

3.3 RESEARCH NEEDS OF INDIRECT LIQUEFACTION

3.3.1 Current Research Activities and Status

Indirect liquefaction involves the gasification of coal to synthesis gas ($\text{CO} + \text{H}_2$) and the subsequent conversion of the syngas to fuels and chemicals. The process involves breaking every bond in the coal structure. The subsequent conversion of the syngas involves the use of a catalyst in every case. Methane is the most thermodynamically favored product and methanol among the least favorable. Syngas is being converted to methane at the Great Plains Gasification Plant. At present, methane is not a product of critical need, since natural gas is available.

Commercialized indirect liquefaction processes include the following:

- o The Fischer-Tropsch (F-T) Process. This is practiced commercially only in South Africa. The SASOL F-T processes convert almost 70,000 tons of coal per day to syngas. The gas is then converted over a cheap iron catalyst to 86,000 barrels per day of gasoline, diesel fuel, ethylene, ammonia, sulfur and other products. The process involves a polymerization of $-\text{CH}_2-$ units and, unfortunately, yields a melange of products, from methane to high-molecular-weight materials. There is now much interest in using syngas with low H_2/CO ratios from modern coal gasifiers for conversion to wax for cracking to desirable distillates; little methane is formed under these conditions.
- o Methanol from Syngas. Methanol is one of the ten largest-volume organic chemicals, produced worldwide at an annual rate of over three billion kg. It is made in numerous plants in greater than 99 percent selectivity when a mixture of CO , H_2 , and CO_2 is passed over a $\text{Cu}/\text{ZnO}/\text{Al}_2\text{O}_3$ catalyst at about 250°C and elevated pressures. Methanol has a high octane number and can be used as a fuel for internal combustion engines. Blends of methanol with cosolvent alcohols are used in varying amounts as octane-enhancing additives in gasoline. Methanol is also a small part of methyl tertiary-butyl ether (MTBE), which is an excellent octane enhancer in gasoline. A liquid-phase methanol process is being developed by Air Products at their 10-tons/day PDU in LaPorte, Texas. The process uses a H_2/CO ratio of 0.8, which is typical of syngas made from coal.

- o The Mobil (MTG) Process. In this process, practiced on a large scale in New Zealand, syngas is converted to methanol, which is then passed over a shape-selective catalyst (ZSM-5) to yield 92-93 octane gasoline. New Zealand selected the MTG process over the F-T process because the former was much more selective, involved fewer upgrading steps, and involved simpler engineering. Some 14,000 barrels per day of high-octane gasoline is now being produced in New Zealand using the MTG process. At the present price of petroleum, this plant is uneconomic.

Many innovative and important research and development efforts to improve indirect liquefaction technology have continued during the 1980's. The major thrust of these new research efforts includes the following:

- o Direct synthesis and optimization to produce higher-alcohol fuels from syngas. Work in this area includes the development of a homogenous catalyst, and binary and ternary heterogenous catalysts.
- o Optimization of the process variables and the catalyst to obtain a product that can be upgraded by conventional hydrocracking techniques to produce diesel and gasoline-range hydrocarbons.
- o Modification of the Fischer-Tropsch catalyst to limit the conventional chain growth mechanism governed by the Shulz-Flory distribution. This includes the use of size- and shape-selective zeolite catalysts, the development of promoted catalysts with alkali, and the operation of the catalytic reactor systems at lower temperatures.
- o Development of a slurry-phase Fischer-Tropsch catalyst and reactor system that can synthesize hydrocarbons from the hydrogen-lean synthesis gas ($H_2/CO < 1.0$) produced from the new-generation gasifiers.

The potential of these emerging indirect liquefaction technologies is recognized, and a number of research and development activities are already underway. Table 3-2 summarizes the representative R&D activities that are currently being pursued by both government and private industry. These activities and other current research are described in more detail in Chapter 5, which contains a review of indirect liquefaction.

