

# CIUDEN experiences in CO<sub>2</sub> capture by oxycombustion

## CIUDEN experiencias en captura de CO<sub>2</sub> por oxicomustión

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### Abstract

One of the most relevant European R&D&D initiatives focusing on Carbon Capture Utilization and Storage (CCUS) is the CIUDEN Carbon Capture and Storage Project, which is supported by the Spanish Government through the Fundacion Ciudad de la Energia (CIUDEN). CIUDEN investigates CCUS in es.CO<sub>2</sub> which has three main facilities: Technology Development Centre for CO<sub>2</sub> Capture, the CO<sub>2</sub> Transport Experimental Facility and the CO<sub>2</sub> Storage Technology Development Plant.

The Technology Development Centre for CO<sub>2</sub> Capture and the CO<sub>2</sub> Transport Experimental Facility, located in Cubillos del Sil (NW Spain), incorporates the world's most advanced equipment for the development of oxycombustion and CO<sub>2</sub> transport. Combustion capacities are based on two technologies: pulverized coal (PC) and circulating fluidized bed (CFB). Furthermore, gasification research can be carried out in a Biomass Gasifier (3 MW<sub>th</sub>). CIUDEN CO<sub>2</sub> Storage Technology Development Plant, based in Hontomin (N Spain), allows carrying out experiments in real scale in saline formations to develop CO<sub>2</sub> storage knowledge.

es.CO<sub>2</sub> will provide a real basis for the design, construction and operation of a future CCUS plants, CO<sub>2</sub> transport and final underground CO<sub>2</sub> storage in a deep saline geological formation.

This paper focuses on first experiences of CIUDEN R&D&D portfolio which includes, among others: OXYCFB300 COMPOSTILLA PROJECT, one of the six projects funded by the European Energy Programme for Recovery (EEPR); FLEXIBURN CFB - Demonstration of flexible high-efficiency CFB combustion technology in air and oxy-modes for CCS; RELCOM - R&D&D activities for reliable full-scale deployment of oxy-PC firing; MACPLUS - Develop and test full-scale prototypes of components to improve performance and reliability of CCS Power Stations; BRISK - integrate networking activities, joint research activities and transnational access to research infrastructures for enhancing biomass utilization.

**Keywords:** oxycombustion, CCS, CFB, Pulverised Coal.

### Resumen

Una de las iniciativas europeas más relevantes en I+D y demostración de la captura, uso y almacenamiento de CO<sub>2</sub> (CCUS) es el proyecto de CIUDEN de captura y almacenamiento de carbono, el cual está apoyado por el Gobierno de España a través de la Fundación Ciudad de la Energía (CIUDEN). CIUDEN investiga el CCUS en es.CO<sub>2</sub>, que se compone de tres instalaciones: El Centro de Desarrollo de Tecnologías de Captura de CO<sub>2</sub>, la Instalación Experimental de Transporte de CO<sub>2</sub> y la Planta de

Desarrollo Tecnológico de Almacenamiento de CO<sub>2</sub>.

El Centro de Desarrollo de Tecnologías de Captura de CO<sub>2</sub> y la Instalación Experimental de Transporte de CO<sub>2</sub> están situadas en Cubillos del Sil (NO de España), incorpora el equipamiento más avanzado a nivel mundial para el desarrollo de la captura por oxicomustión y el transporte de CO<sub>2</sub>. Las capacidades de combustión están basadas en dos tecnologías: carbón pulverizado (CP) y lecho fluido circulante (LFC). Además, es posible llevar a cabo investigación en gasificación en un Gasificador de Biomasa (3 MW<sub>th</sub>). Planta de Desarrollo Tecnológico de Almacenamiento de CO<sub>2</sub> de CIUDEN, localizada en Hontomín (N de España), permite llevar a cabo experimentos en escala real en acuíferos salinos para desarrollar conocimiento en almacenamiento de CO<sub>2</sub>.

es.CO<sub>2</sub> proporcionará una base real para el diseño, construcción y operación de plantas de captura, transporte y almacenamiento geológico de CO<sub>2</sub> en acuífero salino profundo.

