

State of Wyoming Clean Coal Technologies Research Program

Fischer-Tropsch conversion of Wyoming coal-derived syngas using a small channel reactor for improving efficiency and limiting emissions (Topic H: Coal-to-Liquids)

**A Final Executive Report to the Legislature of the State of Wyoming
Clean Coal Technologies Research Program**

**Submitted by
The University of Kentucky Research Foundation
on behalf of the University of Kentucky Center for Applied Energy Research**

**2450 Research Park Drive
Lexington, KY40511**

**PI: Burtron H. Davis, Ph.D.
(859)257-0251 (phone)
(859)257-0302 (fax)
burtron.davis@uky.edu**

**co-PI: Gary Jacobs, Ph.D.
gary.jacobs@uky.edu**

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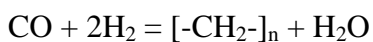
Final Executive Summary

Fischer-Tropsch (FT) synthesis offers a route to produce transportation fuels from coal, natural gas, and biomass. Wyoming possesses a reserve of 68.7 billion tons of coal and is the number one producer of coal in the US. In 2004 alone, Wyoming produced 395.5 million tons of coal. The primary coal producing regions are the Powder and Green River Basins. Wyoming also boasts impressive reserves of natural gas, and the state ranked number two in the US in 2007, producing approximately 2,254 trillion cubic feet of natural gas in that year alone. The natural gas is typically used for heating in industry and homes. Coal bed methane is another significant source of methane gas (e.g., 327.5 billion cubic feet in 2002), which is extracted from Wyoming's coal bed seams. Finally, biomass is another potential resource, its main advantage being that it is renewable and, as such, has the potential to decrease net CO₂ emissions. The US DOE has recently aggressively pursued research in combining biomass with coal in order to offset CO₂ emissions from the latter resource. In comparison with other states, Wyoming produces a moderate level of biomass. For example, total wood produced in 2007 amounted to about 158 million board feet (primarily softwood), compared to the leading producer, Oregon, with approximately 5,968 million board feet (total softwood and hardwood).

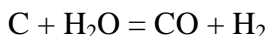
During the energy crisis of the 1970s Kentucky was at the forefront of developing a synfuels industry but "cheap oil" terminated the effort. CAER's direct coal liquefaction group conducted fundamental and applied studies in this area and operated a 1/8th ton per day pilot plant. Since then, the research effort has shifted to Fischer-Tropsch synthesis research funded by KY and DOE. This research is aimed at: (1) indirect coal liquefaction also known as coal-to-liquids or CTL; (2) gas-to-liquids or GTL, and (3) biomass-to-liquids or BTL. Part of the shift in focus was due to more stringent limits on aromatics content in liquid transportation fuels.

One of the most recent activities from our work with companies is testing of a new compact heat exchange reactor (CHER) for FT aimed at overcoming problems associated with heat transfer. A single modular unit of the pilot-scale reactor is a small channel FT reactor. Thus, since one CHER module is representative of the commercial reactor, analysis of the productivity and product distribution from the CHER module provides all the necessary information for designing a plant-scale unit.

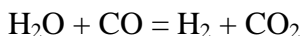
One potential impediment to the development of a synfuels industry based on coal is that of emissions. Because the FT reaction requires a slightly greater than 2:1 H₂/CO stoichiometry in order to grow the hydrocarbon chain,



while coal generates a syngas ratio that is typically on the order of unity,



the water-gas shift reaction,



must be used to boost the H₂/CO ratio so the desired reactant ratio is achieved; this generates CO₂ in the process. Thus, from the standpoint of net CO₂ reduction, renewable carbon sources such as biomass (e.g., wood waste products) will likely be gasified in a blend with coal in the future.

The CAER group has strong interactions with industry and has conducted catalyst testing for more than 25 small and large companies. Industrialists are interested in the CHER for increasing productivity per pass, while at the same time managing heat transfer. CAER personnel have visited the manufacturer of the CHER with industrial personnel.

