuel***
- ***Limiting Oxygen Concentration (LOC):*** minimum fraction of oxygen in a gas mixture to support combustion
- ***Fuel***
  - ***Lower Flammability Limit (LFL):*** minimum fraction of fuel that when mixed with air will burn
  - ***Upper Flammability Limit (UFL)****:* maximum fraction of fuel that when mixed with air will burn
- ***Explosive Gas Mixture:*** A gas that is in its "flammability envelope" – that is, the gas is above LOC, above the LFL, below UFL, and which may:
  - **Burn, Deflagrate, Explode**
- Safety margins should be applied (e.g, see GRC Transactions, Vol. 45, 2021, pp. 1414-1435)

# NCG Handling with $CO_2$ Capture
# Direct Contact Condenser (DCC) Plant

Red lines indicate potential areas for explosive gas mixture.



# Flammability of Hypothetical NCG – Avoid the "Explosive Gas Mixture"

| Gas Species in NCG | NCG Without Added Air | NCG Downstream of Condensing Sys | LOC vol % | LFL vol % | UFL vol % |
|---|---|---|---|---|---|
| Carbon Dioxide ($CO_2$) | 78% | 67.5% | | | |
| Hydrogen ($H_2$) | 11% | 9.5% | 4.6% | 4% | 75% |
| Hydrogen Sulfide ($H_2S$) | 8% | 6.9% | 10% | 4% | 63% |
| Methane ($CH_4$) | 1% | 0.9% | 13.1% | 5% | 15% |
| Ammonia ($NH_3$) | 2% | 0.00% | | | |
| **Total Fuels + Inerts** | | **84.8%** | | | |
| Nitrogen ($N_2$) | 0% | 12.0% | | | |
| Oxygen ($O_2$) | 0% | **3.2%** | | | |
| **Mixture Predicted Properties** | | | **7.7%** | **22.7%** | **50.9%** |
| Safety Margins: 2% below LOC / 60% of LOC | | | **5.7% / 4.6%** | | |
| Safety Margins: 25% of LFL / 60% of LFL | | | | **5.7% / 13.6%** | |
| Safety Margins: UFL + 10% / 170% of UFL | | | | | **60.9% / 86.5%** |

- **$O_2$ content is <$LOC_{mix}$ and concentration of fuels plus inerts is >$UFL_{mix}$ (too rich to burn): mixture not explosive**
- **Safety margin of 170% of UFL not met**

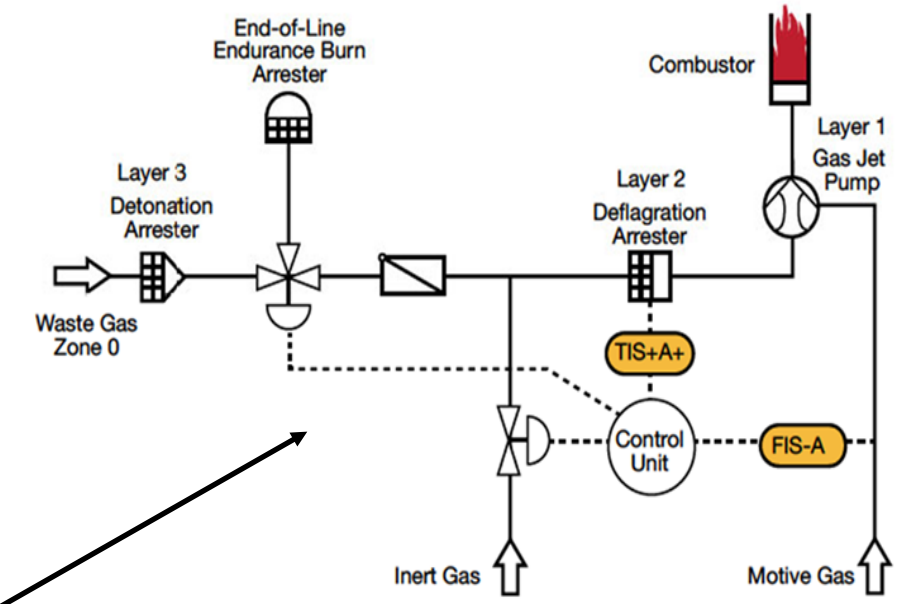
# Flammability of Hypothetical NCG – What Happens with 90% $CO_2$ Capture and 100% $H_2S$ Removal?

| Gas Species in NCG | NCG Upstream of $CO_2$ Removal | NCG Downstream of $CO_2$ Removal | LOC vol % | LFL vol % | UFL vol % |
|---|---|---|---|---|---|
| Carbon Dioxide ($CO_2$) | 67.5% | 20.8% | | | |
| Hydrogen ($H_2$) | 9.5% | 29.4% | | | |
| Hydrogen Sulfide ($H_2S$) | 6.9% | 0.00% | | | |
| Methane ($CH_4$) | 0.9% | 2.7% | | | |
| Total Fuels + Inerts | 84.8% | 52.9% | | | |
| Nitrogen ($N_2$) | 12.0% | 37.2% | | | |
| Oxygen ($O_2$) | 3.2% | 9.9% | | | |
| Mixture Predicted Properties | | | 5.6% | 7.1% | 55.5% |

- **$O_2$ content is >$LOC_{mix}$ and concentration of fuels plus inerts is >$LFL_{mix}$ and <$UFL_{mix}$**
- **NCG downstream of $CO_2$ removal is an 'explosive gas mixture'**
- **Only requires an ignition source to burn, deflagrate, or explode**

# Mitigating Potential Explosive Gas Mixtures

- Minimize oxygen ingress
  - Fix vacuum leaks
  - Do not route gland steam leak-off to main condenser
  - DCC: only use required cooling water, deaerate, replace with surface condenser
- Dilute residual NCG
  - Recycle $CO_2$, add other inert gas ($N_2$), slip steam around final condenser
- On-line monitors: $O_2$, flammability
- Design for explosive gas mixtures
  - Eliminate ignition sources
  - Design vent gas system appropriately




Source of Figure: Davies, M., & Heidermann, T. (December 2013). Protect your process with the proper flame arrestors. Chem. Eng. Prog., 16.

# Conclusions

- Yes, $CO_2$ can and is being captured from geothermal NCG
- However, be aware of both fuels and oxygen when capturing $CO_2$ from NCG from flash and dry-steam type geothermal plants
- Train geothermal operating staff about the potential dangers
- Incorporate measures to reduce $O_2$ ingress
- Implement operating procedures, safety devices, and equipment design changes to mitigate flammability concerns
- For new geothermal plants, account for $CO_2$ capture when designing condensing and NCG handling systems