Este artículo se centra en las primeras experiencias de los proyectos de I+D de CIUDEN, que incluyen entre otros: el PROYECTO COMPOSTILLA OXYCFB300, uno de los seis proyectos financiados por el programa Europeo para la Recuperación Energética (EEPR); FLEXIBURN CFB - Demostración de la tecnología de oxicomustión en LFC en modo aire y oxicomustión; RELCOM - actividades de I+D sobre oxicomustión en calderas CP; MACPLUS - desarrollo de prototipos a gran escala de componentes para mejorar el rendimiento y la fiabilidad de las centrales de captura de CO<sub>2</sub>; BRISK - actividades de trabajo en red, actividades de investigación conjunta y acceso transnacional a infraestructuras de investigación.

**Palabras clave:** oxicomustión, CAC, LFC, carbón pulverizado.

### 1. Introduction

CO<sub>2</sub> concentration to the atmosphere has risen faster than ever in the last century. This is highly due to fossil fuel combustion which is the major anthropogenic CO<sub>2</sub> source. The CCS Roadmap highlighted the significance that will need to be attached to CCS (Carbon Capture and Storage) in achieving an atmospheric CO<sub>2</sub> concentration stabilization of 450 ppm in 2050 [1].

The EU has adopted ambitious targets for reducing the emissions of greenhouse gases in the coming decades. The targets for 2020 are:

1. to reduce greenhouse gas emissions by 20%;
2. to ensure 20% of renewable energy sources in the EU energy mix;
3. to reduce EU global primary energy use by 20% by 2020.

In particular, to reduce CO<sub>2</sub> emissions the EU member states will promote the commercial use of technologies for CO<sub>2</sub> capture, transport and storage through demonstration at industrial scale, including whole system efficiency and advanced research as included in the European Energy Roadmap 2050. Therefore, the EU plans are to set up a network of CCS demonstration plants on the short-term to test their viability, with the aim of commercial scale up of CCS technologies on the mid-term.

CCS consists of four major parts: capture, compression, transport and storage of CO<sub>2</sub>. There are three main routes to capturing CO<sub>2</sub> from power processes: pre-combustion, oxy-fuel combustion and post-combustion.

Fundacion Ciudad de la Energia (CIUDEN) esCO<sub>2</sub> centre is divided in two main facilities: Technology Development Centre for CO<sub>2</sub> Capture and the Technology Development Plant for CO<sub>2</sub> Geological Storage.

CIUDEN Technology Development Plant for CO<sub>2</sub> Geological Storage, situated in Hontomin (N Spain), allows carrying out experiments in real scale in saline formations to develop CO<sub>2</sub> storage knowledge.

The Technology Development Centre for CO<sub>2</sub> Capture is a flexible, modular and integrated installation ready to test and validate any CCS technology (either CO<sub>2</sub> or O<sub>2</sub> and H<sub>2</sub>) under a wide range of conditions in controlled industrial environment. Aerial view of the centre can be seen in figure 1.

## 2. CIUDEN CO<sub>2</sub> capture and transport programme

CIUDEN is a state owned, public R&D institution created by the Spanish Government in 2006. It was conceived to foster economic and social development in El Bierzo Region, through activities related to the energy and environmental sectors.

The es.CO<sub>2</sub> Technology Development Centre for CO<sub>2</sub> Capture is located in Cubillos del Sil (Leon, Spain). It aims to develop CO<sub>2</sub> capture and transport technologies feasibility to reach the industrial scale. It is a industrial size facility for experimental purposes, which includes the following systems:

- Fuel Preparation System
- Pulverized Coal Boiler 20MW<sub>th</sub> (PC)
- Circulating Fluidized Bed Boiler 30MW<sub>th</sub> (CFB)
- Flue Gas Cleaning System
- Oxidant preparation system
- CO<sub>2</sub> Compression and Purification Unit (CPU)
- CO<sub>2</sub> Transport Test rig
- Biomass Gasifier 3MW<sub>th</sub>

The main systems and novelty equipments and advances will be described very briefly in this section.

### 2.1 PC Boiler

The Pulverized Coal Boiler is a 20MW<sub>th</sub> unit focused on research demonstration and technological development. It can operate in air and oxy mode for different types of fuels (anthracite, bituminous, sub-bituminous, petcoke/anthracite mixture). It is a vertical water tube boiler with natural water circulation and balanced draft, equipped with different burners configurations.