The original proposal was to purchase a research scale reactor during the first year and to conduct experiments with this reactor over a 2-year period in order to obtain data to compare the activity and selectivity of catalysts to those obtained in CAER's continuously stirred tank reactors (CSTRs). These data would allow us to decide whether the small channel reactor can be utilized effectively and how closely they approach idealized reactor performance. However, CAER only received the reactor very late in the second year. Therefore, there was only 1 year remaining on the grant to start-up and test the reactor, and this time was dedicated to testing a series of silver-promoted cobalt catalysts, in order to provide a useful comparison between the novel CHER and the conventional slurry phase continuously stirred tank reactor (CSTR). Not to waste time, activities for the first and second year of the grant were thus directed at catalyst development of iron and cobalt catalysts for eventual use in the CHER.

Today, the low temperature reactors are fixed bed and the slurry reactors. Each has advantages and disadvantages, some of which are listed in Table 1. For a reaction with a small heat of reaction, the fixed bed reactor has the highest productivity since the catalyst density per unit reactor volume is much higher than in a slurry phase reactor. However, the Fischer-Tropsch reaction is very exothermic (165 kJ/mol heat release, which is ~4 times that of the heat required to vaporize water) and this means that the temperature profile is not uniform along the reactor length; rather, there will be a severe exotherm near the top of the reactor at the beginning of a reactor run, and this is the region of the reactor where the major fraction of the products are produced. This means that most of the catalyst is used very ineffectively so that the overall productivity is very low when based on the total catalyst loading. Some improvements have been made that manage better the exotherm, but catalyst usage is still not near the optimum. The slurry bubble column reactor (SBCR) which is used in industry, on the other hand, is operated

isothermally but because of the catalyst particle size distribution and the difference in flow rate, as the reaction progresses in moving toward the top of the reactor, there is an uneven distribution of catalyst through the column. In addition, the viscosity of the slurry increases with catalyst loading so that the slurry contains only about 10 wt.% catalyst. These factors therefore limit the productivity per unit reactor volume.

Table 1. Advantages and disadvantages of slurry and fixed bed reactors; and scale of these commercial scale reactors.

<u>SLURRY BED REACTOR</u>	<u>FIXED BED REACTOR</u>
Good heat transfer	Simpler to operate
Poor mass transfer	Moderately easy to scale up
Difficult to operate	Poor temperature control
Difficult to scale up/down	
<u>OPERATE TO DATE</u>	<u>OPERATE TO DATE</u>
33ft diameter, 100 ft long	23,000 1-in Tube 40 ft long
0.2 g HC/g _{cat} h	<0.2 g HC/g _{cat} h (cat diluted)
15,000 – 17,000 bpd per reactor	ca. 7,500 bpd per reactor

Small channel reactors provide an option to overcome the shortcomings of both the larger fixed bed and the slurry reactors. The coolant and the catalyst tubes are close together and the heat transport paths are short. Thus, the aim of the CHER is to obtain the excellent heat management properties of the CSTR with the high productivity of a fixed bed reactor.

Moreover, a benefit of the Chart CHER reactor over typical microchannel reactor technology is that the catalyst is not washcoated onto a surface; rather, it can be easily removed and replaced.

This Executive Summary report is broken up into eight different but related investigations regarding the development of Fischer-Tropsch synthesis catalysts and testing of a Compact Heat Exchange Reactor for X-to-liquids (XTL) technology. They are presented in chronological order according to the dates in which the study was conducted.

1. Cobalt catalysts are typically used to convert natural gas derived synthesis gas. The catalysts possess low intrinsic water gas shift activity, which is an advantage when the H_2/CO ratio is already high. Thus, the catalysts could also be effective in converting Wyoming coal-bed methane and natural gas. The active sites are surface cobalt metal atoms. The cobalt is supported on alumina, a high surface area carrier ($150\text{ m}^2/\text{g}$), in order to disperse the cobalt as nanoparticles to provide sufficient cobalt surface for conducting the catalysis. Because small cobalt particle ($< 2\text{-}4\text{ nm}$) are susceptible to reoxidation by H_2O , a major product of FTS, high loadings of cobalt are used (e.g., $\sim 25\%$ Co by mass), producing nanoparticle which are, on average, $\sim 10\text{ nm}$ in size. However, although alumina stabilizes small nanoparticles, due to the strong interaction between cobalt oxides and alumina, reduction is impeded. To facilitate reduction, a second metal is often added. This metal tends to dissociate H_2 at low temperature, nucleating Co metal sites within the cobalt oxides allowing for reduction to cobalt metal particles. The first investigation explored the ability of the metal-promoted $25\%Co/Al_2O_3$ catalysts to maintain good contact between the metal promoter and cobalt and continue facilitating Co oxide reduction after oxidation-reduction (OR) cycles, an approach designed to simulate the catalyst regeneration process. Regeneration is needed to burn off carbon deposits that build up on the catalyst surface during the FTS run, thus freeing up active sites upon