Table 3-2. Emerging Indirect Liquefaction R&D Activities

Major Research Area	Representative R&D Activities
Direct synthesis of higher alcohols	<ul style="list-style-type: none"> - Search for novel homogeneous catalyst - Modify ruthenium catalyst - Develop binary Cu/ZnO catalyst and Cu/ZnO/Al₂O₃
Fischer-Tropsch process variables and catalyst optimization	<ul style="list-style-type: none"> - Understand wax formation from F-T process variables - Study mechanism of F-T catalysts - Novel catalyst for the selective synthesis of gasoline and diesel - Suppression of CH₄ formation in F-T synthesis - Surface properties of F-T catalysts - Promoted catalyst development
Limitation to F-T chain growth	<ul style="list-style-type: none"> - Novel carbon molecular sieve catalyst for wax suppression - Multifunctional catalyst for direct liquid fuel synthesis - MTG ZSM-5 catalyst to produce gasoline from methanol
Slurry-phase catalyst and reactor system	<ul style="list-style-type: none"> - Develop slurry-phase F-T catalyst - Hydrodynamics of F-T synthesis in slurry bubble column reactor - Diffusibility and solubility of syngas and F-T products in slurry media
Biological technology to produce liquid fuels from coal	<ul style="list-style-type: none"> - Biological conversion of coal derived synthesis gas to liquid hydrocarbons - Design and select microorganisms to achieve desired biochemical activity

3.3.2 High-Priority Recommendations in Indirect Liquefaction

This technology has fewer areas for research because it starts with CO/H₂ instead of coal and the products are either hydrocarbons similar to petroleum streams or oxygenates that need no further processing. Consequently, the research recommendations were concentrated on the synthesis reaction itself -- catalysts, control of product distribution, or reactor configuration. The first two recommendations (Table 3-1), which apply to all CO/H₂ reactions, were supported by at least nine panel members; the other seven recommendations were selected by 2-6 panel members.

Although the recommendations are fairly well balanced between Fischer-Tropsch and oxygenate synthesis, the panel felt that the major interest in indirect liquefaction will be to produce alcohols and ethers as fuels and octane enhancers.

3.3.2.1 Apply New Advances in Materials Science to Catalyst Preparation for F-T and Alcohol Synthesis

The highest-priority recommendation in indirect liquefaction is to apply new advances in material science to catalyst preparation for Fischer-Tropsch and alcohol synthesis reactions.

It is desirable to apply to the catalyst field the major advances in materials science made by high-technology science and industry. Thin layers, monolayers and sub-monolayers of dopants are well controllable today, both by modern preparation methods and by modern characterization tasks. Whereas Europe has annual conferences to review the extensive research in materials science of catalysts, no concerted U.S. effort exists except for single crystal surface science. This work should include research on novel supports, co-precipitated catalyst precursors, novel ways of surface doping, chemical vapor deposition, and plasma doping. Catalyst characterization techniques should include specific chemisorption, x-ray diffraction, electron microscopy, and other spectroscopic techniques.

This research is long range and may possibly result in no significant improvements in indirect liquefaction. The possibility, however, does exist that a completely new catalyst may be discovered that could greatly improve process economics.

3.3.2.2 Analyze the Structure, Reactivity, Function, and Role of Supported Organometallic Complexes

The second-ranking recommendation is to analyze the structure, reactivity, function, and role of supported organometallic complexes to elucidate the mechanisms of heterogenous catalysis in Fischer-Tropsch and alcohol synthesis.

Improved understanding of reaction sequences provides an ideal route for improvement of catalytic processes. Many highly dispersed catalyst systems form surface compounds that are, or resemble, organometallic complexes. Thus, a preferred route to advance understanding in this area is to add organometallic or other cluster complexes to a suitable catalyst support. Studies should then be conducted to elucidate the changes these complexes undergo in attaining reaction conditions which will define the nature of the active site in the working catalyst. Emphasis should be placed upon studies that will utilize these organometallic complexes in reactions, both chemical and catalytic, to elucidate the mechanisms of catalytic reactions and the features imparted by the support.

3.3.2.3 Develop Catalytic Conversion Routes to Maximize Selectivity of the Conversion of Synthesis Gas to Ethanol

The third-ranking recommendation is for the conversion of syngas to alcohols, to develop routes to maximize ethanol selectivity.

Ethanol is a proven transportation fuel, used straight as well as blended in hydrocarbon fuels. It has advantages compared to methanol - it is relatively non-toxic, blends better with hydrocarbons, does not absorb as much water, and is relatively non-corrosive. Yet, ethanol has

a high octane number (BON 110, MON 92, RON 96), low emissions, and has been mandated in Colorado and Nebraska, and sold in other states. An improved process starting with syngas will probably be cheaper than the fermentation route.

This research has a high probability of success, and results could be forthcoming in a relatively short period of time.