### 2.2 CFB Boiler

The Circulating Fluidized Bed Boiler (30MW<sub>th</sub>) is a natural circulation, balanced draft, circulating fluidized bed boiler, designed to test CFB combustion under air and oxy-combustion conditions.

Design fuel is anthracite, but it is able to burn bituminous coal, sub-bituminous coal, pet coke, biomass and its blends, etc.

The oxidant stream required for oxy-combustion is obtained from mixing oxygen with recirculation gas in order to temper combustion. The O<sub>2</sub> concentration design parameters in the oxidant streams vary from 30% to 70%. The scheme of the boiler can be seen in figure 2.

### 2.3 Flue gas cleaning System and Oxidant Preparation System

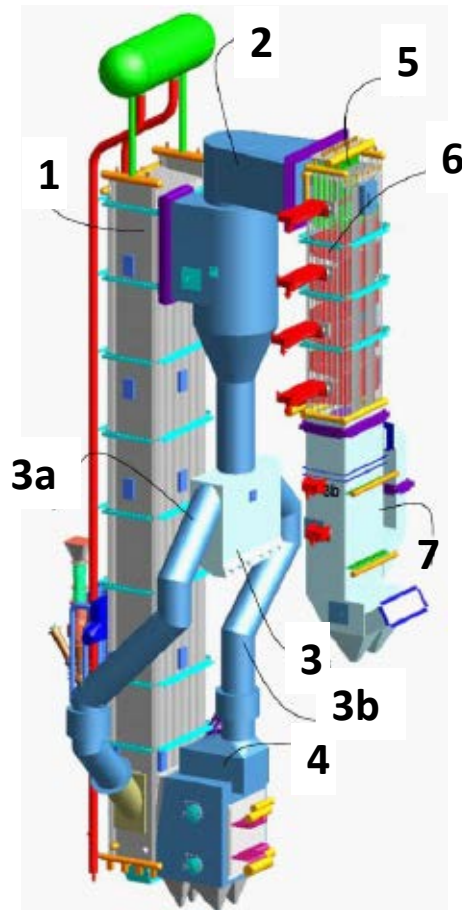
Coal and biomass combustion and oxy-combustion produces particulate matter and gaseous contaminants which need to be treated.



Figure 1. Aerial view of CIUDEN's Technology Development Centre for CO<sub>2</sub> Capture

Figura 1. Vista aérea del Centro de Desarrollo de Tecnologías de Captura de CO<sub>2</sub> de CIUDEN





- (1) Combustion chamber
- (2) Solid separator
- (3) Ash sealing-direction device
- (3a) Ash duct to the furnace
- (3b) Ash duct to the cooler
- (4) Furnace cooler - INTREX™
- (5) Heat recovery zone
- (6) Steam cooled walls
- (7) Economizer

Figure 2. CFB boiler  
 Figura 2. Caldera LFC

The flue gas cleaning system is aimed to treat flue gases emissions from the boilers to meet environmental legislative requirements and to reduce impurities to the maximum levels that can be treated at the CO<sub>2</sub> Compression and Purification Unit (CPU). The system includes the following main equipment: Cyclones, Selective catalytic reduction of NO<sub>x</sub> (SCR) and Bag filter.

**2.4 Capture and Purification Unit (CPU)**

As result of the oxy-combustion process a flue gas highly concentrated in CO<sub>2</sub> is produced almost ready for transport and storage; nevertheless some contaminants need to be removed. Main contaminants from oxy-combustion for transport and storage are: water, O<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub> and particulates.

The Compression and Purification Unit (CPU) is aimed to treat oxy-combustion flue gases remaining impurities, which have not been removed at the Flue Gas Cleaning System, to get CO<sub>2</sub> ready for transport and storage.



Figure 3. CPU general view  
 Figura 3. Vista general de la CPU

**2.5 CO<sub>2</sub> Transport Experimental Facility**

Once CO<sub>2</sub> is captured, it needs to be transported to the geological storage site. One of the most suitable ways, from a technical and economical point of view, to transport high quantities of CO<sub>2</sub>, is doing it by pipeline. The transport is usually performed in dense or supercritical phase.

The CO<sub>2</sub> Transport Experimental Facility at CIUDEN es.CO<sub>2</sub> is a first-of-its-kind facility aimed to test CO<sub>2</sub> behavior in transport by pipelines.