reactivation. One potential benefit of the CHER is that of flexibility. There is the possibility of carrying out regeneration in-situ, or the catalyst can be easily remove for ex-situ regeneration. In the investigation, unpromoted 25%Co/Al₂O₃ catalyst was also examined for oxidation-reduction (OR) cycles and served as a reference. Seven metal promoters were examined in this work, including Pt, Ru, Re, Ag, Au, Rh, and Ir. Fresh and treated catalysts were evaluated by both TPR and XANES spectroscopy, the latter approach utilizing linear combination fittings with appropriate reference compounds. With the unpromoted catalyst, OR cycles tended to have two effects: (1) a fraction of CoO species that lost their interaction with the support emerged and (2) a fraction of more strongly interacting CoO species was formed. A comparison between freshly calcined sample and RO samples was demonstrated. Pt-, Ru-, Re-, Ag-, and Rh-promoted 25%Co/Al₂O₃ catalysts maintained their ability to facilitate Co oxide reduction after undergoing OR cycles even up to 3 cycles, while with Ir- and, especially, Au-25%Co/Al₂O₃ some losses were observed, suggesting some separation between the promoter and cobalt occurred with OR cycles. TPR profiles also suggested that some separation of Ru from Co occurred with OR cycling, although it did not significantly impact the extent of reduction of Co after 3 OR cycles.

2. The second investigation focused on iron catalyst development. Iron catalysts are important for the conversion of synthesis gas when the H₂/CO ratio is low. This is often the case when using coal or biomass as the resource. Promoted iron catalysts possess intrinsic water-gas shift activity which adjusts the H₂/CO ratio upward to obtain the desired stoichiometry needed to run FTS. However, CO₂ is released in the process. Thus, the WGS rate should be tailored to prevent excessive CO₂ generation. In the future, CO₂ may be captured and sequestered underground. Two other points should be noted. If a hydrogen source is available (e.g., solar or nuclear-powered generation of H₂ by electrolysis of H₂O), then the H₂/CO ratio could

conceivably be boosted so that water gas shift is not required. In that case, cobalt catalysts would be used, as they possess low intrinsic water-gas shift activity. With biomass utilization, the objective is net lowering of CO₂ emissions, since a renewable resource is used. However, energy is lost by torrefaction of biomass (essentially making it mimic coal in preparing it for gasification), and energy is lost in transport of biomass. A disadvantage of biomass is low energy density.

The active sites of iron catalysts are deemed to be iron carbides. To achieve carburization of the iron surface, CO or syngas might be used. There would be a benefit if syngas could be used, as it would come directly from the gasifier, and no separation of CO from H₂ would be required. Promotion by Cu doping was found to be beneficial in achieving carburization of iron by syngas. The effects of activation gas and copper promoter loading on the Fischer–Tropsch synthesis performance of potassium promoted precipitated iron-based catalysts were investigated using a continuously stirred tank reactor (CSTR). In this study, CO and syngas (H₂/CO = 0.7) activated catalysts were tested after varying the copper promoter loading (0, 2 and 5 %, atomic ratios relative to iron). After attaining a steady-state conversion for the CO activated catalysts, similar or slightly higher CO conversions were exhibited with increasing copper loading, and the induction period was reduced with increasing copper loading. Partial pressure of hydrogen in the activation gas influenced the resulting activity of the catalysts. For syngas activated catalysts, CO conversion was found to increase with increasing copper loading up to 2 %, and slightly decrease with further increases in copper (5 %) loading. For similar CO conversion levels, the selectivities were similar for the CO activated catalysts, whereas for the syngas activated catalysts, the selectivity varied with copper loading. With increasing copper loading, lower hydrocarbon (methane and C₂–C₄) selectivities decreased and

the corresponding higher hydrocarbon (C₅₊) selectivity increased. This aspect was further explored in the fifth study by synchrotron characterization.