3.3.2.4 Find New Catalyzed Paths to Produce Octane-Enhancing Ethers from Alcohols

The fourth recommendation is to find new catalyzed paths to produce octane-enhancing ethers from alcohols.

Ethers, as octane enhancers, are becoming a significant component of transportation fuels. As such, they may make up to 10 percent of the gasoline volume. Even for the currently used methyl tertiary-butyl ether (MTBE), the synthesis route is dictated by an economical source of both methanol and isobutane. With increasing demand other ethers utilizing other raw materials will become a necessity. Even in the case of MTBE, which is a commercially accepted and heavily used octane enhancer, new raw materials, catalysts, and reaction pathways may be required to satisfy growing demand. Thus, exploratory research is needed to define a group of catalytic materials that will provide a basis to utilize a range of potential feedstocks for ether production. Production can then change to follow market supply and price of potential feedstocks.

3.3.2.5 Investigate Catalysts to Maximize Middle Distillate Yield from Syngas

The fifth recommendation is to investigate maximizing middle distillate yield from syngas, with low methane yield. Develop catalysts for high selectivity to long-chain hydrocarbons which can be cracked selectively to naphtha and distillate fuels.

The Fischer-Tropsch reaction can be controlled to produce a high yield of long-chain hydrocarbon middle distillates and waxes, which can

subsequently be cracked to naphtha and lighter distillate precursors of gasoline, jet fuel, and diesel fuel. Driving the reaction of these products will minimize production of methane. The catalyst must have high selectivity for the production of long-chain hydrocarbons. Additional catalyst development will be needed to obtain selective cracking of the wax. This route to transportation fuels may be more economical than other coal conversion processes.

This research has an excellent chance for success in a relatively short time.

Shell has announced work in this area, but has not published results. UOP is developing a wax hydrocracking process.

3.3.2.6 Develop Sulfur-Tolerant Low-Temperature Water Gas Shift Catalysts

The sixth recommendation in indirect liquefaction is to develop sulfur-tolerant low-temperature water gas shift catalysts.

The current low-temperature (below 250°C) water gas shift (WGS) technology utilizes copper-based catalysts, which are extremely sensitive to sulfur (\leq 1ppm) and chloride (\leq 0.1 ppm) poisoning. The element having such sensitivity is the copper. To avoid an extremely demanding cleanup of the water gas (CO + H₂O+ impurities), it is desirable to develop a catalyst and a process for WGS that works at temperatures below 250°C equally well as the copper catalysts but is insensitive to sulfur and chlorine. A class of catalysts that may satisfy these conditions is transition metal sulfides promoted with alkali.

3.3.2.7 Study the Reaction Kinetics and Develop Alternative Methanol Synthesis Catalysts

The seventh recommendation in indirect liquefaction is to study the reaction kinetics of, and develop alternative catalysts for, methanol synthesis to improve process economics.

Methanol continues to become more attractive as a transportation fuel, from both economic and environmental viewpoints. Today, some regions of the U.S. appear ready to mandate the use of methanol as a gasoline substitute. With increased demand it becomes imperative that the development of improved or alternative methanol synthesis catalysts be emphasized and accelerated. An effort is required to develop catalysts having improved performance with current-quality synthesis gas streams. However, catalyst research should strive especially to develop catalysts that do not require the extensive and expensive cleanup required by current catalysts. Additionally, catalysts should be sought that have the capacity to operate in reactors having unique capability to handle the heat of reaction for this exothermic reaction.

3.3.2.8 Determine the Carbon Form that Leads to Deactivation of F-T Catalysts

The eighth recommendation in indirect liquefaction is to determine the carbon form that leads to deactivation of Fischer-Tropsch catalyst.

In recent years, application of numerous surface science characterization techniques has identified a carbon surface species as an active intermediate associated with syngas conversion. The chemical nature of this species should impact the selectivity for Fischer-Tropsch synthesis. A number of factors could potentially determine the chemical character of this carbon species; these include catalyst promoters, catalytic metal, presence of other adsorbed gases, etc. A coordinated effort should be directed toward defining the factors which are important in generating the active carbon from carbon monoxide, and the catalyst properties which determine the reactivity of this carbon. These efforts should include work directed toward the actual high-pressure conditions encountered with a working commercial catalyst.

3.3.2.9 Use Probe Molecules to Study Product Composition in F-T and Related Synthesis

The last-ranked recommendation is to use probe molecules to understand and modify product composition in Fischer-Tropsch and related syntheses.