The core of the facility consists on ten coiled pipe racks, with a length of 300 m each (total length of 3,000 m) and 2" diameter, which simulates a pressure drop of 150 km of ducts, what is the distance between two pump stations. Between these racks, there are six experimental areas: Depressurization, Leakage, Fracture, Corrosion, Instrumentation testing and Pressure Drop.



Figure 4. CO<sub>2</sub> Transport Experimental Facility at CIUDEN general view  
 Figura 4. Vista general de la instalación experimental de transporte de CO<sub>2</sub> de CIUDEN

**2.6 Biomass gasifier (3 MWt)**

CIUDEN's es.CO<sub>2</sub> Bubbling Bed Biomass Gasifier is an industrial scale facility that can achieve a gross power of 3 MW<sub>th</sub>. It is aimed to test biomass gasification and coal – biomass co-gasification by bubbling bed and atmospheric pressure gasifier.

Simplified process diagram of the full centre can be seen in figure 5.

**3. Main results at CIUDEN Technology Development Centre for CO<sub>2</sub> Capture Circulating Fluidized Bed Boiler**

Several testing campaigns have been carried out at CIUDEN's 30 MW<sub>th</sub> Circulating Fluidized Bed (CFB) boiler using local anthracite and different anthracite/petcoke blends as fuel, in order to explore the capabilities of this technology. Two of the main parameters in which the testing has been focused are the performance on SO<sub>2</sub> capture and NO<sub>x</sub> emissions using oxy-combustion technology.

**3.1 Sulphur Retention in 30 MWth Oxy-CFB Burning Spanish Anthracite**

A set of the testing campaigns has been carried out in CIUDEN's Technological Development Centre, es.CO<sub>2</sub> one of them was the FP7 project FLEXI BURN CFB. The objective was to generate a technical evaluation of the flexible air/oxygen operation to establish high efficiency CFB design requirements.

The experimental runs have been carried out in a 30 MW<sub>th</sub> CFB boiler, designed by Foster Wheeler Energia Oy, using local Spanish anthracite, three different ratios of anthracite/petcoke blends and one anthracite/biomass blend as fuel. Also two limestone types have been tested as sulfur sorbent.

The experimental period was divided in four sessions, resulting in more than 1,500 operational hours, both in air and oxy firing modes. The main parameters that have been studied are fuel and limestone performance at different bed temperatures and pressures, oxygen excess in flue gas, fluidization conditions, oxidants distribution as well as fly ash recirculation.

Preliminary results show that high SO<sub>2</sub> capture efficiency can be achieved by using limestone in-furnace sulfur capture in oxy fuel mode. In chart 1 it can be seen that SO<sub>2</sub> capture efficiency exceeding 95 % has been reached even with Blend 3 containing 5 % of sulfur (d.a.f).

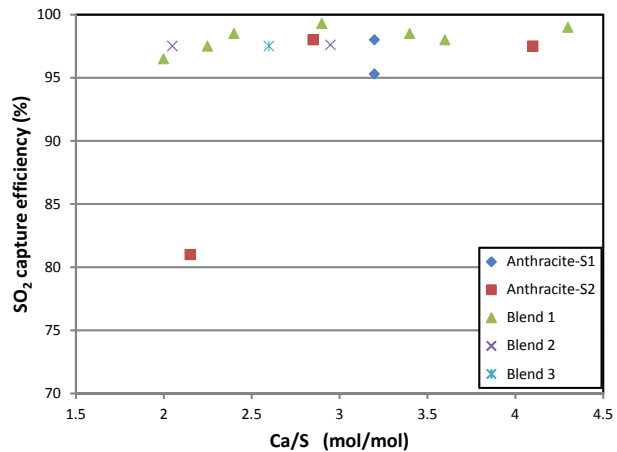


Figure 6. SO<sub>2</sub> capture efficiency for different fuels at high load [2]

Figura 6. Eficiencia de la captura de SO<sub>2</sub> para diferentes combustibles a alta carga [2]

**3.2 NO<sub>x</sub> emissions in 30 MWth Oxy-CFB burning Spanish Anthracite**

During coal combustion, nitrogen oxides (NO<sub>x</sub>) are generated, although CFB technology inherently