3. Potassium is an important electronic promoter of iron catalysts for achieving carburization during activation, as well as maintaining the carbide phase during FTS. However, the effect of K loading has been scarcely reported. The effect of potassium promoter loading (0, 0.5, 1.0 and 2.0 atomic ratio) on the performance of precipitated iron catalysts was investigated during Fischer–Tropsch synthesis using a continuously stirred tank reactor. Characterization by temperature-programmed reduction with CO, Mössbauer effect spectroscopy, and transmission/scanning transmission electron microscopy were used to study the effect of potassium promoter interactions on the carburization, phase transformation and carbon layer formation behavior of the catalysts. Under similar reaction conditions, all four catalysts exhibited similar initial CO conversions (~85 %), whereas stability was found to increase with potassium loading up to 0.5 % (atomic ratio related to the iron), and further increases in potassium led to decreased activity. Unpromoted and excessively K loaded (2.0K/100Fe) catalysts exhibited similar deactivation trends with time and followed essentially similar conversion levels with time-on-stream. The selectivity of various potassium promoted catalysts was found to increase the average molecular weight of hydrocarbon products with increasing potassium loading. The deactivation rate was related to carbon deposition which could embed the iron carbide particles. If not enough K is present, Fe carbides tend to oxidize with TOS; with excessive K-loading, carbon deposition/site blocking become problematic for the stability of the catalyst.

4. In the fourth study, and continuing with the role of K loading on activity and stability, the morphological, phase transformations and carbon-layer growth for unpromoted and K-promoted iron catalysts were investigated over time during Fischer–Tropsch synthesis. Catalysts were

activated in CO for 24 h, which transformed hematite into a mixture containing 93% iron carbide and 7% magnetite for the unpromoted catalyst and 81% iron carbide and 19% magnetite for the K-promoted catalyst. Initially, the activated catalysts had high CO conversions (~85%); however, the conversions decreased to approximately 30% after approximately 280 h of synthesis time. For the unpromoted catalyst, the amount of iron carbide gradually decreased over time while the corresponding magnetite phase increased. However, for the K-promoted one, only one iron carbide phase (χ -Fe₅C₂) gradually decreased, while the other (ϵ' -Fe_{2.2}C) phase steadily increased and magnetite remained unchanged. TEM analyses revealed that for the K-promoted catalyst, carbon deposition increased over time, unlike that of the unpromoted catalyst.

5. Continuing from the second study, the effect of activation gas on the Fischer-Tropsch synthesis (FTS) performance of copper and potassium promoted precipitated iron-based catalysts was further investigated, this time using synchrotron characterization methods. CO and syngas (H₂/CO = 0.7) activation methods were tested after varying the copper promoter loading (0, 2, and 5%, atomic ratios relative to iron). At similar CO conversion level, the selectivities for the CO-activated catalysts were identical for the various copper loaded catalysts, whereas for the syngas activated catalysts, light hydrocarbon (methane and C₂-C₄) selectivities decreased and higher hydrocarbon (C₅+) selectivities increased with increasing copper loading. To understand the reason for that behavior, the catalyst samples were characterized by XANES/EXAFS spectroscopy following each activation procedure before and after exposure to FTS conditions. Cu K-edge normalized XANES results indicate that for the syngas activated catalyst copper is present primarily in the Cu¹⁺ state, whereas for CO activated catalyst the copper is more reduced (greater fraction in the Cu⁰ state). The Cu¹⁺ in the syngas-activated catalyst behaved like the

electronic promoter, K^{1+} ; therefore, the C_{5+} selectivity was enhanced and light hydrocarbon selectivity was suppressed.