The Fischer-Tropsch synthesis of hydrocarbons from synthesis gas has been, apart from a brief period of methanol-to-gasoline synthesis in New Zealand, the only commercial-scale synfuels process in operation during the past ten years. It must therefore remain an important alternative in any energy policy. In spite of the extensive research already carried out and the inability, to date, to alter the product distribution from that required by the Anderson-Schulz-Flory polymerization scheme, additional research in this area would be valuable.

Three research areas to generate fundamental mechanistic understanding should be emphasized. First, the use of probe molecules, appropriately labeled by an isotope or other identifiable chemical characteristic, to better understand the nature of the surface species and to understand the mechanistic implications is essential. Second, in commercial operation it is an exceptional case when a catalyst is used without modification by a promoter, such as potassium in the Fischer-Tropsch synthesis, or an appropriate poison, such as sulfur in commercial Pt-Ru reforming catalysts. Fundamental studies should be directed toward understanding how promoters and poisons alter catalytic properties for commercial iron-based F-T catalysts as well as for novel catalyst materials. Third, the Fischer-Tropsch synthesis is one of the few instances where there are many homogeneous cluster catalysts which effect syngas conversion, and these should be effectively utilized to develop detailed mechanistic understanding of the synthesis. This appears to be a unique opportunity to build an understanding and bridge the gap between well-understood homogeneous catalytic reaction mechanisms and those of the much more complex, but much more practical, heterogeneous catalysts.

3.4 RESEARCH NEEDS IN PYROLYSIS

3.4.1 Current Research Activities and Status

Pyrolysis is the thermal low-pressure cleavage and devolatilization of coal to produce gas, liquid, and char. Pyrolysis is carried out at temperatures lower than commercial coking operations in order to maximize recovery of the volatilized product and minimize retrograde reactions that form char. Pyrolysis has always had the appeal of an inexpensive, thermal, low-pressure process that can recover the liquid easily removed from coal. By now, it is evident that the small liquid yield, the low value of the char, and the high cost of upgrading the pyrolysis liquid have prevented commercial application of this technology.

The major product is char. Liquid yields are 0.5-1 barrel per ton; char yield is about 50 percent of the coal. Hydropyrolysis and catalytic hydropyrolysis increase the liquid yield. The major barrier to commercialization is this high yield of char, which has a value (per pound) lower than that of the starting coal. To make this technology economically attractive, liquid yields must be increased substantially.

Some of the comments about direct liquefaction (see Section 3.2) apply as well to pyrolysis, because pyrolysis contains many similar operations. Coal reactivity is influenced by every operation of the process, starting at the mine, and each operation is a suitable topic for investigation. The quality of the pyrolysis liquid requires more attention, because the heteroatom (O,S,N) concentrations are about an order of magnitude higher than in direct liquefaction products, and these impurities are costly to remove. However, the process improvements in these areas are of secondary importance, compared to the overwhelming issue of the low liquid yield.

The development of pyrolysis technology since 1980 parallels the trends of direct liquefaction. Processes that appeared ready for

demonstration, including processes developed by FMC, Tosco, Occidental Petroleum, and Rockwell/Cities Service, have been shelved.

In general, pyrolysis processes have the potential to be a less expensive route to coal liquids compared to direct liquefaction because they operate at lower pressure and no hydrogen is needed. In the past, low liquid yields from pyrolysis have been accepted as a consequence of the coal structure and the refractory nature of the aromatic component, but recent findings regarding coal structure have resulted in renewed expectations from pyrolysis. The current picture of coal as consisting primarily of relatively small aromatic clusters with considerable hydrogen bonding indicates that pyrolysis tailored to the coal structure may recover these aromatic clusters as liquid product, rather than as char. It has also been discovered that the highest liquid yield can be obtained under mild pyrolysis temperature (400-800°C) and high heating rate.

A renewed effort in pyrolysis has centered around pretreatment of the coal. This pretreatment changes certain bond energies and allows thermal scission to take place more easily and with greater selectivity than was accomplished by the earlier processes. As a result, liquid yields are being increased dramatically in small-scale tests. These trends may put pyrolysis once again in the position of being an economically viable alternative to direct liquefaction. Although current R&D is at a low level of effort compared to direct and indirect liquefaction R&D efforts, pyrolysis may benefit most from a better understanding of coal and its chemistry. A review of pyrolysis is contained in Chapter 6.