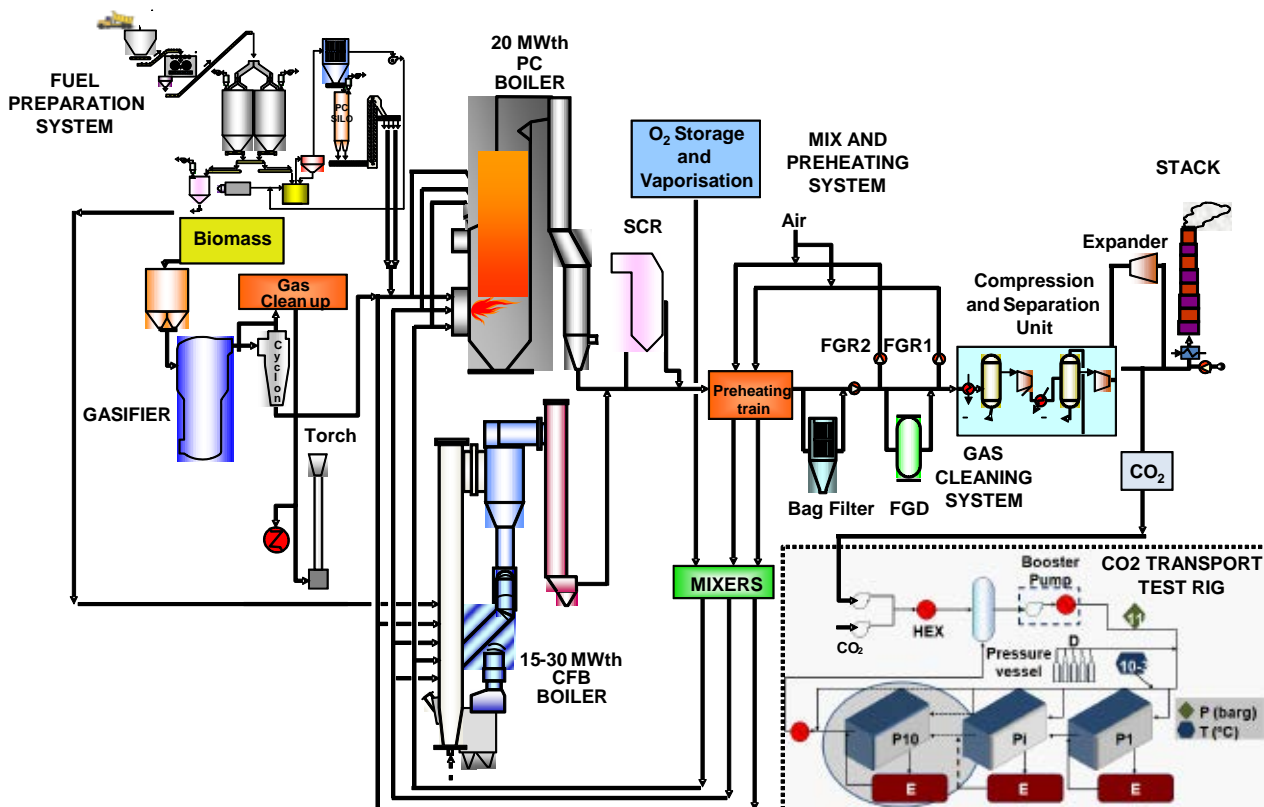


Figure 5. Simplified process diagram  
 Figura 5. Diagrama de proceso simplificado

produces lower  $\text{NO}_x$  emissions due to low combustion temperatures than Pulverized Coal boilers. This assessment is well known and it is described in technical literature as one of the main advantage of using CFB boilers.

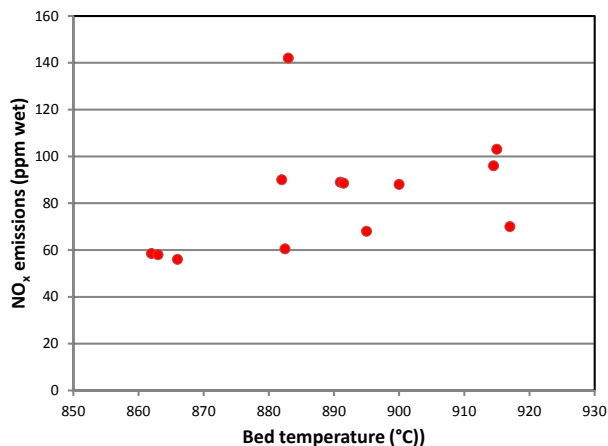
CIUDEN has carried out tests and analysis in the test programs within different R&D projects:

- OXYCFB300, The Compostilla Project – Technology development for  $\text{CO}_2$  oxy-capture, inland transport and storage in saline formations supporting Final Investment Decision of a demo 300  $\text{MW}_e$  (aprox.) CCS oxy-CFB Power Station.
- FLEXIBURN CFB – Demonstration of flexible high efficiency CFB combustion technology in air and oxy-modes for CCS.
- MACPLUS – Development and testing full-scale prototypes of components to improve performance and reliability of CCS Power Stations.

In some of these tests ammonia was injected through nozzles at different points of the boiler for  $\text{NO}_x$  reduction. The cyclone provides proper gas mixing, residence time and reaction temperature for ammonia to reduce  $\text{NO}_x$  emissions effectively. The ammonia injection tests were conducted in flow steps in the reagent feeding, and the unreacted  $\text{NH}_3$  (ammonia slip) was measured in duct using a FTIR analyzer.

Several parameters were modified during the tests to analyze their influence on  $\text{NO}_x$  emissions: fuel, air/oxy firing, bed temperature, oxidant ratio,  $\text{O}_2$  content in oxidants, limestone ratio, fly ash recirculation and ammonia feeding.

The results show that  $\text{NO}_x$  emission levels are significantly lower in CFB oxy-combustion and can be reduced even more using ammonia feeding in the cyclone, where temperature conditions are suitable for Selective Non Catalytic Reduction (SNCR). Chart 2 shows an example of the  $\text{NO}_x$  emission relation with temperature in oxy firing of anthracite/petcoke (70/30 w-%) blend.



**Figure 7.**  $\text{NO}_x$  emissions vs bed temperature. Oxyfiring anthracite/petcoke (70/30 %w) [3]

**Figura 7.** Emisiones de  $\text{NO}_x$  vs temperatura de lecho. Oxidación antracita/petcoke (70/30 %w) [3]

#### 4. Conclusions

CIUDEN investigates CCUS in two main facilities: Carbon Capture and Transport at the Technology Development Centre for  $\text{CO}_2$  Capture (es. $\text{CO}_2$ ) and  $\text{CO}_2$  Storage at the  $\text{CO}_2$  Storage Technology

Development Plant. These two main installations have provided a real basis for the design, construction and operation of a future 300  $\text{MW}_e$  CFB supercritical oxycombustion plant, with dense phase  $\text{CO}_2$  transport line and final underground  $\text{CO}_2$  storage in a deep saline geological formation. CIUDEN facilities are conceived not only for the development of CCUS technologies, but also for the improvement of technologies related with co-combustion of coal and biomass that can result in negative  $\text{CO}_2$  emissions.

An important milestone is that, CIUDEN is the only project in the world which has completed the process from fuel preparation to  $\text{CO}_2$  capture using a circulating fluidized bed boiler in oxy-combustion. Furthermore, CIUDEN has proven and validated the power capacity enlarge from 15  $\text{MW}_{th}$  to 30  $\text{MW}_{th}$  though the increase of  $\text{O}_2$  concentration in the oxidants in oxycombustion.

Based on the experience, no dramatic changes in the boiler between the air-fired and the oxy-fuel modes transitions could be observed. The clearest differences between the combustion modes, in addition to differences between the oxidant and flue gas compositions, were related to emissions. It was found out that both  $\text{SO}_2$  and  $\text{NO}_x$  emissions have the same order of magnitude when the concentrations are considered, but as the flue gas emitted in air mode is approximately four times higher, the total  $\text{SO}_2$  and  $\text{NO}_x$  emission are lower in oxycombustion mode.

Related to  $\text{SO}_2$  capture, oxy mode shows high  $\text{SO}_2$  capture efficiency, above of 95 % in most cases, and it is highly dependent of bed temperature and Ca/S ratio. Regarding  $\text{NO}_x$  emission, at the combustion temperatures tested, are due to the nitrogen content of the fuel, although high limestone addition increases the  $\text{NO}_x$  emissions.

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