6. Current understanding of Co-catalyzed Fischer-Tropsch synthesis is that cobalt clusters should be formulated in a manner such that the particles are not so large as to diminish surface Co site densities (i.e., due to excessive cobalt being locked within the bulk of the metal particle), but not too small as to either hinder reduction of cobalt oxides to the active metallic state (due to either strong interfacial interactions with the support or cobalt-support compound formation), or result in instability in the presence of water (diameter $< 2 - 4$ nm suggested to oxidize Co under FTS conditions). In this investigation, a chemical vapor deposition (CVD) method was utilized to deposit nano-sized Co oxide crystallites. Silica displayed significant interactions with a fraction of the Co oxide prepared by CVD, while SiC interacted strongly with the entire amount of Co oxide. This was remarkable, as SiO_2 and SiC have generally been considered to be weakly interacting supports with Co oxide crystallites prepared by standard impregnation methods. CO conversion was higher for the aqueous impregnated catalysts, consistent with a higher Co site density. Despite the fact that the Co clusters for the CVD catalysts were much smaller, a significant fraction remained unreduced following standard activation in hydrogen. Consistent with our earlier CSTR tests with Pt-Co/carbon and Pt-Co/ TiO_2 catalysts, selectivities to oxygenates were higher for both CVD catalysts relative to the ones prepared by aqueous impregnation, and the effect was more pronounced for the Pt-Co/SiC catalyst. Results were explained on the basis of Co electronic structure, crystallite size, morphology, and degree of interaction with the support. These aspects were measured by temperature programmed reduction, synchrotron-based methods (EXAFS/XANES), and scanning transmission electron microscopy (STEM), among other techniques.

7. One problem with the use of porous catalyst pellets is that problems arising from diffusional restrictions, pore filling by heavy hydrocarbons, and solubility issues may occur. One reported issue is that, because hydrogen diffuses faster than CO, the H₂/CO ratio may change as a function of pore length to the catalyst particles. Therefore, if cobalt is deeply embedded in pores, there may be excessive termination due to the undesired higher hydrogen surface fugacity on the catalyst surface. This is a reason cited by companies for why eggshell catalysts are preferred, where Co is preferred to be on the rim of the pellet. This could be an issue for catalysts used in the CHER, where a catalyst pellet size must be selected to avoid excessive pressure drop in the fixed bed reactor. To explore this issue further, sequential impregnation and calcination was used to pre-fill the pores of a commercial alumina support with alumina. In this manner, two different pore-modified alumina supports were synthesized. To compensate for the diminished pore size, cobalt loadings were lowered as appropriate to ensure similar cobalt sizes and extents of reduction. This was confirmed by measurements from TPR, hydrogen chemisorption / pulse reoxidation, and EXAFS / XANES spectroscopies. Catalysts were tested using a slurry phase CSTR reactor at commercially relevant FTS conditions. Selectivities were compared at both high and low level conversions for the catalyst series. Decreasing the pore length, as measured by PSD data, inhibits the adverse effect that the higher relative diffusional rate of hydrogen versus carbon monoxide has on the H₂/CO surface fugacity ratio on the catalyst surface. That is, moving the cobalt particles closer to the pore mouth prevents the H₂/CO ratio from being augmented at the surface of cobalt particles due to diffusion, and thereby inhibits excessive chain termination that would lead to higher light product selectivities. Pore filling thus results in a catalyst that is similar to an egg-shell catalyst. With increased pore filling by alumina, C₁ – C₄ light gas selectivities decreased, in a systematic way, by as much as 33%

(relative basis), and the C₅+ selectivity improved by as much as 10.3% (relative basis) in comparison with the 25%Co/Al₂O₃ (IWI) reference catalyst. This greater effectiveness offers an opportunity for more environmentally benign chemical processing.