3.4.2 High-Priority Recommendations in Pyrolysis

The recommendation to study the chemistry and the mechanism of catalytic hydrolysis had enthusiastic support from eleven panel members because this approach to pyrolysis has the potential to produce high liquid yields, whereas only marginal improvements of thermal

pyrolysis processes are anticipated from the other recommendations. The panel believed that large increases in liquid yields are necessary to make pyrolysis competitive with other liquefaction technologies.

The studies of coal structure, reactivity, and devolatilization mechanisms may have beneficial effects if they lead to a new technique that increases liquid yield. Thus, the recommendations in these areas were also given high priority.

3.4.2.1 Study the Chemistry and Mechanisms of Catalytic Hydropyrolysis

The highest-priority recommendation in pyrolysis is to study the chemistry and the mechanisms of catalytic hydropyrolysis.

Recent reports indicate that liquid yields can be increased 2-5 fold over Fischer assay by using a catalytic hydropyrolysis approach. Considerably more detailed information is needed to scope, evaluate, and advance these discoveries. Specifically, variables including catalyst composition and form, temperature, pressure, and residence time must be scoped, and a detailed mechanistic understanding of the chemistry involved must be formulated. Product analysis and evaluation in terms of boiling point distribution, heteroatom content and distribution, aromatic ring distributions, etc., must be determined. A number of coals must be looked at to define the generality of the approach.

A catalytic hydropyrolysis approach which produces >50 percent distillable liquids may be an economically viable alternative to direct liquefaction. The above work is proposed in order to define the potential of this approach. Catalytic hydropyrolysis has been successfully demonstrated at laboratory scale. The development must show that the increased liquid yield and improved product justify the added cost of the hydrogen plant and the high-pressure catalytic reaction system.

3.4.2.2 Characterize Coal Functional Groups and Their Relationship to Pyrolysis/Hydrolysis Reactivity

The second recommendation in pyrolysis is to characterize coal functional groups and their relationships to pyrolysis/hydrolysis reactivity.

More detailed molecular level coal characterization in terms of functional group distributions is necessary for all coal conversion (to liquids) approaches. Functional groups in this context include heteroatoms (O,S,N) forms and distribution, aromatic ring size distribution, molecular weight between cross-links (physical structure), definition of bridging links in terms of structure and distributions. Correlation of these structural parameters with reactivity -- here defined as pyrolysis and hydrolysis -- under different temperature, pressure, and residence time conditions could lead to better understanding of conversion mechanisms.

Better understanding of coal chemical and physical structural parameters and correlation of these with reactivity will provide the knowledge base for further advancements. This is work of a fundamental nature which will provide needed information for the successful development of any pyrolysis process.

3.4.2.3 Study Roles of Reactive Gas in the Devolatilization of Coal

The third-ranked recommendation in pyrolysis is to compare pyrolysis yields and products with and without reactive atmospheres (CH_4 , CO , CO_2 , H_2 , H_2O) to understand the roles of these gases in the devolatilization of coal, and seek to understand the chemistry and the mechanisms involved.

Devolatilization rates are the basic information for reactor design and process optimization. There has been little research done on pyrolysis in atmospheres other than inert gases and hydrogen. The use of hydrogen clearly increases the yields of tar and volatiles and results in a better char. Recent work has shown that hydrogen is not the only

atmosphere that increases tar yield. Steam, mixtures of steam and hydrogen, and steam and synthesis gas have also been reported to increase tar yields. The results with methane have been contradictory. It is important to continue this research to improve tar yields by developing a better understanding of the effects of operating parameters on devolatilization rates.

This program is easily carried out at a small scale. The results can be gathered and analyzed in a relatively short time period.

3.4.2.4 Conduct Systems Analysis of Pyrolysis/Hydropyrolysis Coupled with Gasification and Combustion

The fourth recommendation in pyrolysis is to conduct a systems analysis of pyrolysis/hydropyrolysis coupled with gasification and combustion.

A major economic limitation to pyrolysis/hydropyrolysis is disposition of the produced char. In general, char is the major product. Use of char as a fuel for combustion or as a feed for gasification could provide an outlet for this product. A systems analysis study is needed to provide guidance as to the potential for coupling a pyrolysis/hydropyrolysis process in front of a combustor or gasifier. Of particular interest is coupling a hydropyrolysis device to an integrated gasification combined-cycle (IGCC) combustion system, where char would be gasified, and the gases scrubbed and then burned. A slip stream of the gases could be used to provide hydrogen for the hydropyrolysis. In hydropyrolysis most of the char would go toward hydrogen production, and the slip stream would be burned for process energy or electricity.