8. The main goal of the work was performed in our final studies once we received the CHER. The FTS performance of 0.27%Ag-25%Co/Al₂O₃ catalysts were comparatively tested using a CSTR and a compact heat exchange reactor (CHER) using the same activation (i.e., H₂) and FTS conditions (350 °C, H₂/He for 36 h; FTS: 200-225 °C, 1.3 MPa, H₂/CO ratio of 2.0 and ca. 50% CO conversion); catalysts were tested for 550-1200 h. The catalyst activity (Table 2) and deactivation rate in the CHER and CSTR reactor are quite comparable. During the run, the pressure drop in the CHER remained low (< 30 psig), hydrocarbon productivity was high (Table 2), and heat transfer remained reasonably high (temperature difference along bed: ± 0.5 °C), suggesting that the CHER is a viable reactor for the production of clean fuels using XTL processes. The effect of Al₂O₃ pore support and Ag promoter on FTS performance were also investigated. The 0.27%Ag-25%Co/Al₂O₃ catalysts displayed ~50% higher activity than the unpromoted 25%Co/Al₂O₃ catalysts which was ascribed to ability of Ag to significantly facilitate Co oxide reduction (i.e., surface Co⁰ being active sites). The activity and selectivity of the Ag-Co catalysts changed significantly with Al₂O₃ type. The wide pore HP14/150 Al₂O₃ favored the formation of heavier hydrocarbons, promoted catalyst stability, and decreased methane formation. The wide pore HP14/150 Al₂O₃ promotes the formation of heavier hydrocarbons and catalyst stability, as well as decreased methane formation. This may be due to an effect of porosity on relative diffusional rates of H₂ and CO, with the faster H₂ diffusion rate in narrow pores increasing the termination rate relative to wider pores (where the H₂/CO ratio remains more like the bulk gas composition). However, further experiments are needed to elucidate this

effect, perhaps using isotopic tracers. One area of development that is still needed for the CHER is to continue to optimize the catalyst for selectivity control. The light gas selectivity produced by the CHER with the catalysts tested was slightly higher, and C₅₊ selectivity was slightly lower (Table 2); however, some of this is attributed to the fact that measurements were typically made at longer times onstream with the CHER relative to the CSTR, so that the catalyst aging effect on selectivity was present. Nevertheless, we believe that studies like #7 offer direction for catalyst development.

Table 2 Comparison of 0.276% Ag-25% Co/Al₂O₃ catalysts at 210°C.

Support	Reactor	SV	P (psig)	TOS (h)	Ave X _{CO}	Ave S _{CH4}	Ave S _{CO2}	Ave S _{C5+}	FT product rate (g/h g _{cat})
Wide Pore HP14/150	CHER	4.0	157	132-195	44.4	8.0	0.50	84.0	0.368
Wide Pore HP14/150	CSTR	2.5	175	71-138	48.3	4.8	0.77	90.4	0.318
Narrow Pore Catalox 150	CHER	2.5	160	121-200	59.9	8.7	0.90	82.3	0.312
Narrow Pore Catalox 150	CSTR	2.8	175	71-139	47.2	5.5	0.60	88.7	0.247

A number of papers were published and presentations made from the work, as summarized below. Please note that additional manuscripts are under preparation.

Refereed manuscripts from this grant

1. Jermwongratanachai, T.; Jacobs, G.; Shafer, W.D.; Pendyala, V.R.R.; Ma, W.; Gnanamani, M.K.; Hopps, S.; Thomas, G.A.; Kitiyanan, B.; Khalid, S.; Davis, B.H., “Fischer-Tropsch synthesis: TPR and XANES analysis of the impact of oxidation-reduction (OR) cycles on the reducibility of Co/alumina catalysts with different promoters (Pt, Ru, Re, Ag, Au, Rh, Ir),” *Catalysis Today* **228** (2014) 15-21.