Should a systems analysis show potential, this idea could have immediate impact on the electrical power generation industry. In the most optimistic scenario, liquids produced could be used for peaking cycles or for sale, while the IGCC system would provide higher thermal efficiencies (35-40 percent) versus conventional coal combustion. Most

of this work would be an engineering study, based on currently available information.

3.4.2.5 Study Staged Catalytic Hydropyrolysis

The fifth recommendation is to study staged catalytic hydropyrolysis.

Catalytic hydropyrolysis brings to a pyrolysis plant the need for hydrogen production and for high-pressure catalytic reactors. The tar yield is high, but the product quality, as measured by boiling range and heteroatom concentration, is still poor relative to liquids from direct liquefaction. A second catalytic hydrogenation reactor, in which the tar is converted to lighter oils with low heteroatom concentration, would greatly increase the value and utility of the final product, while taking advantage of the availability of hydrogen. Without such a staged approach, it is unlikely that any refinery will be capable of processing the liquid made in a pyrolysis plant. Therefore, this staged approach should be considered for all pyrolysis processes under development.

The results of such a study would enable cost estimates to be done on the use of pyrolysis to make a refinery feed. In scenarios to maximize liquid fuel production, it will be necessary to consider pyrolysis tar (a liquid) as a refinery feed.

This staged approach is a process development, which can easily be added to research on catalytic hydropyrolysis.

3.4.2.6 Study Pyrolysis Reaction Chemistry to Establish Optimum Operating Conditions

The sixth recommendation in pyrolysis is to study the chemistry and the reaction networks in pyrolysis reactions to establish optimum operating conditions.

Much effort in pyrolysis research has been extremely Edisonian. What is needed is more fundamental study on the chemical reactions of

coal under the actual reaction conditions used in coal pyrolysis. Conventional model-compound work and work on unrelated polymers are not a part of this recommendation.

It should be possible to establish the pathways for production of methane, ethane, other key hydrocarbons, carbon oxides, hydrogen cyanide, sulfur-containing substances, and so forth.

Thus, it should be possible to relate the changes in process variables with the changes in the product slate to establish the optimum operating conditions. The rate-determining steps can be identified and the opportunities for improvement can be established. This is a fundamental study that is broadly applicable to all pyrolysis process developments.

3.4.2.7 Study Reaction Mechanisms of Steam-Enhanced Pyrolysis

The seventh recommendation is to study the mechanisms of steam-enhanced pyrolysis.

A recent report indicates that steam-enhanced pyrolysis provides 15 percent higher liquid yields compared to conventional pyrolysis, and the liquids are reported to be of higher quality in terms of stability and lower molecular weights. The steam is often introduced under pressure (sometimes at supercritical temperature and pressure). These observations must be quantified and validated. A study is proposed to define the chemistry and mechanism(s). Fluid bed runs must be made to define whether the effects observed are chemical or physical in origin. Products from the system must be segregated by time and analyzed to define boiling point distribution, heteroatom content, etc.

Understanding the mechanism of what is happening could lead to methods of improving further the liquid yields and products. In addition, detailed product characterization could lead to better understanding and improvement of pyrolysis liquid stability.

Steam-enhanced pyrolysis has been tested successfully in laboratory tests. It should be scaled to larger, continuous operations to determine if the results can be duplicated at conditions closer to commercial operation.

3.4.2.8 Study Coal Moisture Effect to Pyrolysis

The last-ranked recommendation in pyrolysis is to study the effects of moisture in coal on pyrolysis and the physicochemical changes that occur during drying or rewetting of coal.

Research on coal structures shows that the inherent moisture may be free water in bituminous coals, but is bound as a gel in lower-rank coals. Drying of these coals results in an irreversible change in structure. Other programs have shown that rewetting under conditions of high temperature and pressure reduces the particle size, exposes new surfaces, and presumably increases reactivity. Thus, drying and rewetting of coals of different rank may have a profound effect on subsequent pyrolysis rates and yields.

This research should be done with the objective of increasing liquid yields with little or no increase in process complexity or cost. The work can be performed at laboratory scale and provide information within a relatively short period of time.