2. Pendyala, V.R.R.; Jacobs, G.; Hamdeh, H.H.; Shafer, W.D.; Sparks, D.E.; Davis, B.H., “Fischer-Tropsch synthesis: effect of activation gas after varying Cu promoter loading over K-promoted Fe-based catalyst,” *Catalysis Letters* **144** (2014) 1624-1635.
3. Pendyala, V.R.R.; Graham, U.M.; Jacobs, G.; Hamdeh, H.H.; Davis, B.H., “Fischer-Tropsch synthesis: deactivation as a function of potassium promoter loading for precipitated iron catalyst,” *Catalysis Letters* **144** (2014) 1704-1716.
4. Pendyala, V.R.R.; Graham, U.M.; Jacobs, G.; Hamdeh, H.H.; Davis, B.H., “Fischer-Tropsch synthesis: morphology, phase transformation and carbon layer growth of iron-based catalysts,” *ChemCatChem*. **6** (2014) 1952-1960.
5. Pendyala, V.R.R.; Jacobs, G.; Gnanamani, M.K.; Hu, Y.; MacLennan, A.; Davis, B.H., “Selectivity control of Cu promoted iron-based Fischer-Tropsch catalyst by tuning the oxidation state of Cu to mimic K,” *Appl. Catal. A: General* **495** (2015) 45-53.
6. Smiley, D.D.; Gloriot, V.; Jacobs, G.; Pendyala, V.R.R.; Graham, U.M.; Ma, W.; Shafer, W.D.; Thomas, G.A.; Hopps, S.; MacLennan, A.; Hu, Y.; Khalid, S.; Davis, B.H., “Fischer-Tropsch synthesis: comparisons of SiO₂ and SiC supported Co catalysts prepared by aqueous impregnation and CVD methods,” Chapter 5 in Fischer-Tropsch Synthesis, Catalysts, and Catalysis (eds. Burtron H. Davis, Mario Occelli), 2016, Taylor and Francis, CRC Press, Boca Raton, Florida, USA.
7. (submitted) Jacobs, G.; Bertaux, C.; Pendyala, V.R.R.; Shafer W.D.; Poirier, J.-S.; Xiao, Q.; Hu, Y.; Davis, B.H., “Fischer-Tropsch synthesis: Cobalt catalysts on alumina having partially pre-filled pores exhibit higher C₅₊ and lower light gas selectivities,” *Applied Catalysis A: General*, submitted.

Presentations

1. Jacobs, G.; Pendyala, V.R.R.; Gnanamani, M.K.; Hu, Y.; MacLennan, A.; Davis, B.H., “Influence of Cu promoter oxidation state on FTS product selectivity,” 24th North American Meeting of the Catalysis Society, Pittsburgh, Pennsylvania, June 14-19, 2015.

2. Pendyala, V.R.R.; Graham, U.M.; Jacobs, G.; Hamdeh, H.H.; Davis, B.H., “Fischer-Tropsch synthesis: Morphology, phase transformation and carbon-layer growth as a function of potassium promoter loading for a precipitated iron catalyst,” 24th North American Meeting of the Catalysis Society, Pittsburgh, Pennsylvania, June 14-19, 2015.

The authors listed on these publications include researchers from University of Kentucky’s Center for Applied Energy Research, students, and external collaborators.

UK-CAER researchers

PI: Dr. Burtron H. Davis, Associate Director, Clean Fuels and Chemicals Group; Co-PI: Dr. Gary Jacobs, Research Engineer Principal, Clean Fuels and Chemicals Group; Dr. Venkat Ramana Rao Pendyala, Research Scientist Senior, Clean Fuels and Chemicals Group; Dr. Wenping Ma, Research Engineer Senior, Clean Fuels and Chemicals Group; Dennis Sparks, Research Engineer Associate, Clean Fuels and Chemicals Group; Dr. Wilson D. Shafer, Research Scientist Associate, Clean Fuels and Chemicals Group; Dr. Uschi M. Graham, Research Scientist Associate, Clean Fuels and Chemicals Group; Dr. Muthu Gnanamani, Research Scientist Senior, Clean Fuels and Chemicals Group; Gerald A. Thomas, Research Scientist Principal, Analytical Services

Shelley G. Hopps, Research Scientist Senior, Analytical Services

Students: Dr. Thani Jermwongratanachai, Mr. Clement Bertaux, Mr. Damarcus D. Smiley, Mr. Victor Gloriot, Mr. Jean-Samuel Poirier

External Collaborators

Prof. Boonyarach Kitiyanan, Chulalongkorn University, Bangkok, Thailand; Dr. Syed Khalid, National Synchrotron Light Source, Brookhaven National Laboratory, New York; Prof. Hussein

H. Hamdeh, Wichita State University, Kansas; Dr. Yongfeng Hu, Canadian Light Source, Inc.,
Saskatoon, Saskatchewan, Canada; Ms. Aimee MacLennan, Canadian Light Source, Inc.,
Saskatoon, Saskatchewan, Canada